UNIVERSITY OF SOUTHAMPTON

FACULTY OF ENGINEERING AND THE ENVIRONMENT

Transportation Research Group

HUMAN FACTORS IN THE DESIGN OF TRAFFIC MANAGEMENT SYSTEMS

by

Joshua Price

Thesis for the degree of Doctor of Engineering

February 2016

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

FACULTY OF ENGINEERING AND THE ENVIRONMENT

Transportation Research Group

Doctor of Engineering

HUMAN FACTORS IN THE DESIGN OF TRAFFIC MANAGEMENT SYSTEMS

by Joshua Price

This research seeks to investigate how application of Human Factors techniques could be used to improve performance resulting from the use of technical traffic management and SCOOT validation systems. The systems used in both domains have historically been developed without consideration given to the social factors important to their use, designs instead being based solely on technical constraints.

In the first stages of the project traffic management is investigated through conduction of a literature review covering the objectives, functions and constraints acting upon Traffic Management Centres (TMCs) in road, rail, maritime and air domains. Congestion management is then considered in urban road TMCs through application of the Event Analysis of Systematic Teamwork (EAST) method based on observational data collected from four TMCs, Bristol, Cardiff, Dorset and Nottingham, in which the tasks, social agents, information and relationships between these elements are considered. The EAST method is then expanded to enable investigation into TMCs' resilience, providing further knowledge about the domain.

The later stages of the project are concerned with SCOOT validation, the process by which adaptively controlled traffic lights using SCOOT are set up to reflect real traffic conditions. The domain, using the current PC SCOOT Urban Traffic Control system, is assessed through Cognitive Work Analysis (CWA) with the findings used to propose areas suitable for development. One of these areas, STOC validation, is then developed further by applying Ecological Interface Design to develop an alternative display addressing limitations with PC SCOOT's display. This concept display is then evaluated through two empirical experiments examining performance compared to traditional displays and investigating the role of experience within the domain. Finally, by using insights obtained into the STOC validation process an automated STOC selection algorithm is developed which has the potential to redefine how STOC validation is conducted.

Table of Contents

List of Tables

List of Figures

Declaration of Authorship

I, Joshua Price declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

Human Factors in the Design of Traffic Management Systems

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. None of this work has been published before submission

Signed:

....

Joshua Price

Date:

Acknowledgements

This Engineering Doctorate project was funded by the Engineering and Physical Sciences Research Council (EPSRC) and Siemens.

I would firstly like to thank my supervisors Professor Neville Stanton and Dr Ben Waterson for all of their help, advice and support throughout the EndD as well as the supervisory team at Siemens for providing industrial guidance and supporting the project.

Special thanks go to my industrial supervisor Ian Snell for all of the practical assistance and guidance provided throughout the project, to Jackie Davies of Bristol Traffic Management Centre who provided so much of the data used throughout the thesis, and to Huw Fryer whose programming skills were invaluable.

Thank you to Siemens' validators and the personnel at Bristol, Cardiff, Dorset and Nottingham Traffic Management Centres who gave me their time to discuss their work and assisted with the observational studies, without your help the project would not have been possible.

My sincere gratitude goes to all of those who were involved in the empirical studies, whose participation contributed so much to the work.

Huge thanks go to my family and friends, to Mum, Dad, Katie and Hannah for all your love, support and encouragement over the last four years.

Finally, thank you to Jenny; it would not have been possible for me to complete this without your perspective, humour and love.

Definitions and Abbreviations

ADS	Automatic Dependent Surveillance
AH	Abstraction Hierarchy
AIS	Automatic Identification System
ANOVA	Analysis Of Variance
ANPR	Automatic Number Plate Recognition
ARAMIS	Accidental Risk Assessment Methodology for Industries
ATC	Air Traffic Control
ATIS	Advanced Traveller Information System
ATMC	Advanced Traffic Management System
ATP	Automatic Train Protection
B-L	Bavelas-Leavitt (Centrality)
CAA	Civil Aviation Authority
CAASRG	Civil Aviation Authority Safety Regulation Group
CAT	Contextual Activity Template
CCTV	Close Circuit Television
CDA	Coordination Demand Analysis
CDM	Critical Decision Method
CEC	Commission of the European Communities
ConTA	Control Task Analysis
CUD	Communication Usage Diagram
CWA	Cognitive Work Analysis
DEMA	Demand All (SCOOT command)
DfT	Department for Transport
DIPM	Display Plan Monitor (PC SCOOT screen)
DL	Decision Ladder
DoF	Degrees of Freedom
DSA	Driving Standards Agency
DVLA	Driver Vehicle Licencing Authority
EAST	Event Analysis for Systematic Teamwork
EID	Ecological Interface Design
ELAG	End Lag
EV	Eigenvector (Centrality)
FRAM	Functional Resonance Analysis Method
HTA	Hierarchical Task Analysis
HFI-DTC	Human Factors Integration Defence Technology Centre
ICAO	International Civil Aviation Organisation
IFL	Instrument Flight Rules
INS	Information Service
JNYT	Journey Time
KBB	Knowledge-Based Behaviour
LPU	Link Profile Unit

LVAL	Link Validation (PC SCOOT screen)
MCM	Multiple Concurrent Models
MEM	Model Error Minimisation
MONI	Monitor (PC SCOOT screen)
NAS	Navigational Assistance Service
NATO	North Atlantic Treaty Organisation
NFTD	Node Fine Tuning Display (PC SCOOT screen)
ORR	Office of Rail Regulation
PCA	Principal Component Analysis
QCMQ	Queue Clear Maximum Queue
RBB	Rule-Based Behaviour
RSSB	Railway Safety and Standards Board
SBB	Skill-Based Behaviour
SCOOT	Split Cycle Offset Optimisation Technique
SLAG	Start Lag
SME	Subject Matter Expert
SNA	Social Network Analysis
SND	Social Network Diagram
SOCA	Social Organisation and Cooperation Analysis
SOLAS	Safety Of Life At Sea
SRK	Skills, Rules and Knowledge
STAMP	System -Theoretic Accident Modelling and Processes
STOC	Saturation Occupancy
StrA	Strategies Analysis
SUS	System Usability Scale
TLX	Task Load Index
TMC	Traffic Management Centre
TOS	Traffic Organisation Service
TRKC	Transport Research Knowledge Centre
UCD	User-Centred Design
UTC	Urban Traffic Control
UTMC	Urban Traffic Management and Control
VFR	Visual Flight Rules
VHF	Very High Frequency
VMS	Variable Message Sign
VTS	Vessel Traffic Services
WCA	Worker Competencies Analysis
WDA	Work Domain Analysis
WHO	World Health Organisation

Chapter 1: Introduction

1.1 Background

Road transport is fundamental to our economy and our society, enabling economic growth and job creation (Commission of the European Communities [CEC], 2011a), however as our population is projected to increase (Office for National Statistics, 2011) so the demand for transport will also rise (Department for Transport, 2012b) and is likely to exceed existing infrastructure's capacity. This is likely to result in increased congestion (Everall, 1972) and is forecast to cost the UK economy £22 billion by 2025 (Eddington, 2006) in addition to having negative impacts on meeting road safety and environmental impact goals (e.g. CEC, 2006; CEC, 2011a), making it a significant national issue. There are limited options for physically expanding the capacity of our road infrastructure because of land use, environmental and political concerns (Baskar, Schutter, Hellendoorn, & Papp, 2011); therefore it will be necessary to improve the utilisation of our existing road networks (CEC, 2006) through technological means to address the challenges posed.

As a market leader in traffic solutions, Siemens provide a number of products intended to improve the management of road traffic, however these have typically been designed from a technological standpoint with little consideration given to social factors. The road domain is a complex socio-technical system (Walker, Stanton, Salmon, & Jenkins, 2008) therefore human performance and usage of these products must also be considered. To address this gap Siemens sponsored this Engineering Doctorate to investigate how the Human Factors discipline could be applied to elicit performance benefits for their products, supplying an additional competitive advantage. Specifically Siemens wished for two of their key challenges to be addressed, firstly top-down assessment of traffic management with a view to gaining insights for use in their COMET traffic management system, and secondly a bottom-up investigation and design of interfaces for use in SCOOT validation.

In the initial stages of the project the first of these challenges was addressed by focusing on the technical traffic management systems used within Traffic Management Centres (TMCs). TMCs are employed within many urban traffic networks as well as inter-urban routes and are concerned with planning, monitoring and control, or influencing, traffic (Transport Research Knowledge Centre, 2009) in order to increase road safety and capacity (Visser & Klijnhout, 1998), whilst simultaneously reducing delays, congestion and emissions (Cloke & Layfield, 1996; Desai, Loke, Desai, & Singh, 2011), as well as dealing with incidents (Bertini, Monsere, & Yin, 2005). In effect a TMC acts as a central hub to collect information from a wide array of sources and then manages traffic through physical manipulation of infrastructure, by directly assisting vehicles and disseminating information (Murray & Liu, 1997; Nowakowski, Green, & Kojima, 1999), with a wide range of technical systems utilised to achieve these actions.

TMCs have been the subject of many Human Factors studies (Nowakowski et al., 1999), including investigations into their physical structure (Beers & Folds, 1996; Kelly, 1995), educational requirements of operators (Mitta, Folds, Fain, & Beers, 1997) and use of automated assistance systems (Coon & Folds, 1996; Folds & Fain, 1997; Stocks, Folds, & Gerth, 1996). Unfortunately many of these studies are historical and do not reflect the technologies or practices utilised by modern TMCs, there is therefore an opportunity to improve understanding of how modern TMCs manage traffic and to consider how technology is used in pursuit of TMCs' goals. This knowledge can then be utilised to improve these technologies to better support operators and hence improve performance.

The second half of the project was concerned with the second of Siemens' key challenges and focuses on developing the technical systems used to set up adaptively controlled traffic lights which use Split Cycle Offset Optimisation Technique (SCOOT; Hunt, Robertson, Bretherton, & Winton, 1981). SCOOT is used to optimise traffic signals in order to maximise capacity and minimise delays by adjusting light timings using real-time data from detectors and a traffic model. In order to operate effectively, it is important that SCOOT's traffic model accurately reflects on-street conditions; hence a SCOOT system must be validated (Siemens, 2011). Validation is conducted using an Urban Traffic Control (UTC) system called PC SCOOT (Siemens, 2013), which although functional has not evolved to take advantage of advances in display equipment or considered human performance in its design. The area is significantly under researched and there is an opportunity to apply Human Factors techniques in order to better understand the domain and to use these findings in conjunction with contemporary interface design techniques to improve PC SCOOT as a product, elicit performance benefits for validators and hence the traffic network as a whole.

1.2 Aims and Objectives

The aim of this research is to investigate how application of Human Factors techniques can be applied to improve performance resulting from the interaction with technical traffic management systems. Two specific areas are considered, TMCs and SCOOT validation.

Three objectives concern the macro analysis of TMCs:

1. Define and understand the objectives, functions and constraints of traffic management in major transport domains.
2. Define and evaluate the processes, tools and connections utilised by road TMC operators to manage traffic.
3. Investigate system resilience within TMCs through application of Event Analysis of Systematic Teamwork.

Four objectives concern the micro analysis of SCOOT validation:

1. Define and understand SCOOT validation using PC SCOOT to identify limitations and opportunities for improvement.
2. Develop alternative displays to address the limitations identified for (1) through application of Human Factors interface design techniques.
3. Evaluate the performance of the displays developed for (2).
4. Investigate the potential to employ automation to address the limitations identified for (1).

1.3 Outline of the Thesis

The thesis is organised in ten chapters, starting with the introduction (chapter 1) which describes the background to the work and outlines the main research objectives, and ending with the conclusion (chapter 10) which summarises the thesis' findings, considers the contribution to knowledge made and identifies opportunities for further research. The intermediary chapters are introduced in the following subsections.

1.3.1 Chapter 2: A Comparison of Land, Sea and Air Traffic Management

Traffic management is used within all main transport domains, road, rail, maritime and air to improve safety and efficiency whilst reducing negative environmental impacts. Chapter 2 consists of a literature review used to identify objectives, constraints and system functions occurring within the four key traffic management domains. While comparative studies have been conducted there remains a gap in the knowledge regarding the similarities and differences between all four domains. The purpose of this review is threefold. Firstly to improve understanding of road traffic management within the context of the wider transportation system. Secondly to identify those issues affecting road traffic management that are suitable for further investigation. Thirdly to provide the theoretical basis on which more detailed analyses can be conducted in chapters 3 and 4.

1.3.2 Chapter 3: Using EAST to Investigate Congestion Management in Urban Traffic Management Centres

Based on the analysis in chapter 2 congestion management within urban TMCs was selected as a priority for further investigation. This chapter applies the Event Analysis of Systematic Teamwork (EAST) method to the domain with an aim of better understanding how TMCs deal with congestion in practice. EAST was selected because of its ability to comprehensively model cognitively distributed domains such as a TMC, in which a wide range of technical and social agents must collaborate to achieve objectives. Observations are carried out at four medium sized urban TMCs, Bristol, Cardiff, Dorset and Nottingham, with the data used to directly produce EAST's primary, task, social and information, and combined networks. In addition to EAST's application within a novel domain, a method by which social networks are produced by weighting communications links based on qualitative data is employed to account for the links which are difficult to measure empirically. Data analysis is conducted both qualitatively and quantitatively using Social Network Analysis (SNA) metrics, with consideration given to how congestion scenarios are managed, who is involved and what information is required.

1.3.3 Chapter 4: Using EAST to Investigate Urban Traffic Management Centre's Operational Resilience

Resilience engineering is concerned with designing systems such that they can survive both expected and unexpected disruptions to their operation. Most methods to assess resilience are qualitative, with quantitative assessment relatively undeveloped. In this chapter a method to investigate a system's operational resilience by quantifying the effects of failure is developed. EAST is used to model a system based on graphical network diagrams with system properties described using SNA metrics. The networks produced for the TMCs in chapter 3 are used to empirically investigate resilience within urban TMCs. Failure modes are applied to the fully functioning networks with resulting changes to metrics providing a quantitative indication of resilience.

1.3.4 Chapter 5: Using CWA to Investigate SCOOT Validation using PC SCOOT

As previously stated the thesis objectives were changed on completion of chapter 4 to reflect Siemens' business needs, resulting in a change of focus onto SCOOT validation. Siemens are a leading provider of SCOOT adaptive traffic control systems worldwide and as such have significant interest in ensuring their PC SCOOT UTC product retains competitive advantage. To assess validation a full five phase Cognitive Work Analysis (CWA) is utilised, with each phase's representations informed based on data collected from experienced SCOOT validators, providing a comprehensive assessment of the domain's constraints. Ultimately the chapter's aim is to identify potential weaknesses with PC SCOOT and propose areas for development through application of Human Factors methods.

1.3.5 Chapter 6: Using CWA to Design an Ecological STOC Validation Tool

Based on discussions with Siemens regarding the proposed SCOOT validation developments outlined in chapter 5 it was decided to investigate SaTuration OCcupancy (STOC) validation in more detail, because it is a crucial SCOOT parameter and is perceived to be relatively difficult using the traditional Link VALidation (LVAL) display in PC SCOOT. This chapter is concerned with a more detailed analysis of STOC validation using CWA, with the findings used to inform the development of an alternative ecological interface using Ecological Interface Design (EID). CWA is intimately linked to EID however full analyses are rarely used to inform designs, Work Domain and Worker Competencies Analyses receiving most attention. Although consistent with EID's original description all five CWA phases have been argued to have a role in the design process and are therefore presented. Each phase's contribution to the ecological design process is examined and a concept ecological display for STOC validation produced.

1.3.6 Chapter 7: Evaluation of an Ecological STOC Validation Tool

In order to empirically evaluate the concept ecological display developed in chapter 6 an experiment is conducted to compare this display against two traditional interfaces employed within PC SCOOT with the role of experience on performance also considered. Experimental displays are produced in Microsoft Excel with a number of links modelled using traffic detector data from Reading. The experiment is completed by three participant groups, twelve expert validators, twelve novices age and gender matched to the expert group and a further thirty unmatched novices. Both objective and subjective performance measures are considered including accuracy, time spent validating, perceived workload and perceived usability, with the findings used to provide a recommendation regarding further development of the ecological display.

1.3.7 Chapter 8: Further Evaluation of an Ecological STOC Validation Tool

A follow-up experiment to chapter 7 is conducted to compare a developed ecological STOC validation display against the traditional LVAL interface. Several limitations with the first experiment are addressed, specifically real observed clear times are obtained from Bristol TMC and the ecological display is significantly developed from the Excel based prototype used previously. The experiment follows a similar experimental procedure and considers comparable performance measures to those obtained in chapter 7. The findings are used to further consider the potential benefits of employing ecological design techniques in STOC validation.

1.3.8 Chapter 9: Development and Evaluation of an Algorithm to Automatically Select STOC Values

Automation of STOC selection could assist validators and potentially enable multiple links to be validated simultaneously; offering significant time savings compared to both the traditional LVAL and proposed ecological displays. To this end an automated STOC selection algorithm is developed based on the ecological STOC validation task process identified in chapter 6, in which the objective is to minimise the error between modelled and observed clear times. Empirical evaluation of the algorithm's effectiveness in terms of accuracy is then conducted against human validators using the data obtained in chapter 8. The results are used to inform the recommendation as to whether automated STOC validation is possible, provides any benefit and is worth further development.

1.4 Contribution to Knowledge

The work presented in this thesis contributes to the understanding of traffic management and SCOOT validation domains with benefits for academics, practitioners and Siemens in particular. The key contributions for each domain are listed below:

1.4.1 Traffic Management

1. The literature review will consider objectives, functions and domain constraints of traffic management in key transport domains providing a useful reference tool for future studies.
2. Assessment of congestion management in urban TMCs will contribute to the understanding of how road traffic is managed in practice and provide insight into how TMCs' technical systems are used by operators.
3. The EAST method will be applied to quantitatively and qualitatively assess socio-technical systems' resilience, providing a methodological basis for future studies.

1.4.2 SCOOT Validation

1. A CWA analysis will provide a comprehensive assessment of SCOOT validation, aiding understanding of the validation process and use of current validation tools by validators, as well as being a useful reference for future developments.
2. Development of an ecological STOC validation tool will highlight the role of each CWA phase on design, a useful practical case study for those wishing to employ the design philosophy in new domains, as well as to Siemens should they wish to apply the approach in other areas.
3. Empirical testing of STOC validation display will provide useful insights into the relative performance of ecological and traditional displays, adding to the EID literature and providing Siemens with specific design recommendations to implement in their future products.
4. Development of an automated STOC validation algorithm will offer a new approach to validation, which could provide significant time savings.

Chapter 2: Comparison of Land, Sea and Air Traffic Management

2.1 Introduction

Transport is fundamental to our economy and our society, enabling economic growth and job creation (Commission of the European Communities [CEC], 2011a), however as our population is projected to increase (Office for National Statistics, 2011) transport demand is likely to exceed existing infrastructure's capacity. There are limited options for physical expansion (Baskar et al., 2011); therefore it will be necessary to improve utilisation of existing networks to alleviate the threat of increased congestion (CEC, 2006). In addition, policy goals regarding transport safety (CEC, 2009; CEC, 2011b; Office of Rail Regulation [ORR], 2008; United Nations Regional Commission, 2010) and environmental impact (CEC, 2011a) can only be met by considering the entire transport network.

Traffic management is a key part of this wider view within all main transport domains, road, rail, maritime and air. Traffic management is the planning, monitoring and control, or influencing, of traffic within a transport network (Transport Research Knowledge Centre [TRKC], 2009), with the aims of increasing safety and capacity (Visser & Klijnhout, 1998), whilst simultaneously reducing delays (Sud et al., 2009), congestion (Desai et al., 2011) and emissions (Cloke & Layfield, 1996), as well as dealing with incidents (Bertini et al., 2005).

Several studies have considered the Traffic Management Centre (TMC) functions and domain constraints from subsets of these domains comparatively (Curchod & Genête, 2002; Murray & Liu, 1997), however there remains a gap in the knowledge regarding the similarities and differences between all four domains. This chapter aims to address this gap by comparing road, rail, maritime and air TMCs, examining their objectives and operational functions as well as the constraints imposed by the domain's characteristics. This will enable road traffic management to be better understood within the context of the wider transportation system as well as providing the theoretical basis on which further analyses can be conducted in chapters 3 and 4.

2.2 Domain Overviews

2.2.1 Road

Road traffic management facilitates the safe movement of goods and people, with minimal delay, throughout the roadway system (Folds et al., 1993). Used primarily in urban and inter-urban road networks (TRKC, 2009), TMCs aim to maximise road capacity, minimise the impact of incidents, manage demand, assist emergency services and encourage public confidence in the TMC (Folds et al., 1993). Real-time and predicted traffic conditions are used to influence management decisions (Nowakowski et al., 1999), which are implemented using Advanced Traffic Management Systems (ATMSs) and Advanced Traveller Information Systems (ATISs) (Chorus, Molin, & Van Wee, 2006; Technical Committee 16 Network Operations, 2006).

2.2.2 Rail

Rail traffic management aims to ensure train safety and maximise network efficiency. Conflict detection and resolution is a key activity, trains are monitored individually and the network is managed to prevent potential conflicts (Stanton & Baber, 2008). There are three layers of operation, safety, control and traffic management (Davey, 2012). The safety layer concerns the protection of trains, including signalling, control of infrastructure and Automatic Train Protection (ATP) systems. The control layer involves direct train control by a TMC. The traffic management layer concerns indirect train control through timetabling and routing, as well as overall network management.

2.2.3 Maritime

Maritime TMCs are called Vessel Traffic Services (VTSs) and aim to foresee the safe and efficient flow of maritime traffic and to protect the environment (Devoe, Abernathy, Royal, Kearns, & Rudlich, 1979). VTSs are used where traffic volumes are high or there is a significant degree of risk to vessels, such as around ports and in shipping channels (International Maritime Organization [IMO], 2012). There are three areas of operation; Information Service (INS), broadcasting general information, Navigational Assistance Service (NAS), aiding vessel's navigational decision-making and Traffic Organisation Service (TOS), managing traffic by advising, instructing, or directing vessels (VTS Committee, 2008). Vessels are monitored individually, with management centring on conflict detection and resolution (Van Dam, Mulder, & Van Paassen, 2006).

2.2.4 Air

Air Traffic Control (ATC), is tasked with ensuring the safe and efficient flow of aircraft from origin to destination (Wickens, Mavor, & McGee, 1997). ATC manages individual aircraft, routing traffic as efficiently as possible whilst ensuring sufficient separation between aircraft in controlled airspace. There are three key areas of ATC; airport control, covering taxiways and runways, approach control, responsible for aircraft on approach to airports, and en-route control, managing aircraft travelling between airports (Civil Aviation Authority Safety Regulation Group [CAASRG], 2012b).

2.3 System Objectives

System objectives dictate TMCs' reasons for existence; these are similar for all forms of traffic management, all TMCs aiming to increase network efficiency and safety, and reduce environmental impact.

2.3.1 Efficiency

TMCs aim to minimise congestion by optimising traffic flow. This is important economically being forecast to cost the UK £22bn by 2025 (Eddington, 2006). Congestion occurs when demand for the transport network is greater than the infrastructure's capacity (Everall, 1972), either because demand increases or capacity is reduced, for example due to bad weather. To improve travel times and reduce delays TMCs must therefore manage demand and mitigate the effects of reduced capacity (Bertini et al., 2005; Desai et al., 2011; Sud et al., 2009; Visser & Klijnhout, 1998), for example by diverting traffic away from problem areas. A further benefit of an efficient transport network is the potential reduction in fuel costs that could be achieved.

2.3.2 Environmental

TMCs aim to improve the network's environmental impact, in particular reducing emissions and noise pollution, through encouraging environmentally friendly behaviour (Cloke & Layfield, 1996). In addition damaging traffic conditions such as congestion can be minimised, reducing transport emissions (Barth & Boriboonsomsin, 2008). In the maritime domain VTSs are involved in protecting the physical environment, ensuring vessel movements do not cause unintentional damage (Van Dam et al., 2006). Historically environmental objectives have been somewhat secondary to the objectives of efficiency and safety, however recent policy goals such a 60% reduction in transport emissions by 2050 (CEC, 2011a) reflect the ever increasing consideration given to these objectives.

2.3.3 Safety

Safety is crucial to protect life and inspire public confidence in transport networks. Safety objectives are primarily met proactively, TMCs aiming to reduce the occurrence of incidents (Bertini et al., 2005), by monitoring the network and intervening if necessary. The ability to manage specific vehicles independently within rail, maritime and air domains puts the emphasis on conflict detection and collision avoidance (CAASRG, 2012b; Davey, 2012; Van Dam et al., 2006). The road domain lacks this level of control, traffic typically being treated as a flow (Curchod & Genête, 2002), although individual vehicles can be identified using technologies such as Automatic Number Plate Recognition (ANPR) cameras. Management activities therefore focus on the broad dissemination of information to traffic, aiming to encourage desired behaviours (Murray & Liu, 1997).

Reactive management is also important, aiming to minimise incidents' impact once they occur (Bertini et al., 2005), this is particularly prevalent in road traffic management, incidents occurring frequently (World Health Organisation, 2013). TMCs take action to minimise resulting congestion and to maximise the safety of those involved, for example by closing lanes on managed motorways (Simpson & Kamnitzer, 2010). In addition, information regarding the incident can be communicated directly to emergency services as well as to other traffic, in order to improve their decision-making (Nowakowski et al., 1999).

2.4 Domain Characteristics

The characteristics of traffic management domains impose constraints upon TMCs' functions. Curchod and Genête (2002) compared constraints in road and air domains with respect to rail, investigating TMCs' geographical field and management scope, the behaviour of network traffic and the physical capabilities of vehicles within the network. Using this as a basis domains have been compared based on a typical TMC's scope, the capabilities of vehicles and behaviour of traffic. In addition the physical management capabilities of TMCs as well as political constraints have been considered. A concise comparison is provided in Table 2-1.

2.4.1 Scope

The scope of traffic management is the area of operation for a typical TMC within the domain; this entails not only the physical area under the control of a TMC but also the physical extent of management activities. Similarly to Curchod and Genête (2002) the areas of operation have been categorised as local, regional, national and international.

Road and maritime TMCs operate within local and regional areas. Road TMCs primarily manage urban or inter-urban networks (TRKC, 2009), including localised activities such as junction management. VTSs manage specific ports, straits, and other high risk areas (VTS Committee, 2008). Although traffic in both domains may travel nationally or internationally, much of the domain is unmanaged, with legal rules, such as the Highway Code, enforced but no explicit traffic management, limiting the potential for national or international management activities.

Rail traffic is managed throughout its journey; necessitating international and national management in addition to local and regional. Historically international management has been limited due to incompatibilities between countries rail infrastructure, however international cooperation with projects such as Eurotunnel (Anguera, 2006) and OPTIRAILS (Curchod & Genête, 2002) has increased the prevalence of international management.

Air traffic management also involves local (airport control), regional (approach and en-route control), national and international (en-route control) management (CAASRG, 2012b). TMCs may be dedicated to particular areas of operation, for example airport control towers manage at a local and regional level, dealing with aircraft at, approaching to or departing from airports. En-route TMCs operate at regional, national and international levels. As with rail, international management and coordination is becoming increasingly important with initiatives such as the Single European Sky (CEC, 2012) and Open Skies agreements (Chang, Williams, & Hsu, 2009).

Interactions between TMCs within a domain are an important consideration, communication enabling useful information to be shared and wider transport strategies to be implemented. This is particularly important when specific vehicles must be managed across the jurisdictions of multiple TMCs. Therefore although a TMC may be focused on local or regional management, this does not imply that it operates in isolation from the rest of the domain.

2.4.2 Vehicle Capabilities

Vehicle capabilities are defined by the physical realities of the transport mode, additionally within most domains traffic can be segmented by purpose and specific abilities, meaning traffic cannot all necessarily be managed in the same way. To maximise the TMC's effectiveness the context to which the management activity is applied must be considered.

The transport mode constrains the network's possible degrees of freedom (DoF) and therefore how traffic can be directed. Curchod and Genête (2002) stated that rail traffic has one DoF, being confined to tracks and routes directly controlled by TMCs. Road traffic has two DoF, vehicles are free to move within the two dimensional plane of the network. Air traffic has three DoF, the management domain being three dimensional with aircraft able to move vertically and horizontally. Intuitively the maritime domain has two DoF similarly to the road domain.

The training level and motivations of vehicle operators are highly varied within transport domains. The exception is rail which has very stringent training requirements governed by legislation (ORR, 2010) and where all drivers are employed in a professional capacity, management activities can therefore be consistent irrespective of the specific train being managed.

The road domain contains the widest range of traffic segments including motor-vehicles, cyclists and pedestrians (DfT, 2011). Management is focused on motor-vehicles however other segments can impact managed traffic, by being involved in incidents for example. Consideration can also be given to the level of driver training, traffic including basic license holders (Driver Vehicle Licensing Agency, 2012), potentially with limited experience, as well as advanced, emergency service and professional drivers, all of whom have more extensive training and experience (Association of Chief Police Officers, 2009; DfT, 2012a; Stanton, Walker, Young, Kazi, & Salmon, 2007). Furthermore, the context of a driver's journey can influence their abilities, for example regular commuters become practiced at a particular route while other groups may be unfamiliar with the area, necessitating a range of management approaches (Dudek et al., 1978).

Traffic in the maritime domain ranges from cruise ships and bulk carriers, operated by professionals, to small recreational vessels, sailed by members of the public, potentially with no formal training (Maritime and Coastguard Agency, 2012). Similarly to the road domain management is focused on specific traffic segments (large vessels), however other segments must still be considered due to safety implications.

Traffic segments in the air domain include professional civilian and military aircraft as well as recreational traffic piloted by Private Pilot's Licence (PPL) holders. There are rigorous training requirements for all pilots (CAASRG, 2012a), although PPLs are significantly simpler to obtain than professional licences. In addition two sets of flight rules are observed, Visual Flight Rules (VFR) and Instrument Flight Rules (IFR) (CAASRG, 2012b) which define how aircraft are flown. Airspace categories (CAA, 2012), are used to control the different traffic segments, ensuring they do not interfere with one another. These categories also define the extent of management services provided to aircraft.

2.4.3 Traffic Behaviour

Traffic behaviour characteristics are defined by how the domain's traffic operates as a whole. This incorporates its predictability, where the responsibility for routing choices lies and how traffic is treated for monitoring purposes. Traffic behaviour dictates how much a TMC knows about the traffic it is managing and therefore how it can interact with traffic.

Rail and air traffic is relatively predictable; vehicles can be monitored individually, operate to planned timetables and have predetermined routes, both of which are known to TMCs and can be adapted by them (Curchod & Genête, 2002), this enables TMCs to manage individual vehicles. Road traffic is entirely different; routes are known only to the driver, making it highly unpredictable (Murray & Liu, 1997), in addition the volume of road traffic necessitates treatment as a flow (Curchod & Genête, 2002), meaning more general management activities are used, TMCs having limited control over individual vehicles (Nowakowski et al., 1999). Maritime traffic falls in between, all vessels can be monitored individually and their movements can be predicated fairly accurately (Van Dam et al., 2006; VTS Committee, 2008). Routing decisions are the responsibility of a ship's captain and are therefore not necessarily known to the VTS, however certain traffic, such as ferries, operate to fixed routes and timetables. Additionally, most areas controlled by VTSs have high traffic volumes and employ defined shipping lanes, to reduce the likelihood of collisions, which must be observed; these limit vessels possible route choices. The result of this is that similarly to rail and air domains, VTSs are able to manage vessels on an individual basis.

2.4.4 Traffic Management Capabilities

Traffic management capabilities are the methods available for TMCs to intervene within the network and manage traffic. These interventions are varied and often specific to each domain, however their impacts on the network can be described as physical manipulation, direct assistance and information dissemination, or a combination. Physical manipulation involves physically altering variable infrastructure within the network. Direct assistance refers to interacting with an individual vehicle. Information dissemination describes the provision of general information to all relevant vehicles within the network. All three capabilities are available within road and rail domains, physical manipulation is not however available in maritime or air domains because traffic is under local control and variable infrastructure is limited or non-existent. The importance of these constraints is that they define how the TMC is able to interact with traffic, directly influencing the physical management functions available.

2.4.5 Political

Within the UK all transport domains are the responsibility of the Department for Transport, with each domain also having specific governing authorities and legislation regulating them. These political characteristics constrain how TMCs are able to interact with traffic and can also affect the priorities given to each traffic management objective.

Regulation within the road domain is overseen by executive organisations including the Driver Vehicle Licencing Authority (DVLA), Driving Standards Agency (DSA) and Highways Agency as well as local authorities and the police. These enforce required standards for driving and infrastructure, potentially requiring coordination with TMCs. Many TMCs are operated on behalf of their local authority, however motorway and major trunk road TMCs are the responsibility of national executive organisations such as the Highways Agency and Transport Scotland (Highways Agency, 2012), providing these stakeholders with a significant degree of control over TMC's operation.

For the rail domain the Office of Rail Regulation (ORR) is the UK's regulatory authority, with the Railway Safety and Standards Board (RSSB) responsible for developing national safety policies (Dennis, 2004). TMC's functions are directly influenced by these organisations, having to meet prescribed standards, for example signalling procedures that ensure train safety.

The maritime domain is regulated through international organisations such as the United Nations and International Maritime Organisation as well as countries governments (Knapp & Franses, 2010). One of the most widely known treaties is the International Convention for Safety Of Life At Sea (SOLAS) (IMO, 1974), which specifies where VTSs should be provided and how vessels must be operated, thus how they can be directed.

The air domain is heavily regulated nationally and internationally through organisations such as the Civil Aviation Authority (CAA) and the UN's International Civil Aviation Organisation (ICAO). Regulations specify the procedures that ATC and aircraft must follow, such as communication standards, as well as required performance levels, for example ensuring minimum aircraft separation distances are maintained. This influences most ATC functions, defining exactly how they must be implemented to ensure homogeneity throughout the domain.

Table 2-1: Comparison of road, rail, maritime and air domain characteristics for TMCs

		Road	Rail	Maritime	Air
Scope	*Area of operation*	Local, Regional	Local, Regional, National, International	Local, Regional	Local, Regional, National, International
Vehicle Capabilities	*Physical constraints*	2 DoF	1 DoF	2 DoF	3 DoF
	Traffic types	Very Diverse	Uniform	Diverse	Diverse
Traffic Behaviour	*Predictability*	Random	Discrete	Variable	Discrete
	Route choice known to TMC?	No	Yes	Possibly	Yes
	Treatment	Flow	Individual	Individual	Individual
TM Capabilities	*Physical manipulation*	Yes	Yes	No	No
	Direct assistance	Yes	Yes	Yes	Yes
	Information dissemination	Yes	Yes	Yes	Yes
Political	*Regulatory authority examples*	Highways Agency, DVLA, DSA, Police	ORR, RSSB	IMO, UN	CAA ICAO

2.5 System Functions

System functions are the activities undertaken within TMCs in pursuit of their objectives. The traffic management process is comparable across domains; this is evident in how TMC functions can be grouped despite the individual differences caused by domain characteristics. All TMCs monitor their network to establish real-time conditions and predict future changes. This information is the basis for management decisions which are then implemented to affect traffic. Feedback enables the success of decisions to be measured and guides future actions. In addition all TMCs have supporting functions enabling them to operate, for example business functions such as human resources.

TMC functions within all domains have been the subject of many studies enabling a comparison to be produced, useful studies include, for road (Folds et al., 1993; Kelly & Folds, 1998; Mitta, Kelly, & Folds, 1996; Nowakowski et al., 1999; Technical Committee 16 Network Operations, 2006; TRKC, 2009), rail (Curchod & Genête, 2002; Davey, 2012), maritime (Devoe et al., 1979; IMO, 2012; TRKC, 2009; Van Dam et al., 2006; VTS Committee, 2008) and air (CAASRG, 2012b; Hopkin, 1989, 1995; Wickens et al., 1997).

2.5.1 Monitoring

Monitored information relates to the infrastructure, traffic conditions, environmental conditions, geographical information and event information. Examples for each domain are provided in Table 2-2.

Infrastructure

All domains have static infrastructure, including links, such as roads and railway tracks, and destinations, for example stations, ports and airports. Road and rail domains also have dynamic infrastructure which can be manipulated, for example Variable Message Signs (VMSs), points and signals. TMCs must know what infrastructure is within their jurisdiction, as well as the status of variable infrastructure.

Traffic Conditions

Both real-time and predicted traffic conditions are used to guide management decisions. Real-time monitoring methods are dependent on the characteristics of the domain traffic such as its behaviour, while predictions can be based on real-time conditions, historical trends and physical network constraints.

Road traffic flows are defined by their location, direction, speed and occupancy levels (Nowakowski et al., 1999). Assessment is carried out using technologies such as induction loops, ANPR cameras and Close Circuit TeleVision (CCTV; Cooper, 2004; Kelly, 1999).

Rail traffic is monitored on an individual basis, establishing position, speed and direction using track circuits, transponders, CCTV and planned schedules (Davey, 2012).

Maritime traffic includes anchored and shipping vessels, is treated individually and monitored using technologies such as radar, transponders (Automatic Identification Systems (AIS)) and VHF reports (Van Dam et al., 2006). In addition to position, speed and direction, it is necessary to know a vessel's physical properties such as size and maximum speed, to plan movements.

Air traffic includes all aircraft at airports, on approach and en-route. Similarly to the maritime domain radar and transponders are used to identify aircraft's location, altitude, speed and direction (CAASRG, 2012b), visual monitoring is also used at airports. Future ATC systems are expected to rely more on vehicle-centric technologies such as Automatic Dependent Surveillance (ADS) (Prinzo, 2004), which enable aircraft to broadcast information to ATC and other aircraft, this has significant benefits in uncontrolled airspace and is vital for free flight (Grundmann, 1996), where many routing decisions are devolved to the aircraft.

Environmental Conditions

Environmental conditions have a significant impact on vehicle and transport network performance (House of Commons Transport Committee, 2011; Strong, Ye, & Shi, 2010). Real-time information is gathered from sensors and confirmed visually. Sensor information can influence operators decision-making and be used by automated systems (Kelly & Folds, 1998), for example automatically displaying warning messages on VMSs. Weather predictions are used for planning within all domains, but are particularly important for maritime and air domains, each requiring specialised forecasts to operate effectively (Corbet, 1992; Evans, Weber, & Moser, 2006).

Geography

Each domain occupies and interacts with the geographic environment, which can be shown using maps. Road and rail domains can be considered two dimensional, height variations not being considered for traffic management. Maritime and air domains are three dimensional, the topography of the environment being crucial for the safety of ships and aircraft.

Events

Events are planned activities that will impact the network, as opposed to unplanned incidents (Highways Agency, 2009), meaning they can be managed proactively. Events can originate directly from the TMC, for example planned maintenance to TMC systems, or from third parties, such as statutory undertakers. TMCs must coordinate with relevant third parties when required information cannot be gained by the TMC directly.

Table 2-2 shows that within all domains, TMC operators are responsible for monitoring a wide range of information, with varying relevance and importance to the traffic state. Operators must amalgamate these information sources to depict the current traffic state and predict future changes. Enabling operators to do this effectively is a significant Human Factors issue; the design of monitoring functions must show operators what is important and why, without overloading them with information.

Table 2-2: Examples of monitored information for traffic management domains

		Road	Rail	Maritime	Air
Infrastructure	*Static*	Roads, Junctions, Signs	Track, Stations, Signs	Bridges, Canals, Ports	Airports, Airport infrastructure - gates etc.
	Dynamic	Electrical infrastructure (VMS, traffic lights etc.), Events	Electrical infrastructure (Signals etc.), Points, Events	Events	Events
Traffic Conditions	*Real-time*	ANPR, Induction loops, Visual, CCTV, Radio reports / TMC, Floating vehicle data	Track Circuits, Transponders, CCTV, Planned schedule	Radar, AIS, Direction finding, VHF (Radio)	Radar, ADS, VHF (Radio), Visual
	Predictions	Flow predictions and models	Future vehicle position, Conflict detection	Future vehicle position, Conflict detection	Future vehicle position, Conflict detection
Environmental Conditions	*Real-time*	Sensors, Visual	Sensors, Visual	Sensors, Visual	Sensors, Visual
	Predictions	General meteorology	General meteorology	Maritime meteorology	Aviation meteorology
Geography	*Management environment*	2D	2D	3D	3D
Events	*Within TMC*	Planned maintenance	Planned maintenance	Planned maintenance	Planned maintenance
	Third parties	Other TMCs, Statutory undertakers	Other TMCs, Statutory undertakers	Other TMCs, Shipping companies	Other TMCs, CAA, Military

2.5.2 Decision-making

Effective decision-making is fundamentally important for the safe and efficient running of all complex socio-technical systems (Jenkins, Stanton, Salmon, Walker, & Rafferty, 2010), such as traffic management. Decisions are based on monitored information, and are predominantly made by operators; however technical systems may assist, for example automated VMS messages (Kelly & Folds, 1998). Decisions relate to deciding whether action is required, and what form any action should take.

A useful decision-making model is to assume a normal standard of performance and categorise any deviation as an error, prompting a particular corrective sequence of actions (Rasmussen, Pejtersen, & Goodstein, 1994). Although this is idealised, dynamic and uncertain environments, such as those found in traffic management, make it difficult to define the actions that will return normal performance (Jenkins, Salmon, Stanton, Walker, & Rafferty, 2011), it does show how the need for action can be identified.

TMCs are effectively in either a normal or exceptional state. In the normal state network performance is above an acceptable tolerance, any reduction, or potential reduction, below this tolerance causes an exceptional state, implying management decisions are required. The normal state may be theoretical, never being achieved if traffic requires constant management, as is the case in rail and air domains; however the exceptional state must still be defined. Human Factors must be considered to ensure that monitoring information supports operator’s natural decision-making abilities, allowing them to accurately decide whether or not action is required.

The most appropriate response is dictated by the reasons for entering an exceptional state. Reasons can be characterised by scope, the extent of the network being affected, severity, the impact on the affected area, and type, whether it is planned (event) or unplanned (incident). A severe but localised incident will logically require different actions to pre-emptive management of commonly occurring congestion. System design must enable operators to define these characteristics for any context using monitoring information, and then enable potential actions to be judged for their effectiveness before implementation, for example comparing the impact of two diversion routes and choosing the least disruptive.

2.5.3 Interventions

Potential interventions vary between domains and can be specific to each TMC based on local technological constraints (Nowakowski et al., 1999). Within the air domain interventions are also dependent on the category of airspace being managed (CAA, 2012). Intervention’s impacts can be described as physical manipulation of infrastructure, provision of direct assistance and information dissemination; examples for each domain are provided in Table 2-3. An important consideration is that an intervention's impact cannot necessarily be described by a single category, for example within railway signalling, the act of changing the signal is physical manipulation but the message provides direct assistance by interacting with a specific train.

Physical manipulation involves changing a variable component of the network under direct TMC control in order to affect traffic; this is possible in road and rail domains. Methods used by road TMCs include ramp metering and signal timing adjustment (Nowakowski et al., 1999). Physical manipulation is crucial within the rail domain, TMCs being responsible for train routing including adjusting point settings, signalling and in some cases directly operating trains (Davey, 2012). Within maritime and air domains traffic is under local control and variable infrastructure is limited or non-existent, therefore interventions cannot be classified as physical manipulation.

Direct assistance relates to interactions with individual vehicles not physically under the TMC's control. Information provided can be either advisory, to aid decision- making, or mandatory, to instruct when necessary. The volume of traffic being managed in the road domain generally makes direct assistance unfeasible, however TMCs can assist indirectly by interacting with Road Traffic Officers and emergency services (Nowakowski et al., 1999). In rail, signals provide mandatory instructions to trains (Davey, 2012), additionally TMCs can alter planned routes and timetables in response to network conditions. Advisory information can also be provided, for example providing environmental condition warnings. Both ATC and VTSs provide advisory and mandatory information such as routing advice and weather reports, either at the request of the pilot/captain or at the discretion of the TMC (CAASRG, 2012b; VTS Committee, 2008). VTS assistance is largely advisory, in contrast to ATC which is predominately mandatory.

Information dissemination refers to the provision of information to all relevant traffic, this can also be advisory or mandatory, and occurs within all domains. Information can be disseminated using variable infrastructure such as VMSs or directly to vehicles, for example through radio messages. Weather warnings, traffic reports and rule changes, such as speed limit adjustments, are common types of information disseminated to traffic. Wider dissemination is also possible, informing users not currently using the transport network, for example through the internet (Brown, 1997). Information dissemination is particularly important within the road domain due to limited options for direct traffic control, road TMC success has been linked to their ability to influence drivers' decisions through the dissemination of timely, accurate and complete information (Murray & Liu, 1997).

As shown in Table 2-3 there are many potential interventions within all domains for managing a situation. Furthermore, multiple interventions may need to be considered simultaneously, or as alternatives, to solve complex problems. The Human Factors difficulty is ensuring system design links the possible impacts of potential interventions with the operator's requirements for decision-making information. Done effectively this would enable operators to compare intervention options against the demands of the current context, allowing them to intervene as effectively as possible.

Table 2-3: Examples of potential TMC interventions

		Road	**Rail**	**Maritime**	**Air**
Physical Manipulation	*Infrastructure*	Variable lane control, Ramp metering, Signal phasing adjustment,	Points, Signalling	None	None
	Vehicle	None	ATO, ATP	None	None
Direct Assistance	*Mandatory*	Emergency services, RTO	Signalling, Timetabling, Route setting	Traffic Organisation Service	Directing aircraft
	Assistive	Emergency services, RTO	Specific advisories	Navigational Assistance Service	Specific advisories
Disseminate Information	*Via Infrastructure*	Variable speed limits, VMSs, Other signage (car parks etc.)	Platform information	None	None
	To Vehicles	Radio reports, TMC	General advisories	Information Service	General advisories, Weather reports
	Wider Distribution	Radio, Internet,	Radio, Internet	Radio, Internet	Radio, Internet

2.5.4 Feedback

Traffic management systems can be described by the control loop concept, with a desired goal, a means of implementation to achieve the goal and feedback to establish whether the goal has been achieved (Norman, 1990). Feedback enables system performance to be monitored and actions to be adapted if necessary. To do this effectively Norman (1990) stated that feedback must be relevant, unobtrusive and accurate, particularly when operators have a significant monitoring role, such as within traffic management.

Feedback regarding the transport network can alert operators to potential problems as well as providing a measure of intervention's impact. There is crossover between monitoring and feedback functions, for example traffic flow rates monitor traffic conditions at a point-in-time, but can also be used to show changes in response to an intervention, providing feedback regarding the intervention's success.

Dedicated feedback functions provide specific assistance, for example problems caused by vehicle's actions or planned routes can be identified by conflict detection systems in rail, maritime and air domains (Davey, 2012; Hopkin, 1989; Van Dam et al., 2006) and incident detection systems in the road domain (Williams & Guin, 2007). Feedback is also provided regarding TMC's internal systems, providing confidence that they are working correctly. This is important for ensuring decisions are based on accurate information and are implemented effectively.

2.6 Conclusions

TMCs are used to improve transport efficiency and safety, and reduce the environmental impact of road, rail, maritime and air transport networks. While there are similarities in purpose between these domains the environment imposes specific constraints upon TMCs' operation and directly influences interactions with traffic. That said the traffic management process itself was found to be relatively similar across domains, all TMCs monitoring real-time and predicted network conditions, deciding how to manage traffic and intervening within the network when necessary. Functions arising from this process are also directly comparable between domains; all TMCs incorporate monitoring, decision-making, intervention, feedback and support functions. The specific implementation of these functions is however affected by domains' individual characteristics, in particular monitoring and intervention functions, both being dependent on vehicles' capabilities and traffics' behaviour.

Finally considering the key challenges specifically affecting road traffic management gives rise to two unique issues suitable for further investigation. Firstly, how to accurately monitor the road network for problems, given the volume and distributed nature of traffic being managed, and provide this information to operators. Secondly, how to intervene effectively when problems do occur, in particular how to facilitate use of indirect methods to influence traffic, such as information dissemination, given that road TMCs have relatively little physical control over the network. To understand these issues further observational studies will be conducted in urban road TMCs in chapter 3.

Chapter 3: Congestion Management in Urban Traffic Management Centres

3.1 Introduction

Congestion occurs when the demand for transport infrastructure exceeds its capacity (Everall, 1972) and is forecast to cost the UK economy £22 billion by 2025 (Eddington, 2006), making it a significant national issue. With demand for road transport predicted to increase at least 34% by 2035 (Department for Transport, 2012b) and with limited options for physical expansion (Baskar et al., 2011), maximising the utilisation of existing networks will be critical for their future effectiveness (CEC, 2006). Capacity reducing events can also have a detrimental effect on performance, road traffic incidents alone having been estimated to account for 50% of delays on US highways (Bertini et al., 2005) and with road traffic deaths predicted to become the fifth leading cause of death by 2030 (currently eighth) (World Health Organisation, 2013) the problem could increase.

Traffic management is part of the solution, which through planning, monitoring, and control or influencing of traffic (Transport Research Knowledge Centre, 2009) aims to maximise road capacity, minimise incident's impact, manage demand and assist emergency services, facilitating the movement of traffic, with minimal delay, throughout the road network (Folds et al., 1993) and implemented through Traffic Management Centres (TMCs). TMCs manage many urban traffic networks as well as inter-urban routes, acting as a central hub to collect information from a wide array of sources and then managing traffic through physical manipulation of infrastructure, by directly assisting vehicles and disseminating information (see Murray & Liu, 1997; Nowakowski et al., 1999).

TMCs are complex socio-technical systems (Walker et al., 2008) and a form of command and control (Walker et al., 2010), having a common goal with interacting sub-goals, requiring communication and coordination between multiple agents and utilising complex technology. The domain can also be considered from a distributed cognition perspective (e.g. Hutchins, 1995) involving multiple operators, teams and technical artefacts, cognition within the system transcends the boundaries between individual agents (Hutchins, 1995).

Effectively modelling the traffic management domain, indeed any cognitively distributed system, is difficult (Stanton, 2014), individual Human Factors methods being unable to adequately describe their complexity (Stanton, Salmon, Walker, Baber, & Jenkins, 2005). Nevertheless, gaining a better understanding of the traffic management process is vital in order to enable the technical systems used within TMCs to be evaluated and improved.

Distributed cognition has been studied within several types of control centre, including Air Traffic Control (ATC; Inoue et al., 2012; Walker et al., 2010), emergency services (Houghton et al., 2006), energy distribution (Salmon et al., 2008), railways (Farrington-Darby, Wilson, Norris, & Clarke, 2006; Walker et al., 2006) and submarines (Stanton, 2014). A comprehensive analysis framework that has been used is Event Analysis of Systematic Teamwork (EAST; Stanton, Baber, & Harris, 2008). EAST is a systems ergonomics method which considers complex socio-technical systems holistically without favouring either subsystem and enables both quantitative and qualitative analysis based on graphical network diagrams (Stanton, 2014), which themselves have been shown to have advantages over traditional ethnographical approaches (Walker et al., 2010). Temporal aspects of the network can also be modelled effectively (see Griffin, Young, & Stanton, 2010). EAST does not provide direct recommendations but the analyses can be used to identify areas limiting performance or where improvements could be made (Stanton, 2014). This chapter will apply EAST at a macro level to congestion management within urban road TMCs, with an aim that the analysis will go on to inform evaluation of the technical systems used within TMCs and any subsequent redesigns.

3.2 Methodology

EAST was originally a multi-method approach (see Walker et al., 2006) incorporating a number of established ergonomics methods, including Hierarchical Task Analysis (HTA; Annet, 2005), Critical Decision Method (Klein & Armstrong, 2005) and Coordination Demand Analysis (CDA; Burke, 2005), outputs can also be based directly upon observational data (Stanton, 2014), this version is used here.

Systems are considered in terms of the tasks undertaken, social agents involved and information used, each element being depicted graphically through the creation of three primary networks, together providing a detailed view of the system's complexity (Griffin et al., 2010). These primary networks are described below;

- *Task Networks* describe the relationships between tasks and their sequences and interdependences.
- *Social Networks* analyse the organisation of the system (i.e. communication structure) and the communications which take place between agents.
- *Information Networks* show the information used and communicated by agents during a task.

This graphical approach enables networks to be assessed qualitatively (e.g. Leavitt, 1951), through visual assessment, and also quantitatively, by calculating Social Network Analysis (SNA; Driskell & Mullen, 2005) metrics (Stanton, 2014; Stanton et al., 2008). Although quantitative analysis has predominately been used solely within social networks (e.g. Houghton et al., 2006) Stanton (2014) showed that the calculation of SNA metrics for all three primary networks could be beneficial. SNA enables each network to be analysed as a whole as well as investigation into individual node's behaviour and interactions. A description of each metric used is provided in the sections below. A test statistic of a metric's mean plus one standard deviation can then be used to identify significant nodes within each network (Houghton et al., 2006).

A further benefit of the graphical depictions of task, social and information networks is that they can be combined, enabling the interactions between networks to be depicted and providing greater insight into the system's workings. This network of networks approach is fundamental to EAST (Stanton, 2014) and enables distributed cognition to be visualised. Figure 3-1 shows the interactions between primary networks.

3.2.1 Global Metrics

- *Density* is the number of links divided by the number of potential links evaluating the degree to which information is distributed across the network.
- *Cohesion* considers only reciprocal links; quantifying a network's linearity.
- *Diameter* is the distance between each side of the network, comparing it to the maximum possible diameter (n-1, where n is the number of nodes) shows the level of interaction between nodes.

3.2.2 Individual Metrics

- *Emission* and *Reception* are the number of links from and to a node.
- *Eccentricity* is the number of links from a node to the other side of the network.

- *Sociometric Status* relates a nodes emission and reception to the total number of nodes in the network as a measure of its individual importance.
- *PageRank* (see Page, Brin, Motwani, & Winograd, 1998) is a more sophisticated importance measure, a node's value is dictated by the importance of connected nodes and the weighting of links.
- *Centrality* defines a node's influence within the network; there are various methods of calculation including Bavelas-Leavitt (B-L) and Eigenvector (EV). The allocation of decision rights throughout the network can be quantified by dividing the number of nodes exceeding the mean centrality by the network size.
- *Farness* is the sum of the shortest distances between the node and all others.
- *Closeness* shows how fast information can be spread from a node around the network; it is the inverse of farness.
- *Betweeness* describes a node's power as an intermediary by quantifying how often it appears between any two others.

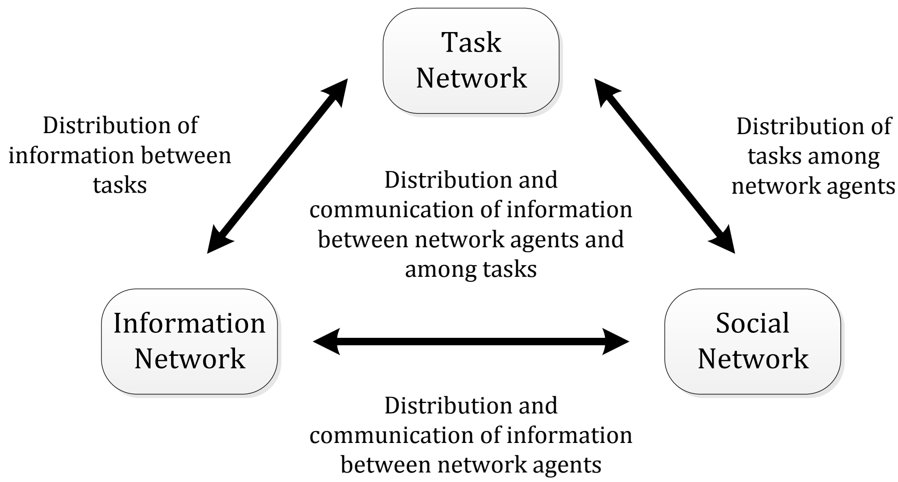


Figure 3-1: EAST's network of networks approach (adapted from Stanton (2014))

3.3 Data Collection and Analysis

Four TMCs were studied, Bristol, Cardiff, Dorset and Nottingham. All are managed by local authorities, Bristol, Cardiff and Nottingham at city level with Dorset at county level. Bristol and Nottingham TMCs are of similar size, responsible for the urbanised areas of each city, 40 and 30 square miles respectively. Although Cardiff is a similar sized city to Bristol and Nottingham its TMC is significantly larger, owing to the amalgamation of police CCTV and public space monitoring control centres into a single location as well as a need to manage Cardiff's tunnel twenty four hours a day. Dorset's TMC is responsible for the entire county though management is predominantly focused around the towns of Christchurch, Dorchester and Weymouth, with some key trunk routes are also managed, the TMC itself is significantly smaller than the others. The photographs in Figure 3-2 show views of each TMC.

Figure 3-2: Bristol, Cardiff (BBC News, 2010), Dorset and Nottingham (Nottingham City Council, 2013) TMCs (clockwise from top left)

TMC operations were observed over a working day at each TMC, with informal interviews conducted with the operators on duty when their workloads allowed. Operators came from a range of backgrounds and had varying experience levels; although typically greater than five years some were new to the profession. Several congestion scenarios were observed, including unexpectedly high traffic demand and vehicle breakdowns, which required management. These provided an opportunity to supplement observations with in-depth technical critiques and insights from the Subject Matter Experts (SMEs).

EAST was conducted as described by Stanton (2014) with task, social and information network diagrams produced from the observational data. Social Network Analysis (SNA) metrics were then calculated for individual nodes and entire networks using AGNA (version 2.1.1) and Gephi (version 0.8.2 beta). Combined (task and social, information and social, information and integrated) networks were then produced and analysed qualitatively. The findings from each EAST phase are presented in the following sections.

3.4 Task Network Analysis

The task network is shown in Figure 3-3 and is applicable to all TMCs. The network can be described as circular, the system assumed to be in a state of normal performance until a problem is identified, causing an exceptional state and triggering the management process. This process is conducted through seven linear phases comprising: monitoring, contextualisation, prioritisation, personnel allocation, strategy development and selection, strategy implementation, and feedback.

Firstly the network is monitored using a range of sources, including CCTV, Urban Traffic Management and Control (UTMC) systems (e.g. vehicle counts, incident detection), digital communications (e.g. email, Twitter), internal communications (i.e. discussion between TMC personnel) and analogue communications (e.g. reports by phone). Monitoring is a constant task with CCTV described as particularly important, being accurate, up-to-date and reliable.

Once identified, the scenario's context is established. General details such as time, location and the overall status of the network are noted and the problem site and surrounding area are investigated further to try and understand the cause and implications to traffic. This enables the extent, severity, complexity and probable time requirement of the scenario to be judged, allowing prioritisation of management activities.

Personnel must then be allocated to the scenario; this is achieved by considering its requirements (e.g. number of personnel required, useful specialist knowledge) against the skills and experience of, and demand for, available personnel. Large or complex scenarios may require coordination between multiple personnel; conversely if a single operator is available this phase is trivial.

Management strategies are then developed, following a linear process and based on information from the contextualisation and prioritisation phases. Available options are considered (e.g. availability of on-site resources and their capabilities) against the scenario's management requirements and used to develop potential strategies. A cost/benefit analysis enables comparison and selection of the perceived best solution. Implementation can incorporate physical manipulation (e.g. signal timing adjustment), direct assistance (e.g. on-site personnel moving a broken down vehicle) and information dissemination (e.g. Variable Message Sign (VMS) messages, Twitter updates). Doing nothing may also be strategically valid, if, for example, the situation is likely to resolve itself quickly or no other options are available.

Finally, feedback is provided by monitoring functions, enabling impacts to be observed. It can then be decided whether normal performance has resumed, if not strategy development, selection and implementation are repeated until the scenario is resolved.

As an example during observation at Bristol excessive congestion was noticed on CCTV. An investigation using CCTV, UTMC systems and online sources identified the problem as inefficient traffic light phasing. There were few other time priorities acting upon the operator, so the issue was dealt with immediately by altering the light's phasing (physical manipulation). The situation was then monitored until the issue was resolved.

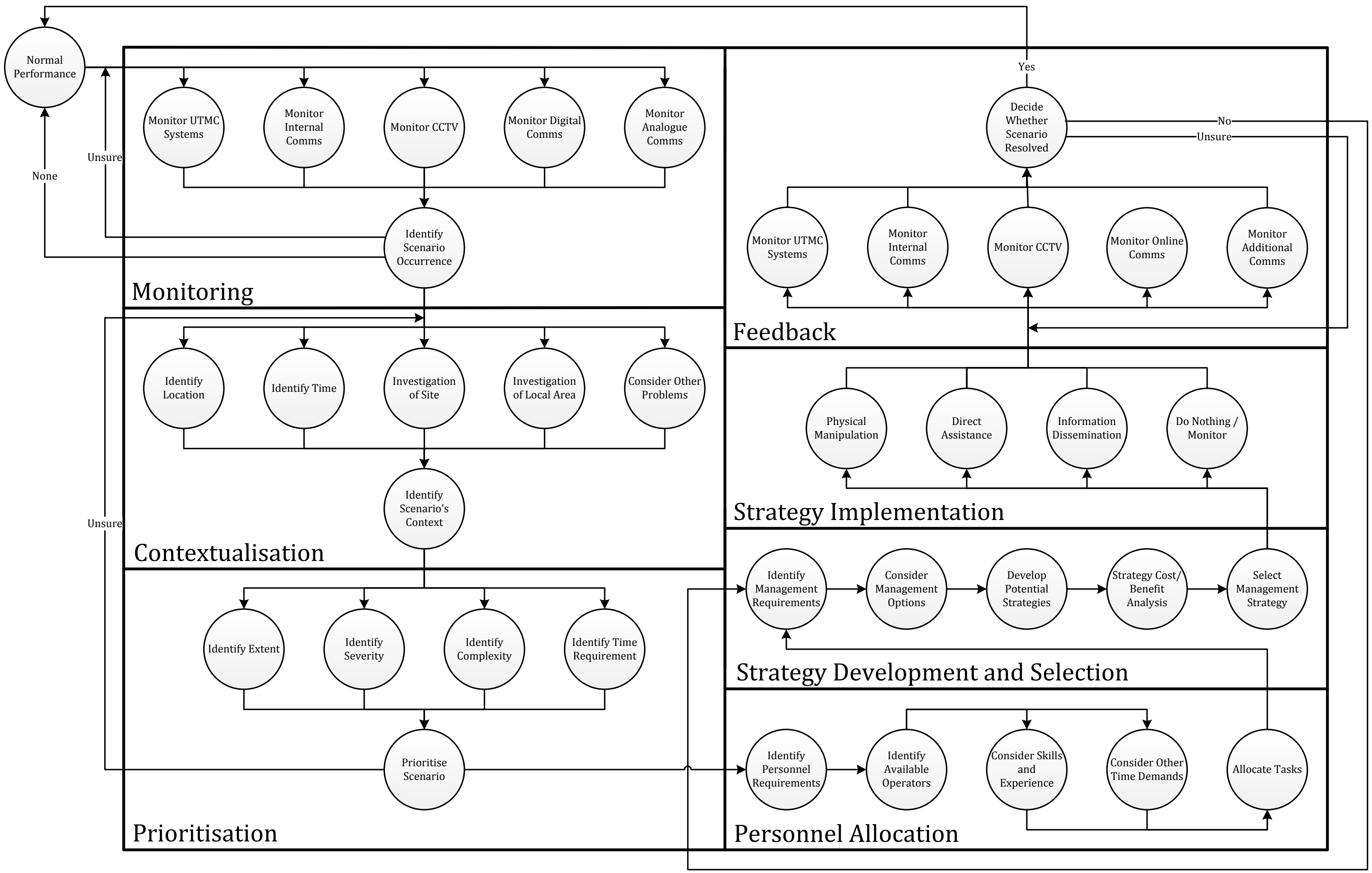


Figure 3-3: Task network for congestion management

Table 3-1: Analysis of task network

Task Node	**Emission**	**Reception**	**Eccentricity**	**Sociometric Status**	**PageRank (x10²)**	**Centrality (B-L)**	**Centrality (EVx10)**	**Closeness (x10³)**	**Farness**	**Betweeness**	
Normal Performance	**5**	2	10	2.19	1.7	16.1	5.4	6.5	154	0	
Monitor UTMC Systems	2	**7**	9	**2.81**	2.8	**19.4**	**7.2**	**7.6**	132	76	Monitoring
Monitor Internal Communications	2	**7**	9	**2.81**	2.8	**19.4**	**7.2**	**7.6**	132	76	
Monitor CCTV	2	**7**	9	**2.81**	2.8	**19.4**	**7.2**	**7.6**	132	76	
Monitor Digital Communications	2	**7**	9	**2.81**	2.8	**19.4**	**7.2**	**7.6**	132	76	
Monitor Analogue Communications	2	**7**	9	**2.81**	2.8	**19.4**	**7.2**	**7.6**	132	76	
Identify Problem Occurrence	**11**	**5**	8	**5**	**6.4**	**18.8**	**10**	**8.3**	121	**347**	
Identify Location	1	2	**16**	0.94	2.3	16.5	3.2	3.6	**274**	50	Contextualisation
Identify Time	1	2	**16**	0.94	2.3	16.5	3.2	3.6	**274**	50	
Investigation of Site	1	2	**16**	0.94	2.3	16.5	3.2	3.6	**274**	50	
Investigation of Local Area	1	2	**16**	0.94	2.3	16.5	3.2	3.6	**274**	50	
Consider Other Problems	1	2	**16**	0.94	2.3	16.5	3.2	3.6	**274**	50	
Identify Problem's Context	4	**5**	15	**2.81**	**10.1**	17.2	4.5	4.1	245	**377**	
Identify Extent	1	1	14	0.63	2.6	16.7	1.3	4.4	228	70	Prioritisation
Identify Severity	1	1	14	0.63	2.6	16.7	1.3	4.4	228	70	
Identify Complexity	1	1	14	0.63	2.6	16.7	1.3	4.4	228	70	
Identify Time Requirement	1	1	13	0.63	2.6	16.7	1.3	4.4	228	70	
Prioritise Problem	**6**	4	15	**3.13**	**9.3**	17.2	1.5	5.0	199	**377**	
Identify Personnel Requirements	1	1	15	0.63	1.8	13.2	0.5	3.3	**302**	306	Personnel Allocation
Identify Available Operators	2	1	15	0.94	2.0	13.2	0.2	3.5	**285**	306	
Consider Skills and Experience	1	1	**16**	0.63	1.3	12.8	0.1	3.5	**284**	137	
Consider Other Time Demands	1	1	**16**	0.63	1.3	12.8	0.1	3.5	**284**	137	
Allocate Tasks	1	2	15	0.94	2.6	13.2	0.2	3.7	267	**306**	
Identify Management Requirements	1	2	15	0.94	3.5	17.5	2.9	4.0	250	**420**	Strategy Dev. + Selection
Consider Management Options	1	1	14	0.63	3.4	17.5	0.8	4.4	225	**420**	
Develop Potential Strategies	1	1	13	0.63	3.4	17.5	0.3	5.0	200	**420**	
Strategy Cost/Benefit Analysis	1	1	12	0.63	3.3	17.5	0.1	5.7	175	**420**	
Select Management Strategy	4	1	11	1.56	3.3	17.5	0.1	6.7	150	**420**	
Physical Manipulation	**5**	1	10	1.88	1.1	16.5	0.1	6.7	149	81	Strategy. Impl.
Direct Assistance	**5**	1	10	1.88	1.1	16.5	0.1	6.7	149	81	
Information Dissemination	**5**	1	10	1.88	1.1	16.5	0.1	6.7	149	81	
Do Nothing	**5**	1	10	1.88	1.1	16.5	0.1	6.7	149	81	
Test Statistic	5.0	4.8	15.5	2.76	5.1	18.6	6.0	7.0	268	323	

Task Node	Emission	Reception	Eccentricity	Sociometric Status	PageRank ($x10^2$)	Centrality (B-L)	Centrality (EVx10)	Closeness ($x10^3$)	Farness	Betweeness	
Monitor UTMC Systems*	2	**7**	9	**2.81**	2.8	**19.4**	**7.2**	**7.6**	132	76	Feedback
Monitor Internal Communications*	2	**7**	9	**2.81**	2.8	**19.4**	**7.2**	**7.6**	132	76	
Monitor CCTV*	2	**7**	9	**2.81**	2.8	**19.4**	**7.2**	**7.6**	132	76	
Monitor Digital Communications*	2	**7**	9	**2.81**	2.8	**19.4**	**7.2**	**7.6**	132	76	
Monitor Analogue Communications*	2	**7**	9	**2.81**	2.8	**19.4**	**7.2**	**7.6**	132	76	
Decide Whether Problem Resolved*	**7**	**5**	10	**3.75**	**6.4**	18.1	**10**	**7.4**	135	130	
Test Statistic	5.0	4.8	15.5	2.76	5.1	18.6	6.0	7.0	268	323	

The task network is uniform and directed (non-symmetric) with 33 nodes and 86 links. The network's diameter is 16 corresponding to moderate interaction. The network's density is 0.08, meaning there is low distribution of information throughout the network, while cohesion is 0.02 indicating a relatively low amount of feedback throughout the task process. The network is deep and essentially linear with each phase completed in order, even though tasks within most phases can be undertaken concurrently, there are therefore strict dependencies within the network.

Individual metrics are presented in Table 3-1 and indicate the importance of the output tasks from each phase, all typically having high importance (sociometric status and PageRank) and betweeness values. Monitoring task's importance (including as feedback) is evident with all of these tasks having high sociometric status, centrality and closeness. Tasks within the strategy development and selection phase all have high betweeness, owing to this phase's central position within the task process, as well as relatively high PageRank values.

Fourteen tasks have B-L centrality scores higher than the mean value (16.7) representing moderate allocation of decision rights throughout the task process. This, combined with low information distribution and moderate interaction, is consistent with a hybrid hierarchical (chain) and star network archetype (see Leavitt, 1951; Stanton, Walker, & Sorensen, 2012).

3.5 Social Network Analysis

Social agents can be grouped by geographical location and are described below.

Traffic Management Centre

- *TMC Operators* are responsible for managing traffic and the system's SMEs; typically two operators are present however this can vary.
- *Bus Lane Enforcement Personnel* identify and prosecute vehicles illegally using or obstructing public transport infrastructure using CCTV.
- *Parking Enforcement / Bollard Control Personnel* monitor CCTV for illegal parking and direct parking enforcement personnel, responsible for controlling security bollards around the city centre.
- *Public Space Monitoring Personnel* monitor CCTV for antisocial behaviour, assisting police.
- *Police CCTV Personnel* monitor CCTV for crime, assisting police operations.
- *Third Party Representatives* act as a liaison between the TMC and a third party, e.g. public transport providers.
- *SCOOT Engineers* are responsible for maintaining and upgrading the adaptively controlled traffic light systems using SCOOT.
- *CCTV Application* controls the TMC's CCTV cameras.
- *UTMC Applications* are software used to manage the network, e.g. COMET (Siemens Traffic Solutions, 2009), Argonaut (Cloud Amber, 2012).

Road Network

- *Traffic Monitoring Equipment*, for example CCTV cameras and induction loops.
- *Traffic Management Equipment*, for example traffic lights and VMSs.
- *On-site Monitoring Personnel,* for example parking enforcement personnel.
- *On-site Management Personnel*, for example traffic management contractors.
- *Vehicular, Public Transport, Emergency Services, Cyclists and Pedestrians* are the categories of traffic using (or potentially using) the road network.

External

- *Public Space Monitoring* and *Emergency Services Control Centres* monitor public areas for criminal activity and manage emergency service operations respectively.

- *Additional Information Providers* provide extra information to aid decisions such as weather reports (e.g. the Met Office) or wider traffic conditions (e.g. the Highways Agency)
- *Radio Stations* distribute information to traffic and other agents.
- *Traffic Data Distribution* incorporates the dissemination of information to traffic and third parties directly by the TMC and through intermediaries.
- *Other Transport Control Centres* includes other road TMCs as well as public transport control centres (e.g. Bus, Tram)

There is a temporal dimension to the task process, with significant social differences between phases. Three social networks were therefore constructed for each TMC, the first covering 'information phases' (monitoring, contextualisation, prioritisation and feedback), the second modelling personnel allocation, the third describing 'strategy phases' (strategy development, selection and implementation).

Construction of each Social Network Diagram (SND) utilised an association matrix to quantify the importance of links between agents through weighting. Within most previous application of EAST weights have been based upon empirical measurement of the number of communication transactions that occur (e.g. Houghton et al., 2006; Stanton, 2014), however within traffic management many communications occur outside of the TMC making them difficult to measure and the volume of communications may not reflect importance, for example if the communication is irrelevant to the scenario being managed. To resolve this issue links have been constructed using a qualitative method utilised within social sciences in which links are weighted based on their frequency of use and relevance (see Bevelas, 1948; Leavitt, H.J., 1951). Each link is assigned a score of 1-3 for how frequently it occurs (1 = low frequency, 2 = moderate frequency, 3 = high frequency) and its relevance (1 = low relevance, 2 = moderate relevance, 3 = high relevance) based on discussion with SMEs. The relative importance of a link can then be calculated by multiplying frequency by relevance, giving a score between 1 and 9. To aid clarity links have been colour coded according to importance, green for high importance (7-9), yellow for moderate importance (4-6) and red for low importance (1-3).

3.5.1 Monitoring, Contextualisation, Prioritisation and Feedback

Within these phases the flow of information is generally from the road network and external environment into the TMC where it is used within operator's decision-making. This can be seen in all association matrixes (Table 3-2 to Table 3-5) with 53%, 65%, 41% and 47% of links received within the TMC in Bristol, Cardiff, Dorset and Nottingham respectively.

Overall the TMC's information gathering networks are relatively similar, with all employing comparable sources to build a picture of what is happening, this is reflected within both individual and global metrics. The main differences observed are in the physical structures of the control rooms themselves. While all have human operators and several technical systems are used to support them, most employ a variety of other personnel who perform additional functions, for example CCTV monitoring and traffic enforcement. These personnel provide additional links to the environment and the informal communications between them and operators are invaluable for enabling as much of the network as possible.

Each social network is weighted (non-uniform), directed (non-symmetric) and has a diameter of 5, suggesting a moderate amount of interaction compared to the maximum possible diameters. The network densities of 0.234 (Bristol), 0.262 (Cardiff) and 0.225 (Dorset and Nottingham) corresponds to moderate-low information distribution in each location. Two thirds of the communications are reciprocal as shown by the cohesion values of 0.153 (Bristol), 0.177 (Cardiff), 0.137 (Dorset) and 0.14 (Nottingham), many of the links representing a dialogue between operators and another agent, whether face-to-face, via phone, internet or machine interface.

Qualitatively the networks resemble a star archetype (see Leavitt, 1951) with TMC operators central, being the ultimate recipients of information. Quantitative metrics (Table 3-4) support this, TMC operators having the highest sociometric status and EV centrality as well as high betweeness. This contrasts with other control room domains where technical agents have been the most central (e.g. Houghton et al., 2006; Walker et al., 2010), possibly because humans provide the necessary degree of adaptability required to deal with frequently unpredictable scenarios. In each case approximately half of the nodes exceed the mean exceed the mean B-L centrality values (9.54 (Bristol), 10.86 (Cardiff), 8.47 (Dorset) and 8.99 (Nottingham)) corresponding to moderate allocation of decision rights. This along with the observed values of information distribution and interaction are consistent with a star network type (see Stanton et al., 2012).

Star networks have been shown to be effective for problem-solving tasks (Leavitt, 1951) and would therefore seem appropriate for the task of identifying network problems and establishing their context, presumably having evolved over many generations of traffic management. A potential issue however is that any reduction in the central agent's performance is likely to significantly impact the entire system.

A surprising finding from the individual metrics is that while traffic provides the purpose for the TMC all types having fairly high farness with low scores for other metrics. This is because communications with the TMC are indirect, putting them on the system's periphery. External agents have high centrality but low importance, having extensive connections but low relevance due to their generalised focus, therefore this information is predominantly supplemental to local sources such as CCTV and dedicated equipment which typically have higher importance, centrality and betweeness metrics.

Table 3-2: Association Matrix for information phases at Bristol

		Frequency / Relevance (Importance)																				
ID	**Agent**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	
1	TMC Operator 1		2/3 (6)	2/2 (4)	2/2 (4)	3/3 (9)	3/3 (9)			2/3 (6)	1/3 (3)							1/3 (3)			1/3(3)	**Traffic Management Centre**
2	TMC Operator 2	2/3 (6)		2/2 (4)	2/2 (2)	3/3 (9)	3/3 (9)			2/3 (6)	1/3 (3)							1/3 (3)			1/3 (3)	
3	Bus Lane Enforcement Personnel	2/2 (4)	2/2 (4)		1/1 (1)		3/1 (3)															
4	Third Party Representative	2/2 (4)	2/2 (4)	1/1 (1)			1/2 (2)											3/2 (6)				
5	UTMC Applications	3/3 (9)	3/3 (9)					3/3 (9)	3/2 (6)													
6	CCTV Application	3/3 (9)	3/3 (9)	3/1 (3)	1/2 (2)			3/3 (9)													3/1 (3)	
7	Traffic Monitoring Equipment					3/3 (9)	3/3 (9)															**Road Network**
8	Traffic Management Equipment					3/2 (6)																
9	On-site Monitoring Personnel	2/3 (6)	2/3 (6)																			
10	On-site Management Personnel	1/3 (3)	1/3 (3)																			
11	Vehicular Traffic							3/3 (9)		2/3 (6)							2/2 (4)			1/2 (2)		
12	Cyclists							3/3 (9)		2/3 (6)							1/2(2)			1/2 (2)		
13	Pedestrians							3/3 (9)		2/3 (6)							1/2(2)			1/2 (2)		
14	Public Transport							3/3 (9)		2/3 (6)							2/2 (4)	3/2 (6)				
15	Emergency Services							3/3 (9)		2/3 (6)											3/1 (3)	
16	Traffic Data Distribution	2/2 (4)	2/2 (4)															2/1 (2)	2/1 (2)	2/1 (2)	2/1(2)	**External**
17	Other Control Centres	1/3 (3)	1/3 (3)		3/2 (6)										3/2 (6)		2/1 (2)					
18	Additional Information Providers	2/2 (4)	2/2 (4)	2/2 (4)	2/2 (4)													2/1 (2)				
19	Radio Stations	1/2 (2)	1/2 (2)	1/2 (2)	1/2 (2)													1/1 (1)				
20	Public Space Monitoring + Emergency Services Control Centres	1/3 (3)	1/3 (3)				3/1 (3)									3/1 (3)	2/1(2)					
		Traffic Management Centre						**Road Network**									**External**					

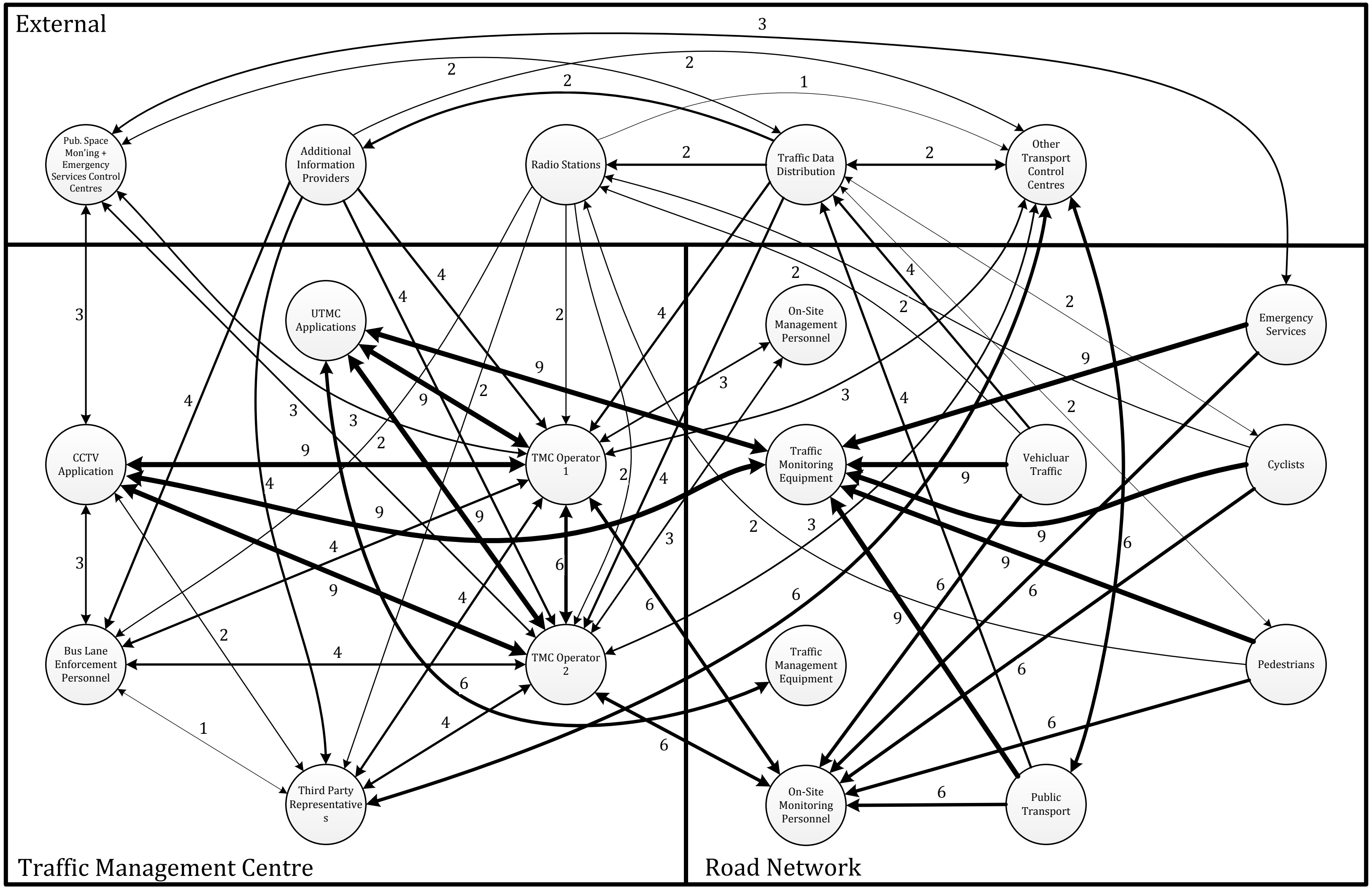


Figure 3-4: Social Network Diagram for information phases at Bristol

Table 3-3: Association Matrix for information phases at Cardiff

		Frequency / Relevance (Importance)																						
ID	**Agent**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	
1	TMC Operator 1 (Traffic)		2/3 (6)	2/2 (4)	2/2 (4)	2/2 (4)	2/2 (4)	2/3 (6)	3/3 (9)											1/3 (3)			1/3 (3)	**Traffic Management Centre**
2	TMC Operator 2 (Tunnel)	2/3 (6)		2/2 (4)	2/2 (4)	2/2 (4)	2/2 (4)	2/3 (6)	3/3 (9)					1/3 (3)						1/3 (3)			1/3 (3)	
3	Parking Enforcement / Bollard Ctrl.	2/2 (4)	2/2 (4)		2/1 (2)	1/1 (1)	1/2 (2)		3/1 (3)			3/1 (3)	3/1 (3)											
4	Public Space Monitoring Personnel	2/2 (4)	2/2 (4)	2/1 (2)		1/1 (1)	1/2 (2)		3/1 (3)														2/1 (2)	
5	Police CCTV Personnel	2/2 (4)	2/2 (4)	1/1 (1)	1/1 (1)		1/2 (2)		3/1 (3)									3/1 (3)					3/1 (3)	
6	SCOOT Engineer	2/2 (4)	2/2 (4)	1/2 (2)	1/2 (2)	1/2 (2)		2/2 (4)	2/2 (4)															
7	UTMC Applications	2/3 (6)	2/3 (6)				2/2 (4)			3/3 (9)	2/3 (6)													
8	CCTV Application	3/3 (9)	3/3 (9)	3/1 (3)	3/1 (3)	3/1 (3)	2/2 (4)			3/3 (9)														
9	Traffic Monitoring Equipment							3/3 (9)	3/3 (9)															**Road Network**
10	Traffic Management Equipment							2/3 (6)																
11	On-site Monitoring Personnel	2/3 (6)	2/3 (6)	3/1 (3)																				
12	On-site Management Personnel	1/3 (3)	1/3 (3)	3/1 (3)																				
13	Vehicular Traffic		1/3 (3)							3/3 (9)		2/3 (6)							2/2 (4)			2/1 (2)		
14	Cyclists									3/3 (9)		2/3 (6)							1/2 (2)			2/1 (2)		
15	Pedestrians									3/3 (9)		2/3 (6)							1/2 (2)			2/1 (2)		
16	Public Transport									3/3 (9)		2/3 (6)							2/2 (4)	3/2 (3)				
17	Emergency Services					3/1 (3)				3/3 (9)		2/3 (6)											3/1 (3)	
18	Traffic Data Distribution	2/2 (4)	2/2 (4)																	2/1 (2)	2/1 (2)	2/1 (2)	2/1 (2)	**External**
19	Other Control Centres	1/3 (3)	1/3 (3)														3/2 (6)		2/1 (2)					
20	Additional Information Providers	2/2 (4)	2/2 (4)	1/2 (2)	1/2 (2)	1/2 (2)	2/1 (2)													2/1 (2)				
21	Radio Stations	2/1 (2)	2/1 (2)	2/1 (2)	2/1 (2)	2/1 (2)	2/1 (2)													1/1 (1)				
22	Emergency Services Control Centres	1/3 (3)	1/3 (3)		2/1 (2)	3/1 (3)												3/1 (3)	2/1 (2)					
		Traffic Management Centre								**Road Network**									**External**					

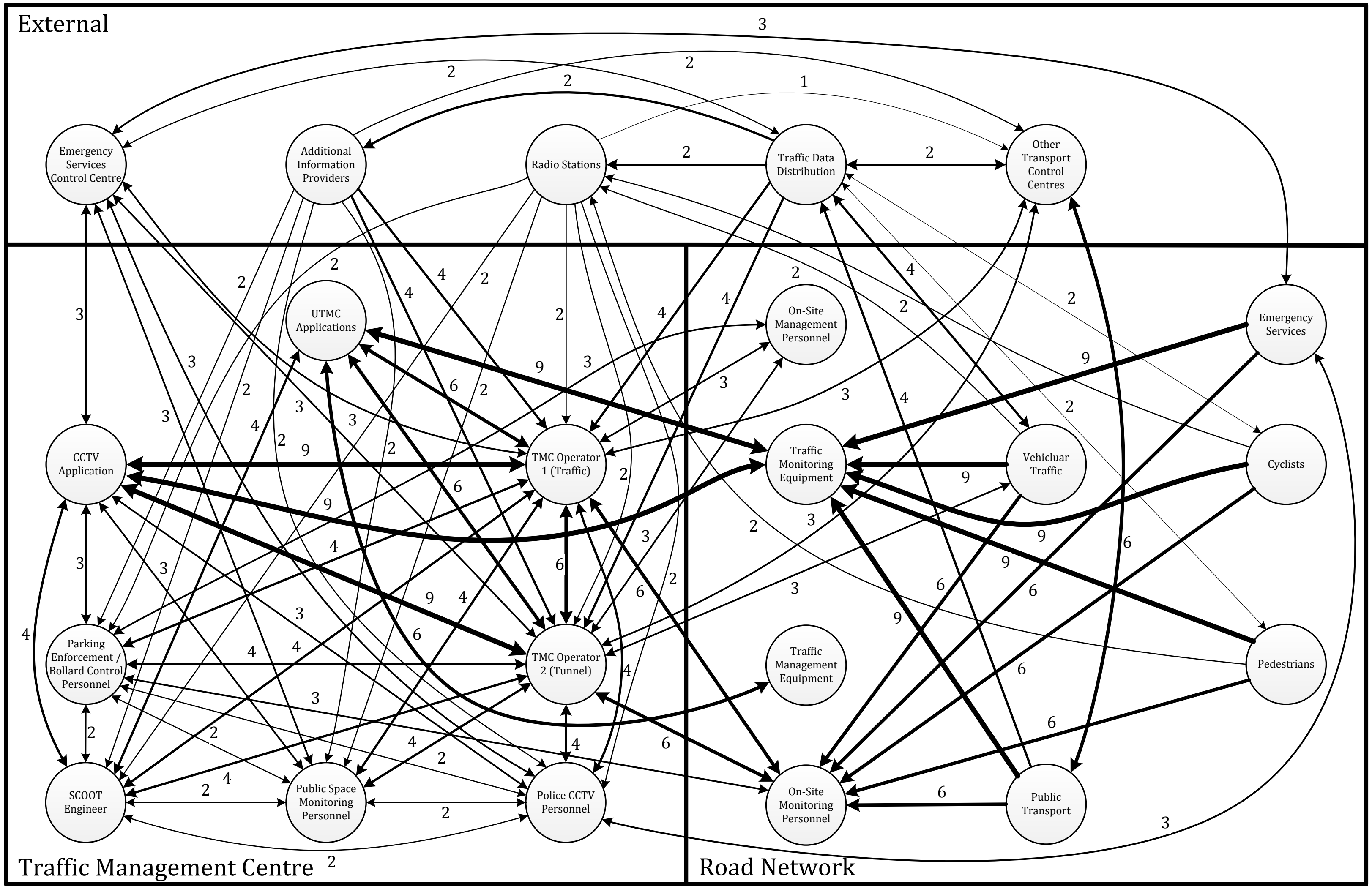


Figure 3-5: Social Network Diagram for information phases at Cardiff

Table 3-4: Association Matrix for information phases at Dorset

ID	Agent	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Group
		Frequency / Relevance (Importance)																		
1	TMC Operator 1		2/3 (6)	3/3 (9)	3/3 (9)			2/3 (6)	1/3 (3)							2/3 (6)			2/3 (6)	Traffic Management Centre
2	TMC Operator 2	2/3 (6)		3/3 (9)	3/3 (9)			2/3 (6)	1/3 (3)							2/3 (6)			2/3 (6)	
3	UTMC Applications	3/3 (9)	3/3 (9)			3/3 (9)	3/2 (6)													
4	CCTV Application	3/3 (9)	3/3 (9)			3/3 (9)													3/1 (3)	
5	Traffic Monitoring Equipment			3/3 (9)	3/3 (9)															Road Network
6	Traffic Management Equipment			3/2 (6)																
7	On-site Monitoring Personnel	2/3 (6)	2/3 (6)																	
8	On-site Management Personnel	1/3 (3)	1/3 (3)																	
9	Vehicular Traffic					3/3 (9)		2/3 (6)							2/2 (4)			1/2 (2)		
10	Cyclists					3/3 (9)		2/3 (6)							1/2 (2)			1/2 (2)		
11	Pedestrians					3/3 (9)		2/3 (6)							1/2 (2)			1/2 (2)		
12	Public Transport					3/3 (9)		2/3 (6)							2/2 (4)	3/2 (6)				
13	Emergency Services					3/3 (9)		2/3 (6)											3/1 (3)	
14	Traffic Data Distribution	3/2 (6)	3/2 (6)													2/1 (2)	2/1 (2)	2/1 (2)	2/1 (2)	External
15	Other Control Centres	2/3 (6)	2/3 (6)										3/2 (6)		2/1 (2)					
16	Additional Information Providers	3/2 (6)	3/2 (6)													2/1 (2)				
17	Radio Stations	3/2 (6)	3/2 (6)													1/1 (1)				
18	Public Space Monitoring + Emergency Services Control Centres	2/3 (6)	2/3 (6)		3/1 (3)									3/1 (3)	2/1 (2)					
		Traffic Management Centre				Road Network									External					

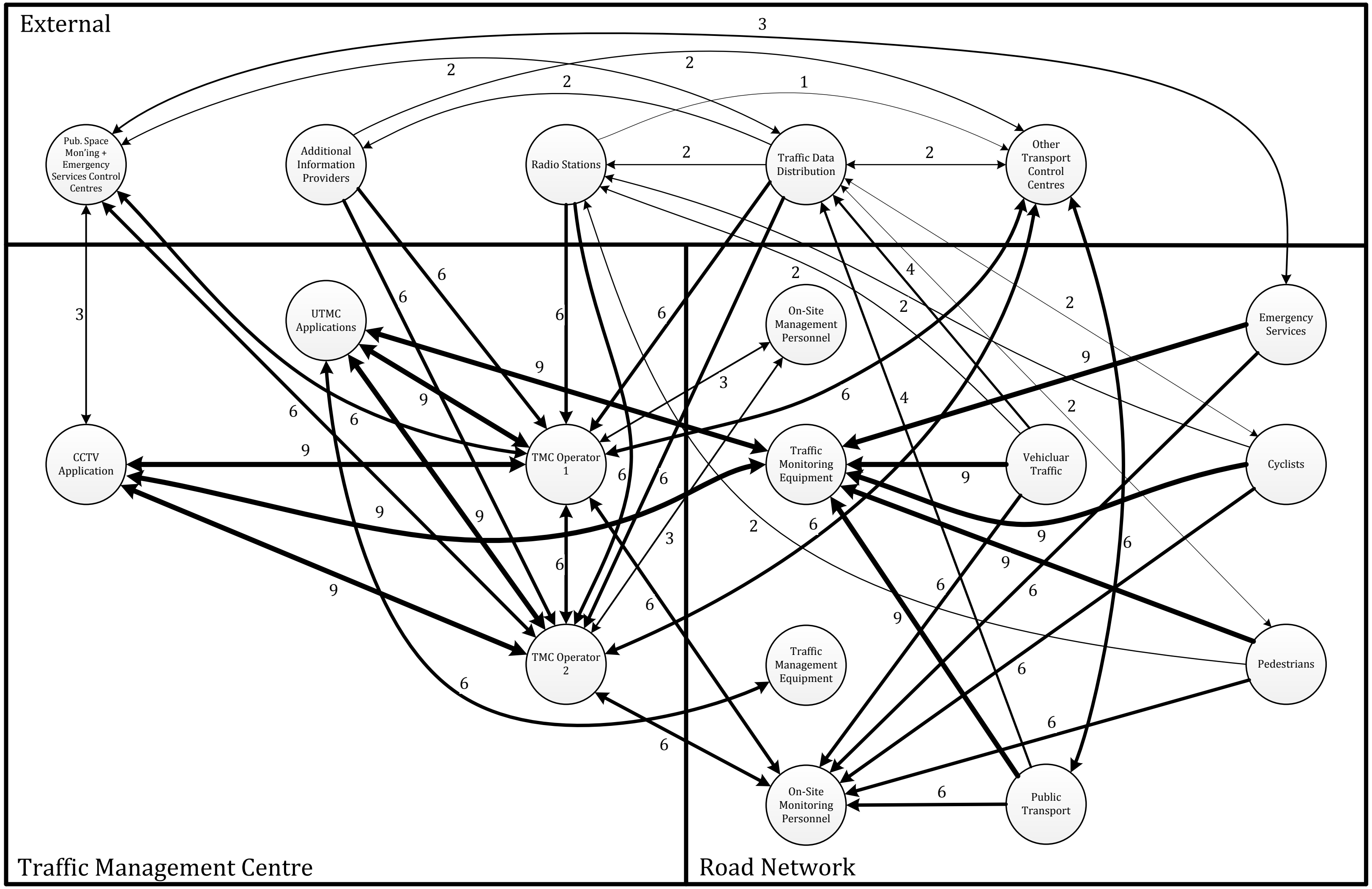


Figure 3-6: Social Network Diagram for information phases at Dorset

Table 3-5: Association Matrix for information phases at Nottingham

		Frequency / Relevance (Importance)																			
ID	Agent	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	TMC Operator 1		2/3 (6)	1/2 (2)	3/3 (9)	3/3 (9)			2/3 (6)	1/3 (3)							2/3 (6)			2/3 (6)	Traffic Management Centre
2	TMC Operator 2	2/3 (6)		1/2 (2)	3/3 (9)	3/3 (9)			2/3 (6)	1/3 (3)							2/3 (6)			2/3 (6)	Traffic Management Centre
3	Bus Lane Enforcement Personnel	1/2 (2)	1/2 (2)			3/1 (3)															Traffic Management Centre
4	UTMC Applications	3/3 (9)	3/3 (9)				3/3 (9)	3/2 (6)													Traffic Management Centre
5	CCTV Application	3/3 (9)	3/3 (9)	3/1 (3)			3/3 (9)													3/1 (3)	Traffic Management Centre
6	Traffic Monitoring Equipment				3/3 (9)	3/3 (9)															Road Network
7	Traffic Management Equipment				3/2 (6)																Road Network
8	On-site Monitoring Personnel	2/3 (6)	2/3 (6)																		Road Network
9	On-site Management Personnel	1/3 (3)	1/3 (3)																		Road Network
10	Vehicular Traffic						3/3 (9)		2/3 (6)							2/2 (4)			1/2 (2)		Road Network
11	Cyclists						3/3 (9)		2/3 (6)							1/2 (2)			1/2 (2)		Road Network
12	Pedestrians						3/3 (9)		2/3 (6)							1/2 (2)			1/2 (2)		Road Network
13	Public Transport						3/3 (9)		2/3 (6)							2/2 (4)	3/2 (6)				Road Network
14	Emergency Services						3/3 (9)		2/3 (6)											3/1 (3)	Road Network
15	Traffic Data Distribution	2/2 (4)	2/2 (4)														2/1 (2)	2/1 (2)	2/1 (2)	2/1 (2)	External
16	Other Control Centres	2/3 (6)	2/3 (6)											3/2 (6)		2/1 (2)					External
17	Additional Information Providers	2/2 (4)	2/2 (4)	2/2 (4)													2/1 (2)				External
18	Radio Stations	1/2 (2)	1/2 (2)	1/2 (2)													1/1 (1)				External
19	Public Space Monitoring + Emergency Services Control Centres	2/3 (6)	2/3 (6)			3/1 (3)									3/1 (3)	2/1 (2)					External
		Traffic Management Centre					Road Network									External					

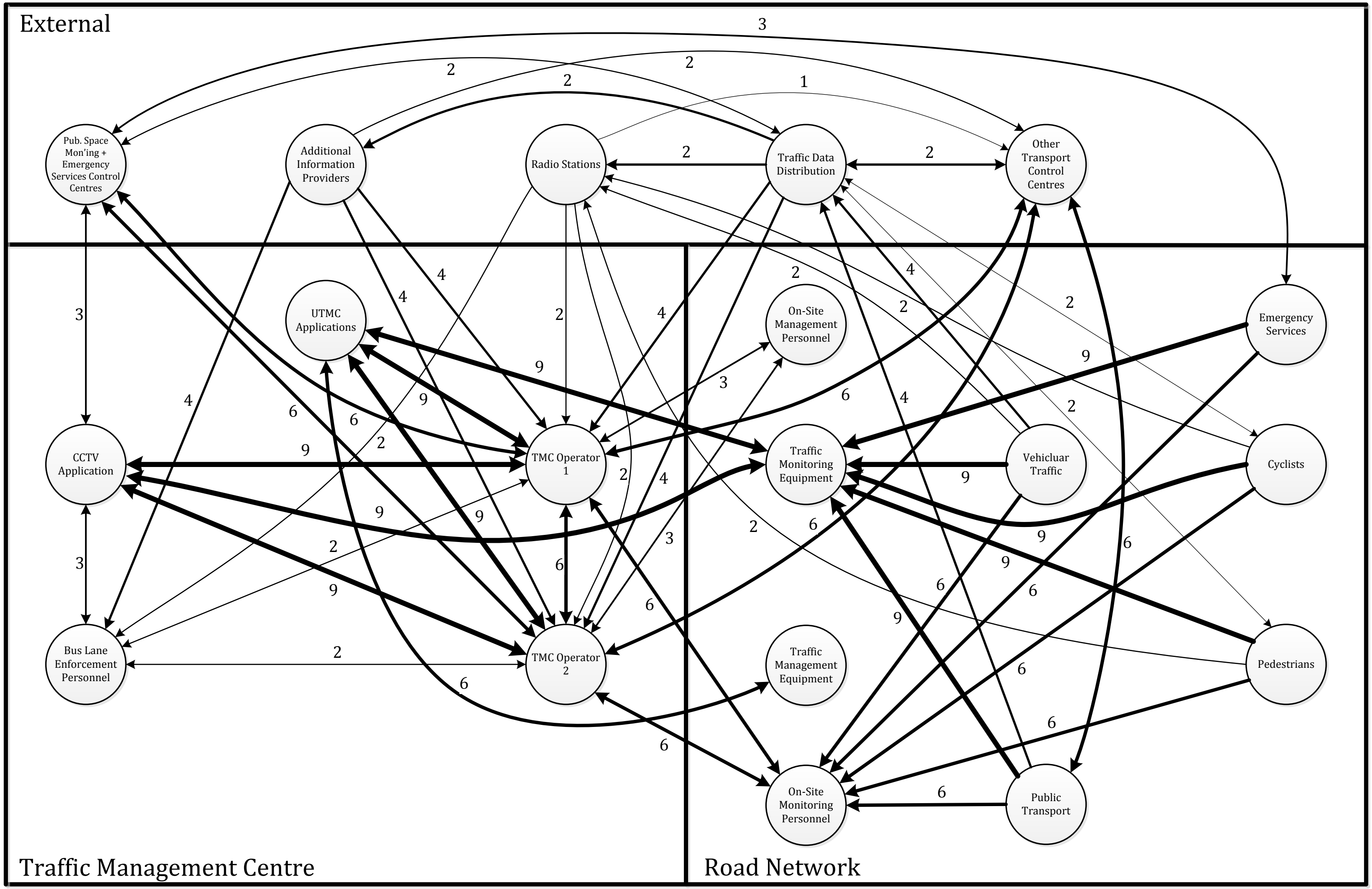


Figure 3-7: Social Network Diagram for information phases at Nottingham

Table 3-6: Comparison of social network metrics for information phases

	Emission				**Reception**				**Eccentricity**				**Sociometric Status**				**PageRank (x10²)**			
	Bristol	**Cardiff**	**Dorset**	**Notts.**	**Bristol**	**Cardiff**	**Dorset**	**Notts.**	**Bristol**	**Cardiff**	**Dorset**	**Notts.**	**Bristol**	**Cardiff**	**Dorset**	**Notts.**	**Bristol**	**Cardiff**	**Dorset**	**Notts.**
TMC Operator 1 (Traffic*)	47	43	45	47	57	62	63	54	3	3	3	3	5.47	5.00	6.35	5.61	9.9	12.7	11.4	10.5
TMC Operator 2 (Tunnel*)	47	46	45	47	57	65	63	54	3	3	3	3	5.47	5.29	6.35	5.61	9.9	13.0	11.4	10.5
Bus Lane Enforcement	12	N/A	N/A	7	18	N/A	N/A	13	4	N/A	N/A	4	1.58	N/A	N/A	1.11	3.5	N/A	N/A	3.0
Parking Enforcement / Bollard Control Personnel	N/A	22	N/A	N/A	N/A	26	N/A	N/A	N/A	4	N/A	N/A	N/A	2.29	N/A	N/A	N/A	5.6	N/A	N/A
Public Space Monitoring Personnel	N/A	18	N/A	N/A	N/A	22	N/A	N/A	N/A	3	N/A	N/A	N/A	1.90	N/A	N/A	N/A	5.1	N/A	N/A
Police CCTV Personnel	N/A	21	N/A	N/A	N/A	25	N/A	N/A	N/A	3	N/A	N/A	N/A	2.19	N/A	N/A	N/A	5.4	N/A	N/A
Third Party Representative	17	N/A	N/A	N/A	23	N/A	N/A	N/A	3	N/A	N/A	N/A	2.11	N/A	N/A	N/A	4.4	N/A	N/A	N/A
SCOOT Engineer	N/A	22	N/A	N/A	N/A	26	N/A	N/A	N/A	4	N/A	N/A	N/A	2.29	N/A	N/A	N/A	6.3	N/A	N/A
UTMC Applications	33	31	33	33	33	31	33	33	4	4	4	4	3.47	2.95	3.88	3.67	6.2	9.7	6.6	6.5
CCTV Application	35	40	30	33	35	40	30	33	3	4	3	4	3.68	3.81	3.53	3.67	6.1	11.3	5.5	6.1
Traffic Monitoring Equipment	18	18	18	18	63	63	63	63	4	5	4	4	4.26	3.86	4.76	4.50	10.7	7.5	11.4	11.3
Traffic Management Equipment	6	6	6	6	6	6	6	6	5	5	5	5	0.63	0.57	0.71	0.67	1.7	2.3	1.8	1.8
On-site Monitoring Personnel	12	15	12	12	42	33	42	42	4	4	4	4	2.84	2.29	3.18	3.00	7.3	2.8	7.8	7.7
On-site Management Personnel	6	9	6	6	6	3	6	6	4	4	4	4	0.63	0.57	0.71	0.67	1.6	1.3	1.8	1.7
Vehicular Traffic	21	24	21	21	0	3	0	0	4	3	3	4	1.11	1.29	1.24	1.17	3.9	1.4	4.1	4.1
Cyclists	19	19	19	19	0	0	0	0	4	3	3	4	1.00	0.90	1.12	1.06	3.6	0.7	3.8	3.8
Pedestrians	19	19	19	19	0	0	0	0	4	3	3	4	1.00	0.90	1.12	1.06	3.6	0.7	3.8	3.8
Public Transport	25	25	25	25	6	6	6	6	4	3	3	4	1.63	1.48	1.82	1.72	4.5	1.7	4.8	4.8
Emergency Services	18	21	18	18	3	6	3	3	4	4	4	4	1.11	1.29	1.24	1.17	3.5	1.9	3.7	3.6
Traffic Data Distribution	16	16	20	16	16	16	16	16	3	3	3	3	1.68	1.52	2.12	1.78	5.2	2.0	6.1	5.5
Other Transport Control Centres	20	14	20	20	23	17	23	23	3	3	3	3	2.26	1.48	2.53	2.39	4.3	2.9	4.5	4.5
Additional Information Providers	18	18	14	14	2	2	2	2	3	3	3	3	1.05	0.95	0.94	0.89	3.9	0.9	3.3	3.5
Radio Stations	9	13	13	7	8	8	8	8	3	3	3	3	0.89	1.00	1.24	0.83	3.4	1.1	4.2	3.3
Emergency Services Control Centres	14	16	20	14	14	16	20	20	3	3	3	3	1.47	1.52	2.35	1.89	2.9	3.7	4.0	4.0
Test Statistic	32	32	32	32	41	42	44	41	4	5	4	4	3.70	3.41	4.33	3.87	7.6	8.5	8.6	8.1

*Cardiff Only

	Centrality (B-L)				Centrality (EV x10)				Closeness (x10³)				Farness				Betweeness			
	Bristol	**Cardiff**	**Dorset**	**Notts.**	**Bristol**	**Cardiff**	**Dorset**	**Notts.**	**Bristol**	**Cardiff**	**Dorset**	**Notts.**	**Bristol**	**Cardiff**	**Dorset**	**Notts.**	**Bristol**	**Cardiff**	**Dorset**	**Notts.**
TMC Operator 1 (Traffic*)	13.2	14.5	11.4	12.4	10	9.8	10.0	10	4.0	3.2	4.3	4.2	25	31	23	24	58	46	46	54
TMC Operator 2 (Tunnel*)	13.2	15.2	11.4	12.4	10	10.0	10.0	10	4.0	3.4	4.3	4.2	25	29	23	24	58	86	46	54
Bus Lane Enforcement	9.5	N/A	N/A	8.8	6.3	N/A	N/A	5.7	2.8	N/A	N/A	2.9	36	N/A	N/A	35	1	N/A	N/A	1
Parking Enforcement / Bollard Control Personnel	N/A	12.4	N/A	N/A	N/A	7.9	N/A	N/A	N/A	2.8	N/A	N/A	N/A	36	N/A	N/A	N/A	35	N/A	N/A
Public Space Monitoring Personnel	N/A	12.2	N/A	N/A	N/A	8.2	N/A	N/A	N/A	2.9	N/A	N/A	N/A	35	N/A	N/A	N/A	4	N/A	N/A
Police CCTV Personnel	N/A	12.5	N/A	N/A	N/A	8.5	N/A	N/A	N/A	2.9	N/A	N/A	N/A	34	N/A	N/A	N/A	21	N/A	N/A
Third Party Representative	10.5	N/A	N/A	N/A	7.2	N/A	N/A	N/A	3.2	N/A	N/A	N/A	31	N/A	N/A	N/A	4	N/A	N/A	N/A
SCOOT Engineer	N/A	12.2	N/A	N/A	N/A	8.1	N/A	N/A	N/A	2.8	N/A	N/A	N/A	36	N/A	N/A	N/A	9	N/A	N/A
UTMC Applications	9.7	10.9	8.8	9.3	3.2	4.4	3.9	3.6	2.9	2.4	3.2	3.0	35	41	31	33	39	46	35	37
CCTV Application	10.7	11.7	9.1	10.0	5.6	7.7	4.7	5.2	3.3	2.7	3.6	3.4	33	37	28	29	20	18	12	16
Traffic Monitoring Equipment	8.7	9.4	7.8	8.3	3.3	2.3	4.6	4.0	2.4	2.0	2.7	2.6	41	51	37	39	16	14	16	16
Traffic Management Equipment	6.6	7.4	6.0	6.3	0.5	0.6	0.6	0.5	2.0	1.7	2.3	2.1	50	59	44	47	0	0	0	0
On-site Monitoring Personnel	9.3	10.2	8.4	8.9	4.8	1.7	6.3	5.6	2.6	2.3	2.9	2.7	39	43	35	37	7	11	6	7
On-site Management Personnel	8.2	8.9	7.3	7.8	2.7	1.1	3.1	2.9	2.6	2.3	2.9	2.7	39	43	35	37	0	0	0	0
Vehicular Traffic	N/A	10.2	N/A	N/A	3.3	1.4	4.5	3.9	2.9	2.7	3.3	3.1	34	37	30	32	0	16	0	0
Cyclists	N/A	N/A	N/A	N/A	3.3	0	4.5	3.9	2.9	2.4	3.3	3.1	34	41	30	32	0	0	0	0
Pedestrians	N/A	N/A	N/A	N/A	3.3	0	4.5	3.9	2.9	2.4	3.3	3.1	34	41	30	32	0	0	0	0
Public Transport	8.0	8.5	7.3	7.6	3.2	0.5	4.4	3.8	3.1	2.4	3.7	3.3	32	41	27	30	2	2	2	2
Emergency Services	7.5	9.2	6.9	7.2	1.8	2.0	2.6	2.3	2.6	2.4	3.1	2.9	38	42	32	35	1	3	1	1
Traffic Data Distribution	10.0	10.4	9.3	9.6	8.1	1.6	10.0	9.1	3.6	2.8	4.2	3.8	28	36	24	26	50	41	46	48
Other Transport Control Centres	10.7	11.2	9.4	10.0	7.1	3.3	7.4	6.8	3.4	2.7	3.8	3.6	29	37	26	28	38	33	31	33
Additional Information Providers	7.7	8.6	6.9	7.3	6.5	0.3	5.7	6.1	3.2	2.9	3.4	3.3	31	34	29	30	1	2	0	1
Radio Stations	8.0	9.8	7.2	7.6	7.9	0.5	7.8	7.8	3.2	2.9	3.4	3.3	31	34	29	30	13	18	6	9
Emergency Services Control Centres	10.7	11.7	9.8	10.3	4.8	5.7	5.8	5.4	3.4	2.9	4.0	3.7	29	35	25	27	42	28	38	41
Test Statistic	11.4	12.9	10.1	10.8	7.8	7.5	8.2	7.51	3.4	3.0	4.0	3.7	39	45	35	38	39	41	35	37

*Cardiff Only

3.5.2 Personnel Allocation

This phase is conducted by operators talking to each other and is therefore trivial from a social network perspective. Communications are highly relevant but only moderately frequent, potentially not occurring at all. This network's simplicity does not warrant the SND, association matrix or metrics to be shown.

3.5.3 Strategy Development, Selection and Implementation

Within these phases decisions made within the TMC are transferred back to the road network and external environment. This can be seen in all association matrixes (Table 3-7 to Table 3-10) with 72% of links received in these locations at Bristol, Dorset and Nottingham and 59% at Cardiff.

Greater similarity was observed between the TMCs for strategy phases than for information phases. The reduced number of TMC agents involved in strategies meant that local differences were not as prevalent in the TMCs' social structures, Cardiff having the only significant differences owing to it having police, public space monitoring and parking enforcement personnel within the TMC and thus increasing its capability to physically intervene with the road environment.

All social networks are weighted (non-uniform), directed (non-symmetric) and have diameters of 5 (moderate interaction). The network densities are 0.2 (Bristol), 0.212 (Cardiff), 0.248 (Dorset) and 0.205 (Nottingham) corresponding to moderate-low information distribution. Approximately 70% of communications are reciprocal as shown by cohesion values of 0.142 (Bristol), 0.16 (Cardiff), 0.176 (Dorset) and 0.123 (Nottingham), as with the information phases most communications represent a dialogue between agents.

From the individual metrics (Table 3-7) it can be seen that approximately half of the agents exceed the mean B-L centrality values (8.8 for Bristol, Dorset and Nottingham, 10.3 for Cardiff) corresponding to moderate allocation of decision rights. Quantitatively these networks appear to be best described as star archetypes, however qualitatively chain network structures (see Leavitt, 1951) can be observed, decisions emanating from TMC operators and being implemented through intermediary agents to affect traffic. This suggests that a hybrid star-chain network is a more accurate description. Circular feedback loops can also be observed, notably between management and monitoring equipment, which facilitated by UTMC applications, enables the creation of complex strategies able to adapt to traffic conditions without further intervention by operators.

The highest importance, centrality and betweeness metrics occur within intermediary agents, such as monitoring and management equipment, UTMC applications and traffic data distribution, and TMC operators, who occupy a critical position as strategy developers. Unexpectedly, on-site management personnel are the most central agents because of their links to traffic, management personnel having reciprocal links while other intermediary's links are one-way. The relative infrequent use of this agent at Bristol is reflected in the differences between sociometric status and PageRank metrics for each TMC.

Traffic agents have a moderate reception degree, indicative that they are strategies end users; however all other metric scores are low as found within information phases. While not significant, the capability to use emergency services within strategies raises their importance, centrality and betweeness above other traffic types.

Information dissemination, both directly and through third parties, is a key tool for traffic management (Murray & Liu, 1997). Traffic data distribution, which facilitates information dissemination, has high EV centrality, closeness, betweeness and moderate sociometric status, arising from its connectivity to other third parties, traffic and the TMC. All other external agents have low metric scores, presumably because their distance from the TMC's area of control reduces the relevance of any communications, which are aimed at wider audiences. This does not however mean information dissemination is not useful, as it enables TMCs to interact with a far greater range of people than would otherwise be possible.

Table 3-7: Association Matrix for strategy phases at Bristol

		Frequency / Relevance (Importance)																				
ID	**Agent**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	
1	TMC Operator 1		2/3 (6)			3/3 (9)	3/3 (9)				1/3 (3)						2/3 (6)	1/3 (3)			1/3 (3)	**Traffic Management Centre**
2	TMC Operator 2	2/3 (6)				3/3 (9)	3/3 (9)				1/3 (3)						2/3 (6)	1/3 (3)			1/3 (3)	
3	Bus Lane Enforcement Personnel																					
4	Third Party Representatives																					
5	UTMC Applications	3/3 (9)	3/3 (9)					3/3 (9)	3/3 (9)													
6	CCTV Application	3/3 (9)	3/3 (9)					3/3 (9)														
7	Traffic Monitoring Equipment					3/3 (9)	3/3 (9)															**Road Network**
8	Traffic Management Equipment					3/3 (9)						3/3 (9)	3/3 (9)	3/3 (9)	3/3 (9)	3/3 (9)						
9	On-site Monitoring Personnel																					
10	On-site Management Personnel	1/3 (3)	1/3 (3)									1/3 (3)	1/3 (3)	1/3 (3)	1/3 (3)	1/3 (3)						
11	Vehicular Traffic							3/3 (9)			1/3 (3)					2/2 (4)						
12	Cyclists							3/3 (9)			1/3 (3)					2/2 (4)						
13	Pedestrians							3/3 (9)			1/3 (3)					2/2 (4)						
14	Public Transport							3/3 (9)			1/3 (3)					2/2 (4)		3/1 (3)				
15	Emergency Services							3/3 (9)			1/3 (3)	2/2 (4)	2/2 (4)	2/2 (4)	2/2 (4)						3/1 (3)	
16	Traffic Data Distribution	2/3 (6)	2/3 (6)									2/2 (4)	2/2 (4)	2/2 (4)				2/2 (4)	2/2 (4)	2/2 (4)		**External**
17	Other Transport Control Centres	1/3 (3)	1/3 (3)												3/1 (3)							
18	Additional Information Providers											2/2 (4)	2/2 (4)	2/2 (4)								
19	Radio Stations											2/2 (4)	2/2 (4)	2/2 (4)								
20	Public Space Monitoring + Emergency Services Control Centres	1/3 (3)	1/3 (3)													3/1 (3)						
		Traffic Management Centre						**Road Network**									**External**					

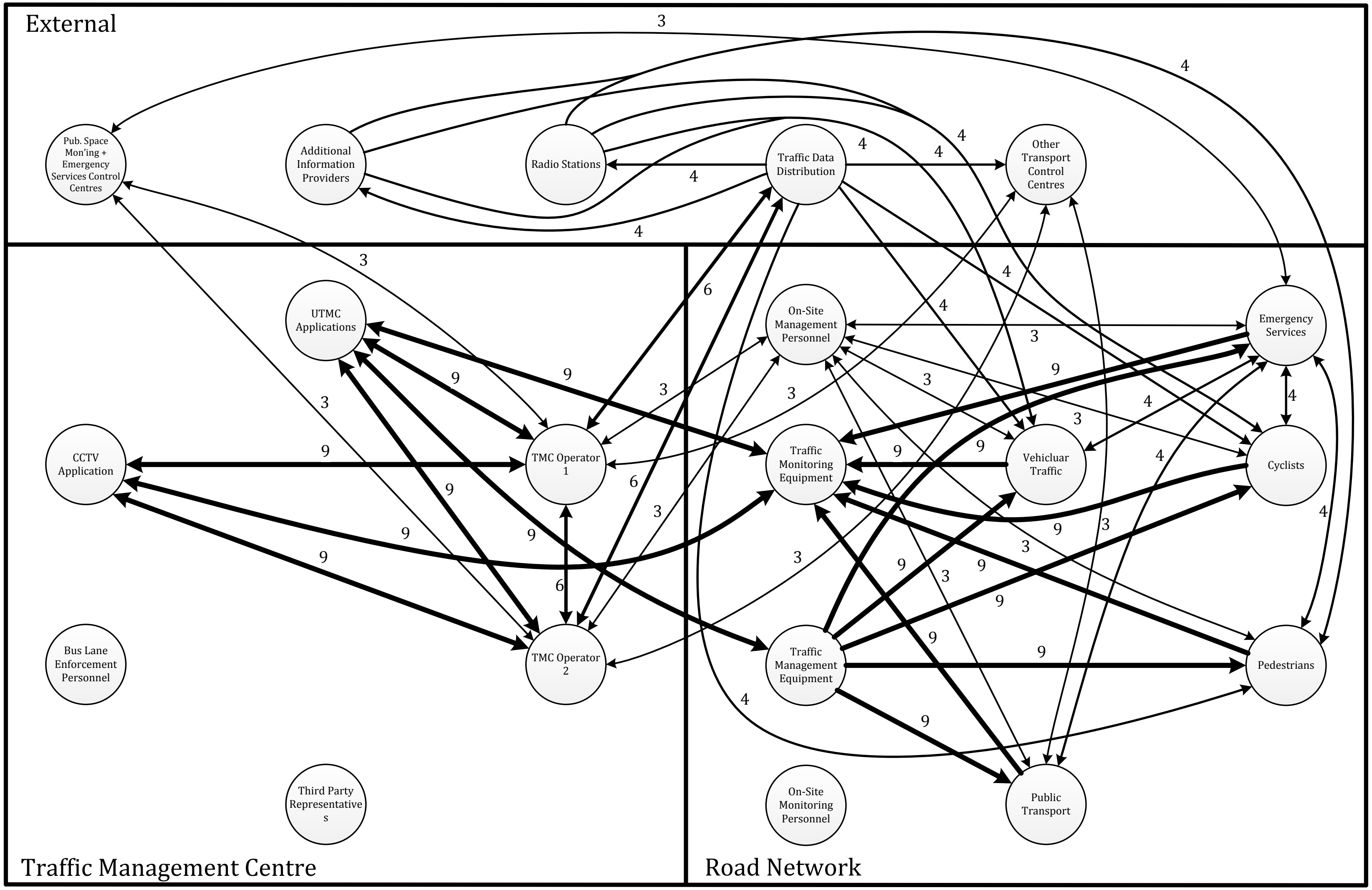


Figure 3-8: Social Network Diagram for strategy phases at Bristol

Table 3-8: Association Matrix for strategy phases at Cardiff

		Frequency / Relevance (Importance)																						
		Traffic Management Centre								Road Network									External					
ID	**Agent**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	
1	TMC Operator 1 (Traffic)		2/3 (6)	2/3 (6)		1/3 (3)	1/3 (3)	3/3 (9)	3/3 (9)				1/3 (3)						2/3 (6)	1/3 (3)			1/3 (3)	**Traffic Managment Centre**
2	TMC Operator 2 (Tunnel)	2/3 (6)		2/3 (6)		1/3 (3)	1/3 (3)	3/3 (9)	3/3 (9)				1/3 (3)						2/3 (6)	1/3 (3)			1/3 (3)	
3	Parking Enforcement / Bollard Ctrl.	2/3 (6)	2/3 (6)						3/1 (3)				1/3 (3)											
4	Public Space Monitoring Personnel																							
5	Police CCTV Personnel	1/3 (3)	1/3 (3)															1/3 (3)					3/1 (3)	
6	SCOOT Engineer	1/3 (3)	1/3 (3)					1/3 (3)	1/3 (3)															
7	UTMC Applications	3/3 (9)	3/3 (9)				1/3 (3)			3/3 (9)	3/3 (9)													
8	CCTV Application	3/3 (9)	3/3 (9)	3/1 (3)			1/3 (3)			3/3 (9)														
9	Traffic Monitoring Equipment							3/3 (9)	3/3 (9)															**Road Network**
10	Traffic Management Equipment							3/3 (9)						3/3 (9)	3/3 (9)	3/3 (9)	3/3 (9)	3/3 (9)						
11	On-site Monitoring Personnel																							
12	On-site Management Personnel	1/3 (3)	1/3 (3)	3/1 (3)										1/3 (3)	1/3 (3)	1/3 (3)	1/3 (3)	1/3 (3)						
13	Vehicular Traffic									3/3 (9)			1/3 (3)					2/2 (4)						
14	Cyclists									3/3 (9)			1/3 (3)					2/2 (4)						
15	Pedestrians									3/3 (9)			1/3 (3)					2/2 (4)						
16	Public Transport									3/3 (9)			1/3 (3)					2/2 (4)		3/1 (3)				
17	Emergency Services					3/1 (3)				3/3 (9)			1/3 (3)	2/2 (4)	2/2 (4)	2/2 (4)	2/2 (4)						3/1 (3)	
18	Traffic Data Distribution	2/3 (6)	2/3 (6)											2/2 (4)	2/2 (4)	2/2 (4)				2/2 (4)	2/2 (4)	2/2 (4)		**External**
19	Other Control Centres	1/3 (3)	1/3 (3)														3/1 (3)							
20	Additional Information Providers													2/2 (4)	2/2 (4)	2/2 (4)								
21	Radio Stations													2/2 (4)	2/2 (4)	2/2 (4)								
22	Emergency Services Control Centres	1/3 (3)	1/3 (3)			3/1 (3)												3/1 (3)						
		Traffic Management Centre								**Road Network**									**External**					

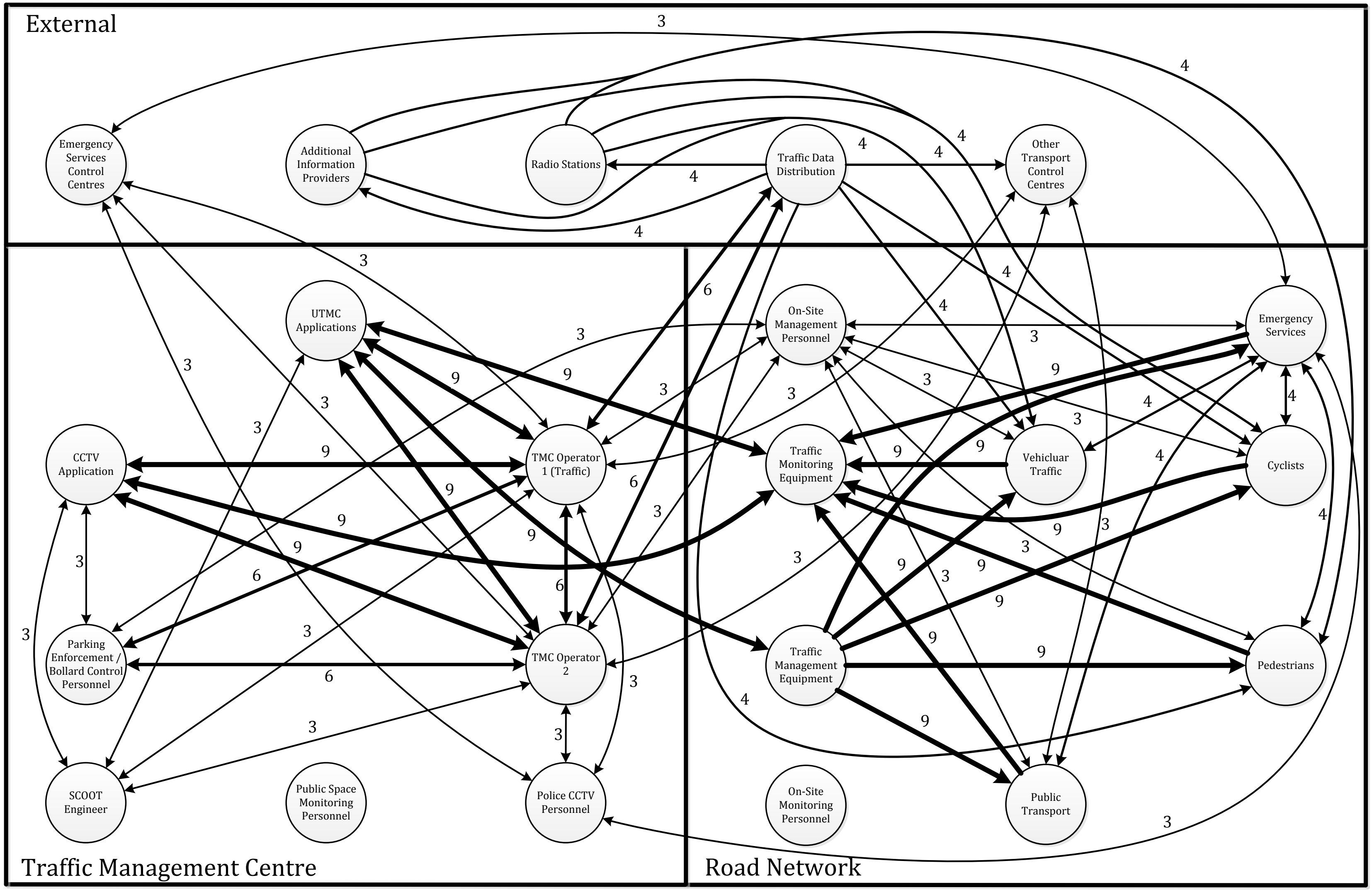


Figure 3-9: Social Network Diagram for strategy phases at Cardiff

Table 3-9: Association Matrix for strategy phases at Dorset

		Frequency / Relevance (Importance)																		
ID	**Agent**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	
1	TMC Operator 1		2/3 (6)	2/3 (6)	2/3 (6)				1/3 (3)						2/3 (6)	1/3 (3)			1/3 (3)	**Traffic Management Centre**
2	TMC Operator 2	2/3 (6)		2/3 (6)	2/3 (6)				1/3 (3)						2/3 (6)	1/3 (3)			1/3 (3)	
3	UTMC Applications	2/3 (6)	2/3 (6)			3/3 (9)	3/3 (9)													
4	CCTV Application	2/3 (6)	2/3 (6)			3/3 (9)														
5	Traffic Monitoring Equipment			3/3 (9)	3/3 (9)															**Road Network**
6	Traffic Management Equipment			3/3 (9)						3/3 (9)	3/3 (9)	3/3 (9)	3/3 (9)	3/3 (9)						
7	On-site Monitoring Personnel																			
8	On-site Management Personnel	1/3 (3)	1/3 (3)							1/3 (3)	1/3 (3)	1/3 (3)	1/3 (3)	1/3 (3)						
9	Vehicular Traffic					3/3 (9)			1/3 (3)					2/2 (4)						
10	Cyclists					3/3 (9)			1/3 (3)					2/2 (4)						
11	Pedestrians					3/3 (9)			1/3 (3)					2/2 (4)						
12	Public Transport					3/3 (9)			1/3 (3)					2/2 (4)		3/1 (3)				
13	Emergency Services					3/3 (9)			1/3 (3)	2/2 (4)	2/2 (4)	2/2 (4)	2/2 (4)						3/1 (3)	
14	Traffic Data Distribution	2/3 (6)	2/3 (6)							2/2 (4)	2/2 (4)	2/2 (4)				2/2 (4)	2/2 (4)	2/2 (4)		**External**
15	Other Transport Control Centres	1/3 (3)	1/3 (3)										3/1 (3)							
16	Additional Information Providers									2/2 (4)	2/2 (4)	2/2 (4)								
17	Radio Stations									2/2 (4)	2/2 (4)	2/2 (4)								
18	Public Space Monitoring + Emergency Services Control Centres	1/3 (3)	1/3 (3)											3/1 (3)						
		Traffic Management Centre				**Road Network**									**External**					

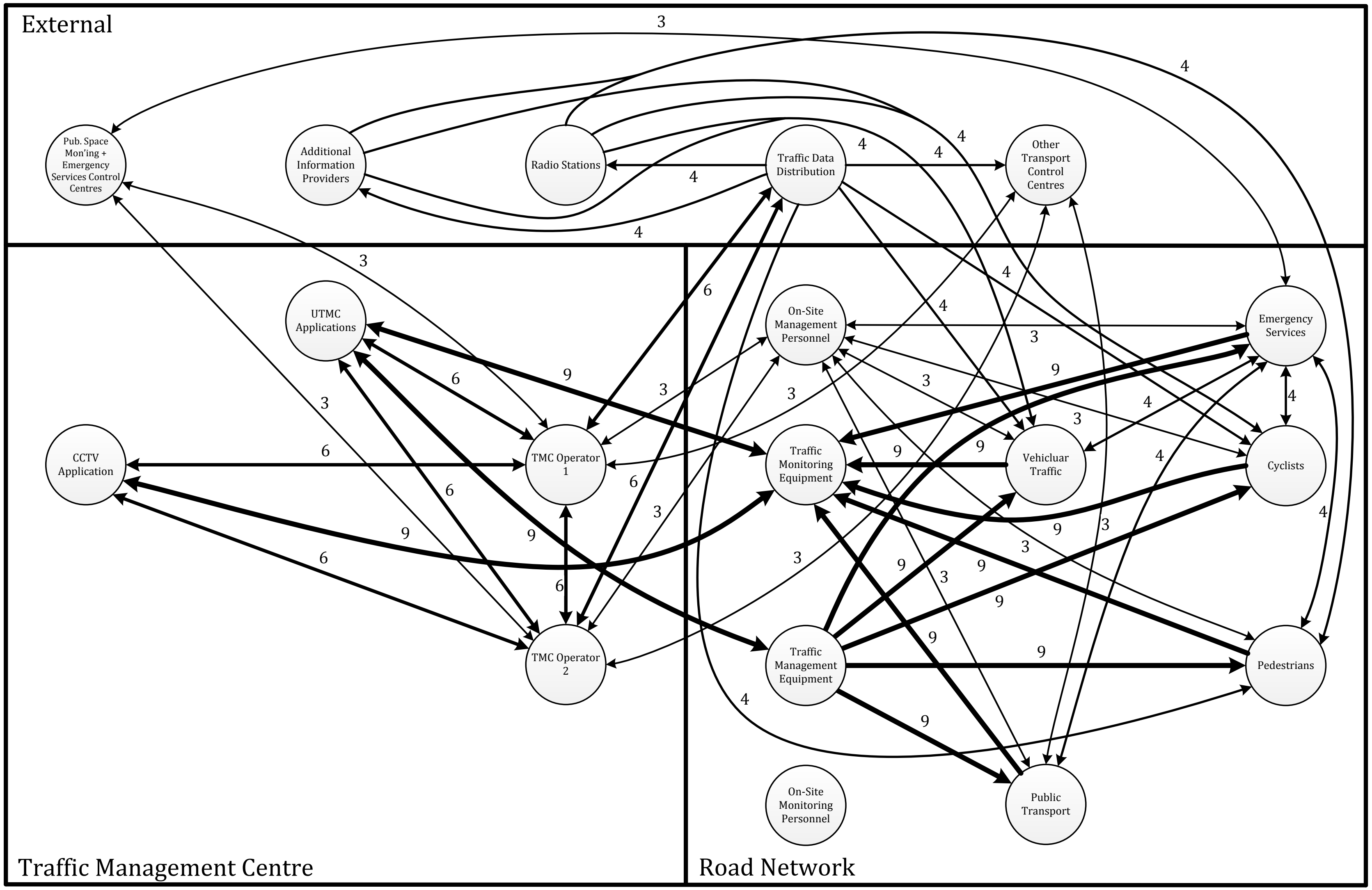


Figure 3-10: Social Network Diagram for strategy phases at Dorset

Table 3-10: Association Matrix for strategy phases at Nottingham

		Frequency / Relevance (Importance)																			
ID	**Agent**	**1**	**2**	**3**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	
1	TMC Operator 1		2/3 (6)		3/3 (9)	3/3 (9)				2/3 (6)						2/3 (6)	1/3 (3)			1/3 (3)	**Traffic Management Centre**
2	TMC Operator 2	2/3 (6)			3/3 (9)	3/3 (9)				2/3 (6)						2/3 (6)	1/3 (3)			1/3 (3)	
3	Bus Lane Enforcement Personnel																				
4	UTMC Applications	3/3 (9)	3/3 (9)				3/3 (9)	3/3 (9)													
5	CCTV Application	3/3 (9)	3/3 (9)				3/3 (9)														
6	Traffic Monitoring Equipment				3/3 (9)	3/3 (9)															**Road Network**
7	Traffic Management Equipment				3/3 (9)						3/3 (9)	3/3 (9)	3/3 (9)	3/3 (9)	3/3 (9)						
8	On-site Monitoring Personnel																				
9	On-site Management Personnel	2/3 (3)	2/3 (3)								2/3 (6)	2/3 (6)	2/3 (6)	2/3 (6)	2/3 (6)						
10	Vehicular Traffic						3/3 (9)			2/3 (6)					2/2 (4)						
11	Cyclists						3/3 (9)			2/3 (6)					2/2 (4)						
12	Pedestrians						3/3 (9)			2/3 (6)					2/2 (4)						
13	Public Transport						3/3 (9)			2/3 (6)					2/2 (4)		3/1 (3)				
14	Emergency Services						3/3 (9)			2/3 (6)	2/2 (4)	2/2 (4)	2/2 (4)	2/2 (4)						3/1 (3)	
15	Traffic Data Distribution	2/3 (6)	2/3 (6)								2/2 (4)	2/2 (4)	2/2 (4)				2/2 (4)	2/2 (4)	2/2 (4)		**External**
16	Other Transport Control Centres	1/3 (3)	1/3 (3)											3/1 (3)							
17	Additional Information Providers										2/2 (4)	2/2 (4)	2/2 (4)								
18	Radio Stations										2/2 (4)	2/2 (4)	2/2 (4)								
19	Public Space Monitoring + Emergency Services Control Centres	1/3 (3)	1/3 (3)												3/1 (3)						
		Traffic Management Centre					**Road Network**									**External**					

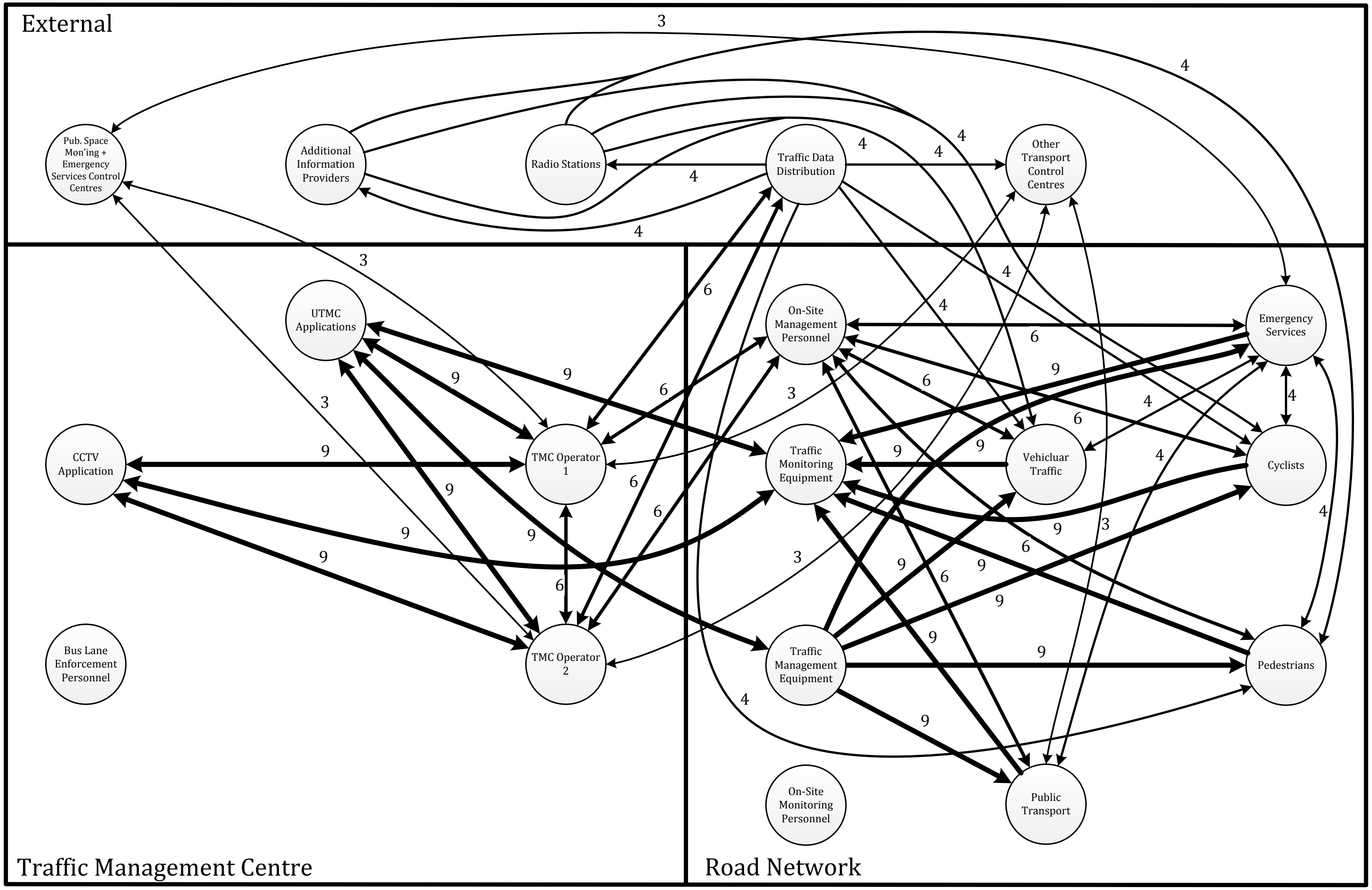


Figure 3-11: Social Network Diagram for strategy phases at Nottingham

Table 3-11: Comparison of TMC's social network metrics for strategy phases

	Emission				Reception				Eccentricity				Sociometric Status				PageRank ($x10^2$)			
	Bristol	**Cardiff**	**Dorset**	**Notts.**	**Bristol**	**Cardiff**	**Dorset**	**Notts.**	**Bristol**	**Cardiff**	**Dorset**	**Notts.**	**Bristol**	**Cardiff**	**Dorset**	**Notts.**	**Bristol**	**Cardiff**	**Dorset**	**Notts.**
TMC Operator 1 (Traffic*)	39	51	33	42	39	51	33	42	2	2	2	2	4.11	4.86	3.88	4.67	7.3	11.7	6.7	7.3
TMC Operator 2 (Tunnel*)	39	51	33	42	39	51	33	42	2	2	2	2	4.11	4.86	3.88	4.67	7.3	11.7	6.7	7.3
Parking Enforcement / Bollard Control Personnel	N/A	18	N/A	N/A	N/A	18	N/A	N/A	N/A	3	N/A	N/A	N/A	1.71	N/A	N/A	N/A	4.4	N/A	N/A
Police CCTV Personnel	N/A	6	N/A	N/A	N/A	12	N/A	N/A	N/A	3	N/A	N/A	N/A	0.86	N/A	N/A	N/A	2.7	N/A	N/A
SCOOT Engineer	N/A	12	N/A	N/A	N/A	12	N/A	N/A	N/A	3	N/A	N/A	N/A	1.14	N/A	N/A	N/A	3.4	N/A	N/A
UTMC Applications	36	39	30	36	36	39	30	36	3	3	3	3	3.79	3.71	3.53	4.00	6.3	10.3	5.6	5.9
CCTV Application	27	33	21	27	27	33	21	27	3	3	3	3	2.84	3.14	2.47	3.00	5.0	10.5	4.3	4.7
Traffic Monitoring Equipment	18	18	18	18	63	63	63	63	4	4	4	4	4.26	3.86	4.76	4.50	10.5	11.6	10.9	9.8
Traffic Management Equipment	54	54	54	54	9	9	9	9	4	4	4	4	3.32	3.00	3.71	3.50	9.0	2.8	9.3	8.5
On-site Management Personnel	21	24	21	42	21	24	21	42	3	3	3	3	2.21	2.29	2.47	4.67	4.1	4.7	4.3	6.9
Vehicular Traffic	16	16	16	19	28	28	28	31	4	4	4	4	2.32	2.10	2.59	2.78	6.6	3.0	6.8	6.6
Cyclists	16	16	16	19	28	28	28	31	4	4	4	4	2.32	2.10	2.59	2.78	6.6	3.0	6.8	6.6
Pedestrians	16	16	16	19	28	28	28	31	4	4	4	4	2.32	2.10	2.59	2.78	6.6	3.0	6.8	6.6
Public Transport	19	19	19	22	19	19	19	22	4	4	4	4	2.00	1.81	2.24	2.44	5.1	2.8	5.3	5.2
Emergency Services	31	34	31	34	31	31	31	34	4	4	4	4	3.26	3.10	3.65	3.78	7.0	4.5	7.2	7.0
Traffic Data Distribution	36	36	36	36	12	12	12	12	3	3	3	3	2.53	2.29	2.82	2.67	6.8	3.1	7.1	6.4
Other Transport Control Centres	9	9	9	9	13	13	13	13	3	3	3	3	1.16	1.05	1.29	1.22	2.9	2.6	3.1	2.8
Additional Information Providers	12	12	12	12	4	4	4	4	5	5	5	5	0.84	0.76	0.94	0.89	3.3	1.0	3.4	3.2
Radio Stations	12	12	12	12	4	4	4	4	5	5	5	5	0.84	0.76	0.94	0.89	3.3	1.0	3.4	3.2
Emergency Services Control Centres	9	12	9	9	9	9	9	9	3	3	3	3	0.95	1.00	1.06	1.00	2.3	2.3	2.4	2.2
Test Statistic	37	40	34	40	40	40	40	43	5	5	5	5	3.70	3.61	3.81	4.30	8.1	8.8	8.1	8.0

*Cardiff Only

	Centrality (B-L)				Centrality (EV x10)				Closeness (x10³)				Farness				Betweeness			
	Bristol	**Cardiff**	**Dorset**	**Notts.**	**Bristol**	**Cardiff**	**Dorset**	**Notts.**	**Bristol**	**Cardiff**	**Dorset**	**Notts.**	**Bristol**	**Cardiff**	**Dorset**	**Notts.**	**Bristol**	**Cardiff**	**Dorset**	**Notts.**
TMC Operator 1 (Traffic*)	11.0	13.8	11.0	11.0	6.9	10.0	6.9	6.9	4.0	3.6	4.0	4.0	25	28	25	25	39	66	39	39
TMC Operator 2 (Tunnel*)	11.0	13.8	11.0	11.0	6.9	10.0	6.9	6.9	4.0	3.6	4.0	4.0	25	28	25	25	39	66	39	39
Parking Enforcement / Bollard Control Personnel	N/A	10.8	N/A	N/A	N/A	5.9	N/A	N/A	N/A	2.7	N/A	N/A	N/A	37	N/A	N/A	N/A	2	N/A	N/A
Police CCTV Personnel	N/A	9.8	N/A	N/A	N/A	5.0	N/A	N/A	N/A	2.2	N/A	N/A	N/A	45	N/A	N/A	N/A	2	N/A	N/A
SCOOT Engineer	N/A	9.5	N/A	N/A	N/A	5.4	N/A	N/A	N/A	2.4	N/A	N/A	N/A	41	N/A	N/A	N/A	1	N/A	N/A
UTMC Applications	9.6	11.4	9.6	9.6	4.8	5.5	4.8	4.8	3.3	2.9	3.3	3.3	30	35	30	30	31	39	31	31
CCTV Application	8.3	10.4	8.3	8.3	3.6	6.3	3.6	3.6	2.7	2.4	2.7	2.7	37	41	37	37	5	11	5	5
Traffic Monitoring Equipment	8.4	9.8	8.4	8.4	8.3	5.3	8.3	8.3	2.3	2.0	2.3	2.3	43	50	43	43	23	26	23	23
Traffic Management Equipment	7.4	8.7	7.4	7.4	7.7	1.0	7.7	7.7	3.1	2.6	3.1	3.1	32	39	32	32	10	11	10	10
On-site Management Personnel	10.6	12.5	10.6	10.6	9.2	7.7	9.2	9.2	3.6	3.0	3.6	3.6	28	33	28	28	48	68	48	48
Vehicular Traffic	8.8	10.0	8.8	8.8	9	3.2	9.0	9	2.8	2.3	2.8	2.8	36	43	36	36	10	12	10	10
Cyclists	8.8	10.0	8.8	8.8	9	3.2	9.0	9	2.8	2.3	2.8	2.8	36	43	36	36	10	12	10	10
Pedestrians	8.8	10.0	8.8	8.8	9	3.2	9.0	9	2.8	2.3	2.8	2.8	36	43	36	36	10	12	10	10
Public Transport	8.7	9.9	8.7	8.7	6.4	3.2	6.4	6.4	2.9	2.4	2.9	2.9	34	41	34	34	9	9	9	9
Emergency Services	9.9	11.1	9.9	9.9	10	4.7	10.0	10	3.2	2.7	3.2	3.2	31	37	31	31	22	30	22	22
Traffic Data Distribution	8.7	10.3	8.7	8.7	9.2	3.4	9.2	9.2	4.0	3.2	4.0	4.0	25	31	25	25	36	44	36	36
Other Transport Control Centres	8.1	9.7	8.1	8.1	4.8	4.6	4.8	4.8	2.9	2.4	2.9	2.9	35	41	35	35	5	6	5	5
Additional Information Providers	5.9	6.9	5.9	5.9	5.8	0.6	5.8	5.8	2.3	1.9	2.3	2.3	44	54	44	44	0	0	0	0
Radio Stations	5.9	6.9	5.9	5.9	5.8	0.6	5.8	5.8	2.3	1.9	2.3	2.3	44	54	44	44	0	0	0	0
Emergency Services Control Centres	9	10.7	9.0	9	3.9	4.3	3.9	3.9	3.1	2.7	3.1	3.1	32	37	32	32	4	4	4	4
Test Statistic	10.2	12.1	10.2	10.2	9.1	7.3	9.1	9.1	3.6	3.1	3.6	3.6	40	47	40	40	33	45	33	33

*Cardiff Only

3.6 Information Network Analysis

The information network (Figure 3-12) contains 57 nodes and 67 connections (note that the 'exceptional' node has been duplicated to disentangle links). Key concepts were identified as those having at least four connections and are described below.

- *Strategy* is the course of action taken to manage the scenario.
- *Cause* is the reason for entering the exceptional state.
- *Infrastructure* details the physical network components and their capabilities.
- *Management Options* are the potential methods available to deal with scenarios.
- *Exceptional* is the information relating to the event causing exceptional performance.
- *Location* is where traffic and infrastructure is within the domain.
- *Traffic* considers the properties of road users, such as speed and route.
- *Personnel* is information relating to TMC operators, including availability and time demands.
- *Network Conditions* detail how the network is operating.
- *Affected Traffic* is the subset of traffic directly or indirectly involved with the scenario.
- *Traffic Type* includes vehicular, cyclists, pedestrians, public transport and emergency services.

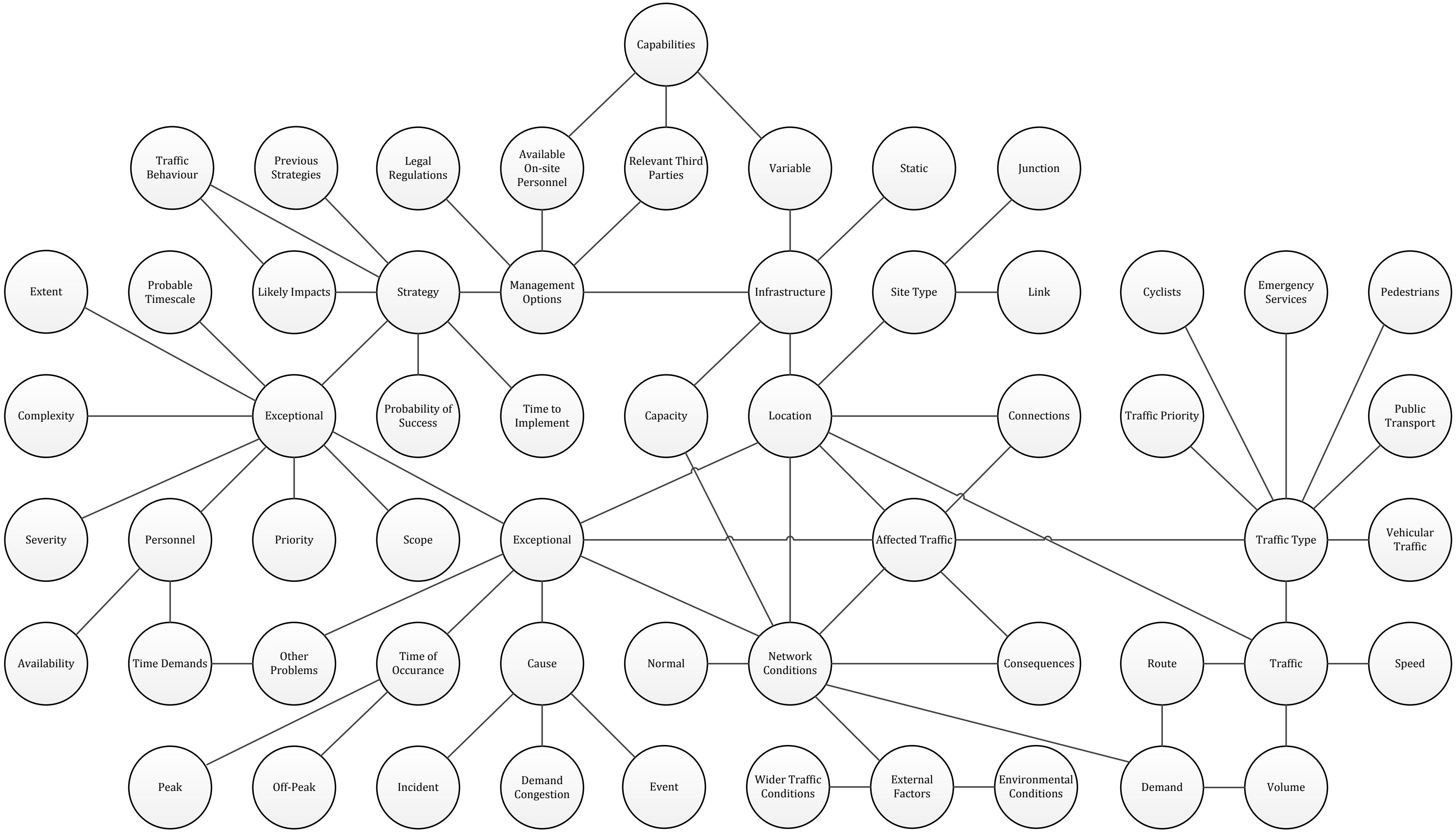


Figure 3-12: Information network for congestion management

Table 3-12: Analysis of information network

Information Network Node	Emission	Reception	Eccentricity	Sociometric Status	PageRank (x10^2)	Centrality (B-L)	Centrality (EV x10)	Closeness (x10^3)	Farness	Betweeness
Traffic Type	8	8	5	2.86	5.87	32.1	2.8	5.7	176	635
Vehicular Traffic	1	1	6	0.36	0.89	24.5	0.7	4.3	231	0
Pedestrians	1	1	6	0.36	0.89	24.5	0.7	4.3	231	0
Cyclists	1	1	6	0.36	0.89	24.5	0.7	4.3	231	0
Public Transport	1	1	6	0.36	0.89	24.5	0.7	4.3	231	0
Emergency Services	1	1	6	0.36	0.89	24.5	0.7	4.3	231	0
Traffic	5	5	4	1.79	3.27	34.9	2.7	6.1	162	354
Route	2	2	5	0.71	1.38	27.2	1.0	4.8	208	9
Volume	2	2	5	0.71	1.38	27.2	1.0	4.8	208	9
Demand	3	3	5	1.07	1.97	30.6	1.6	5.4	185	77
Speed	1	1	5	0.36	0.82	26.1	0.6	4.6	217	0
Location	7	7	3	2.5	4.27	44.2	6.4	7.8	128	974
Network Conditions	7	7	4	2.5	4.43	39.5	5.3	7.0	143	660
Normal	1	1	5	0.36	0.80	28.6	1.1	5.1	198	0
Exceptional	15	15	4	5.36	10.8	48.3	10	8.5	117	1957
External Factors	3	3	5	1.07	2.41	29.1	1.3	5.2	194	218
Wider Traffic Conditions	1	1	6	0.36	0.95	22.7	0.3	4.0	249	0
Environmental Conditions	1	1	6	0.36	0.95	22.7	0.3	4.0	249	0
Capacity	2	2	5	0.71	1.38	31.1	1.7	5.5	182	44
Infrastructure	5	5	4	1.79	3.43	34.9	2.5	6.2	162	497
Physical	1	1	5	0.36	0.85	26.1	0.6	4.6	217	0
Variable	2	2	5	0.71	1.68	26.3	0.6	4.6	215	110
Traffic Priority	1	1	6	0.36	0.89	24.5	0.7	4.3	231	0
Affected Traffic	5	5	4	1.79	3.1	39.8	5.1	7.0	142	582
Consequences	2	2	5	0.71	1.33	31.2	2.2	5.5	181	24
Connections	2	2	4	0.71	1.31	32.5	2.4	5.7	174	0
Site Type	3	3	4	1.07	2.37	31.6	1.6	5.6	179	218
Link	1	1	5	0.36	0.93	24.2	0.4	4.3	234	0
Junction	1	1	5	0.36	0.93	24.2	0.4	4.3	234	0
Cause	4	4	5	1.43	3.29	34.1	2.6	6.0	166	324
Incident	1	1	6	0.36	0.96	25.6	0.6	4.5	221	0
Demand Congestion	1	1	6	0.36	0.96	25.6	0.6	4.5	221	0
Event	1	1	6	0.36	0.96	25.6	0.6	4.5	221	0
Other Problems	2	2	5	0.71	1.49	33.3	2.4	5.9	170	53
Time of Occurrence	3	3	5	1.07	2.48	33.7	2.4	6.0	168	218
Peak	1	1	6	0.36	0.96	25.4	0.5	4.5	223	0
Off-Peak	1	1	6	0.36	0.96	25.4	0.5	4.5	223	0
Severity	1	1	5	0.36	0.84	32.9	2.1	5.8	172	0
Probable Timescale	1	1	5	0.36	0.84	32.9	2.1	5.8	172	0
Extent	1	1	5	0.36	0.84	32.9	2.1	5.8	172	0
Complexity	1	1	5	0.36	0.84	32.9	2.1	5.8	172	0
Test Statistic	4.8	4.8	5.9	1.75	3.47	34.9	3.4	6.2	232	469

Information Network Node	Emission	Reception	Eccentricity	Sociometric Status	PageRank (x10^2)	Centrality (B-L)	Centrality (EV x10)	Closeness (x10^3)	Farness	Betweeness
Priority	1	1	5	0.36	0.84	32.9	2.1	5.8	172	0
Scope	1	1	5	0.36	0.84	32.9	2.1	5.8	172	0
Personnel	3	3	5	1.07	2.26	33.7	2.5	6.0	168	163
Availability	1	1	6	0.36	0.90	25.4	0.5	4.5	223	0
Time Demands	2	2	6	0.71	1.53	25.6	1.1	4.5	221	2
Management Options	5	5	5	1.79	3.71	31.1	1.7	5.5	182	369
Legal Regulations	1	1	6	0.36	0.89	23.9	0.4	4.2	237	0
Available On-site Personnel	1	1	6	0.36	0.89	23.9	0.4	4.2	237	0
Relevant Third Parties	1	1	6	0.36	0.89	23.9	0.4	4.2	237	0
Capabilities	1	1	6	0.36	0.98	20.9	0.2	3.7	270	0
Strategy	6	6	4	2.14	3.44	37.2	3.2	6.6	152	620
Previous Strategies	1	1	5	0.36	0.85	27.3	0.7	4.8	207	0
Traffic Behaviour	2	2	5	0.71	1.48	27.5	1.0	4.8	206	0
Likely Impacts	2	2	5	0.71	1.48	27.5	1.0	4.8	206	0
Time to Implement	1	1	5	0.36	0.84	32.9	2.1	5.8	172	0
Probability of Success	1	1	5	0.36	0.84	27.3	2.1	4.8	207	0
Test Statistic	4.8	4.8	5.9	1.75	3.47	34.9	3.4	6.2	232	469

The information network is uniform and non-directed (symmetric), hence the cohesion metric is not presented. The network has a diameter of 6 and a density of 0.04 corresponding to low interaction and distribution of information respectively. Assessing the individual metrics (Table 3-12) shows that twenty five agents exceed the mean B-L centrality value (29.4) representing moderate allocation of decision rights. Similarly to all other networks these quantitative measures suggest a star archetype.

Consideration of several additional metrics provides further insights. Firstly, the network's average clustering coefficient of 0.14 represents a high level of clustering when compared to the value for a random graph of similar size (0.061). Secondly, the average path length is 3.52 which is shorter than the random graph's (4.1) and significantly shorter than the maximum possible diameter of 56. Finally, the distribution of B-L centrality (Figure 3-13) can approximately be modelled by a power law. Networks with these three characteristics are known as 'small world' networks and have been shown to have advantages in a wide range of settings (Stanton et al., 2012; Watts & Strogatz, 1998).

Individually the key concepts have the highest metric scores with 'exceptional' being most central and having the highest sociometric status, PageRank, closeness and betweeness. This is not surprising given the task being investigated.

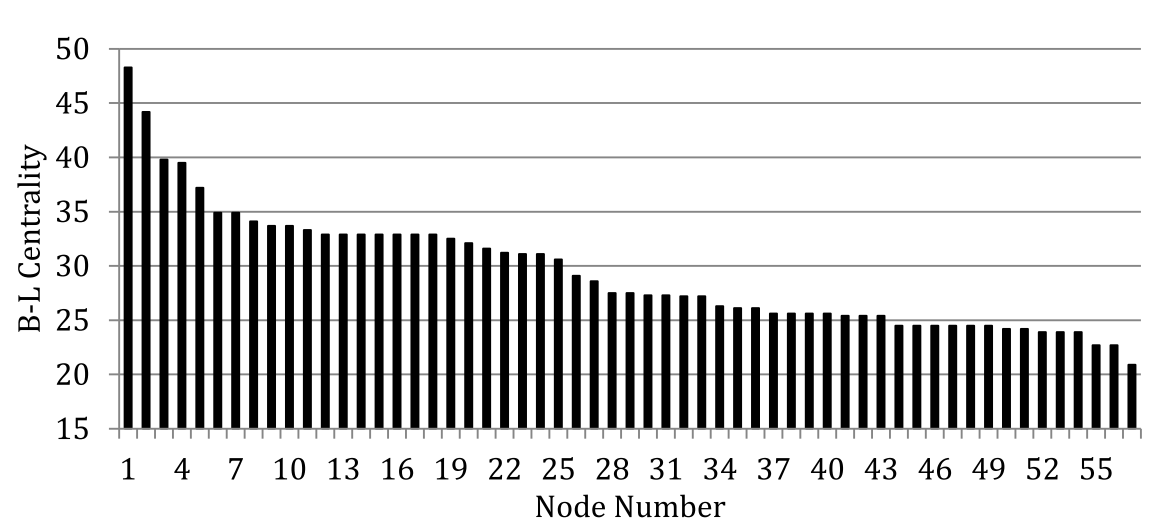


Figure 3-13: Information network nodes B-L centrality rank ordered

3.7 Combined Networks

3.7.1 Task and Social Network

TMC operators are involved in all tasks and are the sole social agents in the prioritisation, personnel allocation and strategy development and selection phases, as shown in Figure 3-14. All decision-making tasks, such as judging the problem's context and deciding whether it has been resolved, are the responsibility of TMC operators, reinforcing their central position within the system as indicated within the social network analysis.

Monitoring, contextualisation, prioritisation and feedback phases involve the TMC interacting with the road network and external environment; they therefore involve a wide range of social agents. It can be seen that these interactions occur at the beginning and end of the task process, information being gathered from a wide range of agents, decisions made internally by operators based on this information, and then implemented, affecting other agents and hence the road network and external environment.

While decision-making was predominantly observed to be a manual process in the TMCs visited, most made use of some automated strategies. These are implemented automatically by UTMC systems to deal with certain scenarios, e.g. sporting events. Therefore UTMC systems can conduct some of the tasks identified as solely conducted by operators, though they are limited in their application and manual decision-making is required for the majority of scenarios as well as to adapt pre-set strategies as needed.

3.7.2 Information and Social Network

Similarly to the task network, TMC operators are concerned with virtually all information within the system (Figure 3-15). The only exception is traffic's route, which is known only to the traffic itself, making it inherently unpredictable (Murray & Liu, 1997). Furthermore, 26 of 55 nodes are known only to TMC operators, including half of the key concepts, strategy, management options, exceptional, personnel and network conditions. This represents the private information known only within the TMC and is in many cases created by the operators. In contrast the other 29 nodes and half of the key concepts, cause, infrastructure, location, traffic, affected traffic and traffic type, can be known to many agents. This information is public and is obtained by the TMC through interactions with other agents in the system.

There can of course be multiple operators, therefore no information is necessarily owned by a single agent, one characteristic of distributed cognition (Stanton, 2014). This means that effective interaction between agents is imperative for the system's performance; in particular the transmission of information to operators given their central role within the task process.

3.7.3 Information and Task Network

Figure 3-16 shows how information nodes appear to be clustered into task groups with a significant degree of overlap between phases. This is most evident in the 'exceptional' node which occurs within all phases, representing known information regarding the scenario which is expanded and clarified as each task phase is completed. It can also be seen that the contextualisation phase considers all of the information nodes used within the monitoring phase. During monitoring information relating to the entire network is obtained, during contextualisation this is constrained to the specific scenario and hence is required to be more detailed. As might be expected from 'information phases' a wide range of information nodes are utilised, 29 and 35 for monitoring and contextualisation respectively.

The prioritisation and personnel allocation phases are the most focused in terms of information, each employing only 6 nodes. In both cases the 'exceptional' node provides a link to the other phases, specialist information utilised within each phase furthering the overall understanding of the scenario's management requirements and enabling the physical outputs of each phase.

Once the scenario's management requirements are known possible actions are considered against the potential consequences to form a strategy. This requires information relating to the capabilities of network agents and the likely response of traffic. Once a strategy has been implemented its impacts, compared to predicted consequences, are monitored through the feedback phase. This utilises similar information to monitoring though of course only that which is relevant to the scenario is considered.

3.7.4 Integrated Network

Figure 3-17 shows how the distribution of social agents amongst information nodes is dependent on the task phase in which that information is used. All phases are conducted by TMC operators though as discussed in section 3.7.2 no single agent owns all of the information within the system making interactions between agents a core property within TMCs.

The purpose of the monitoring phase is to enable operators to identify the occurrence of problems within the network and hence the commencement of a scenario. Information relating to both fixed (e.g. layout, traffic rules) and variable (e.g. traffic) components of the network is transferred to the operators from a variety of other agents providing them with a model of the network's state. As discussed in section 3.5 information provided by agents varies in frequency and relevance and hence importance. A further distinction can be drawn between agents who discriminate in terms of the information provided (e.g. monitoring personnel telephoning the TMC regarding a specific scenario) and those which are indiscriminate (e.g. viewing random CCTV pictures). A key challenge for TMCs given the quantity of available information and its varying quality is how to identify genuine scenarios accurately and consistently.

The detailed information obtained during the contextualisation phase is provided through the same social interactions as during monitoring. Similarly to the previous phase information is transferred to operators who are solely responsible for the phase's output. This dependence on operators was shown in the task and social network (Figure 3-14) and can further be seen here, in particular in the prioritisation and personnel allocation phases for which information used is almost exclusively the property of the operators.

During strategy phases viable strategies are formulated, predominately using operator's specific knowledge of the scenario and the network though consultation with other agents may be required, and the perceived best solution selected. Implementation is achieved through interactions between operators and the relevant social agents required for the strategy.

The final task phase, feedback, is undertaken similarly to the monitoring phase, interactions between operators and other social agents providing information relating to the road network, however because the objectives and predicted outcomes are known, only information relating to the scenario is considered. This enables the strategy's impacts and success to be judged and adjustments to be made if necessary.

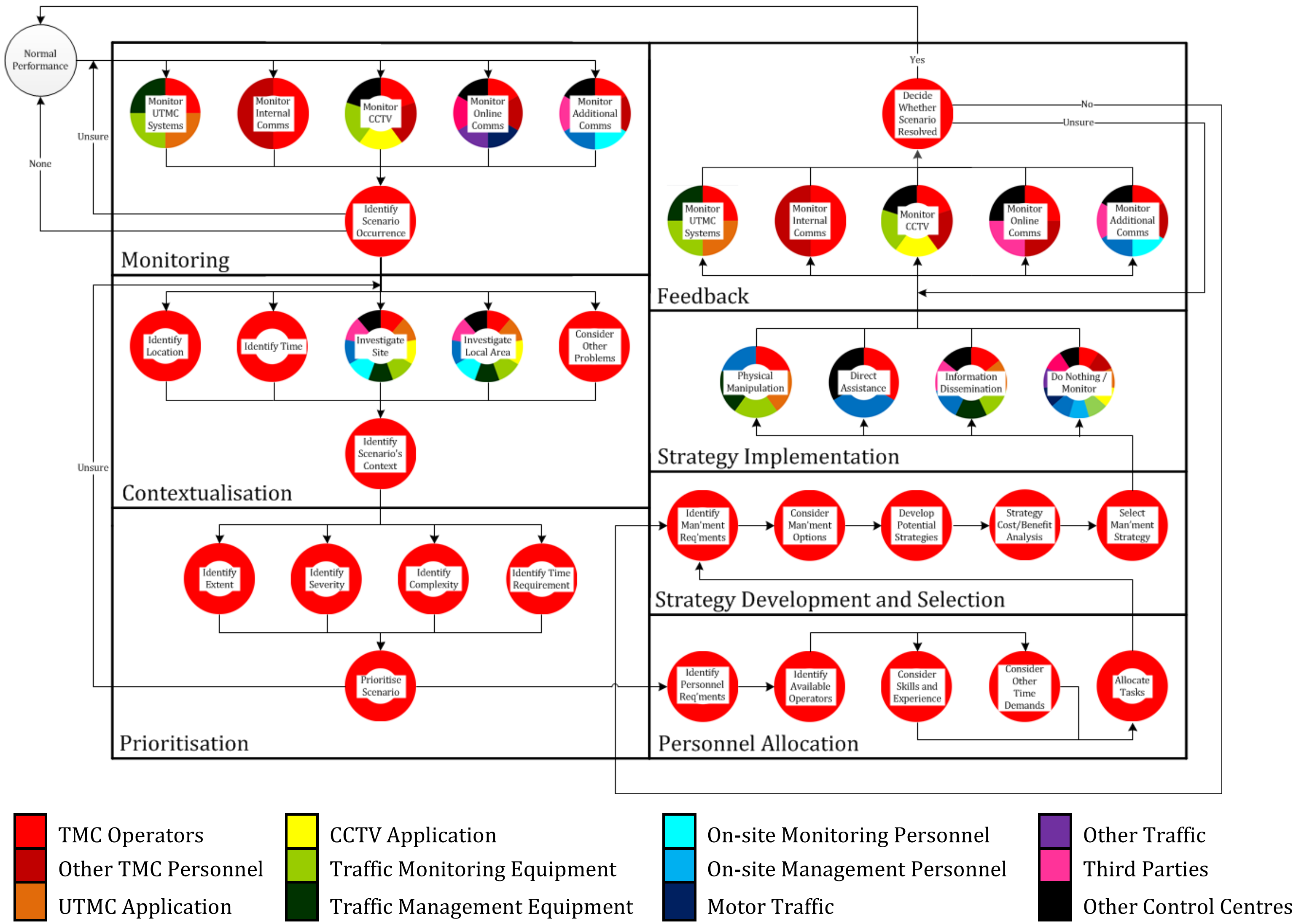


Figure 3-14: Task network coded by social agent

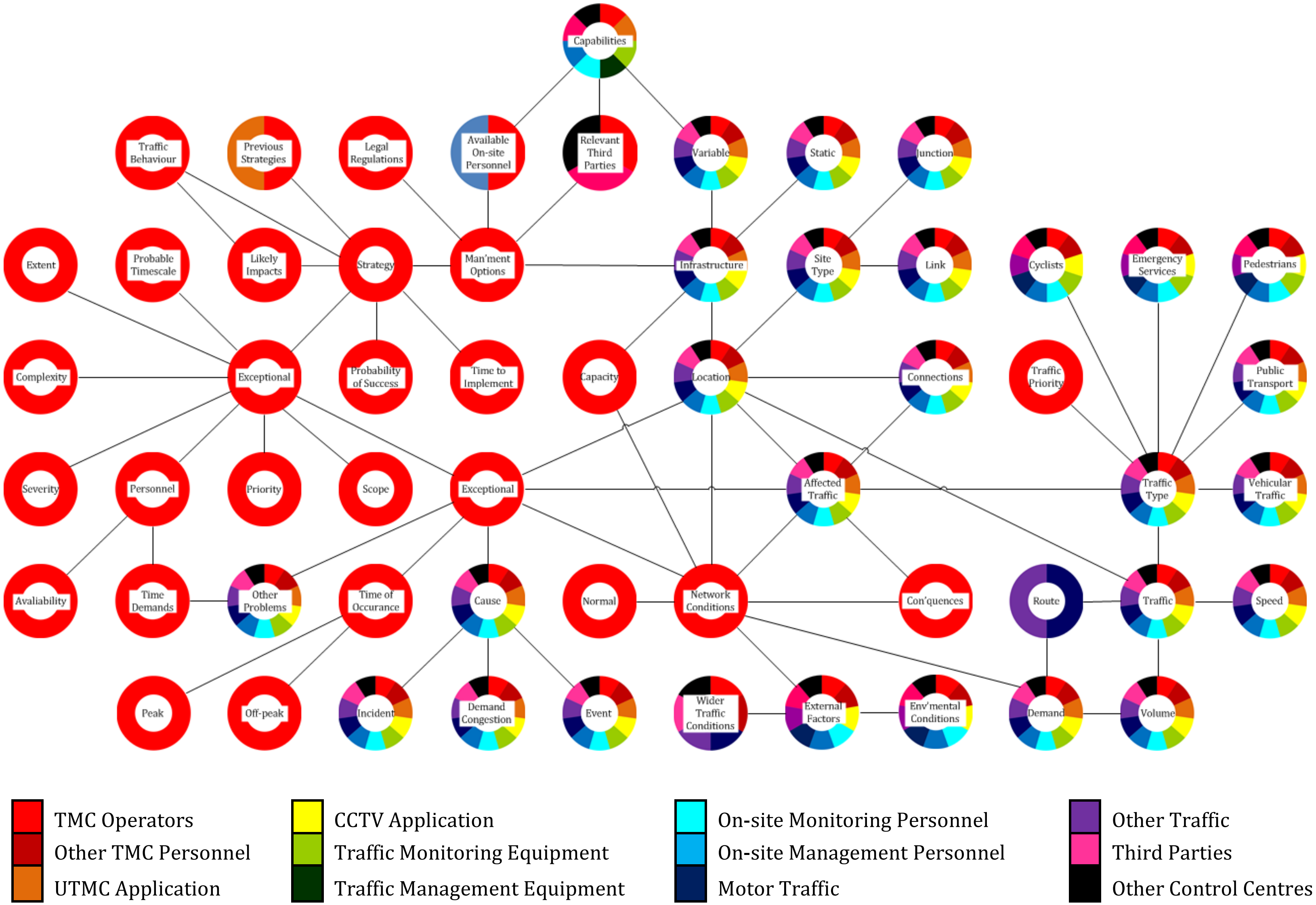


Figure 3-15: Information network coded by social agents

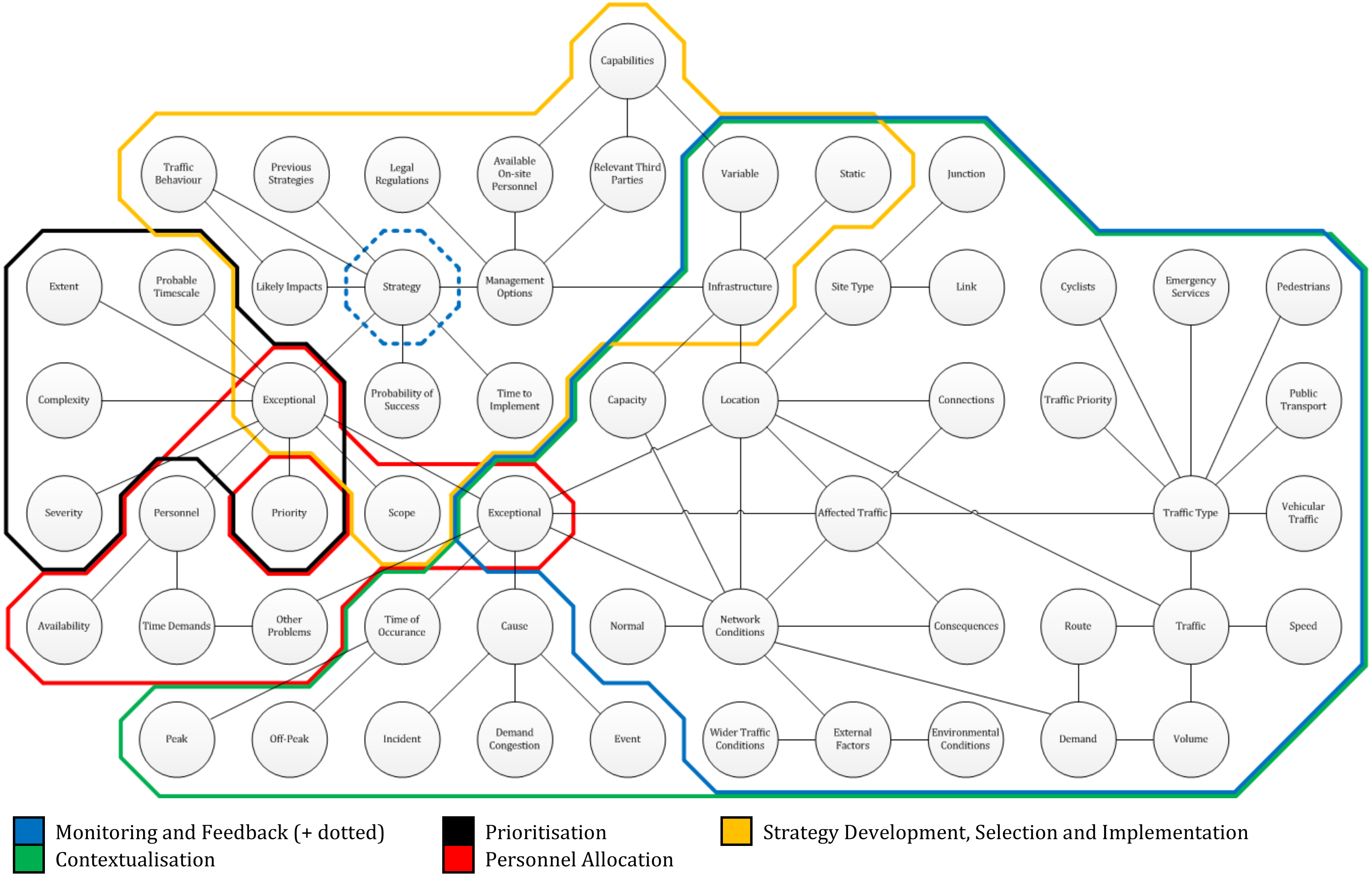


Figure 3-16: Combined information and task network

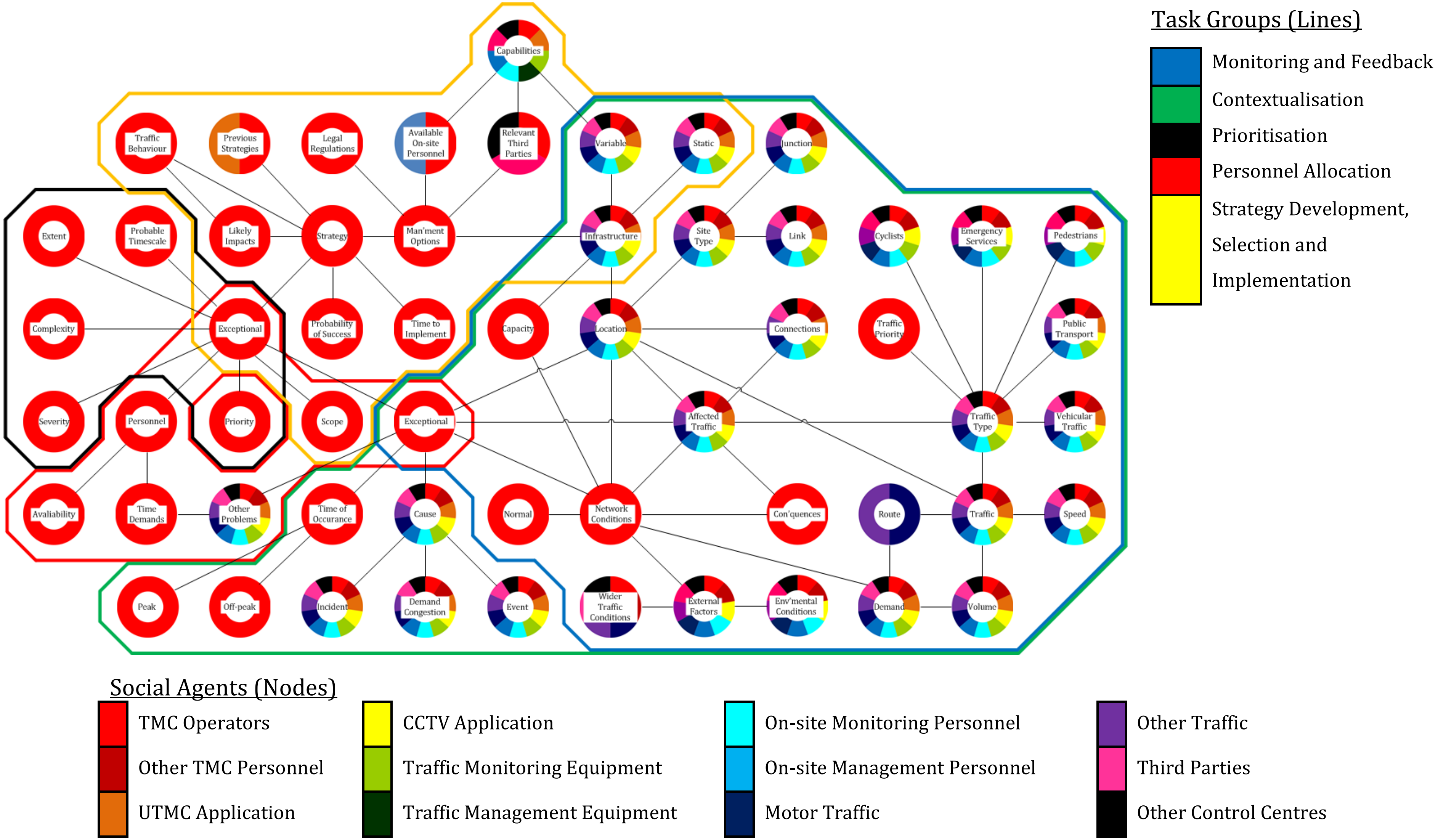


Figure 3-17: Integrated networks model

3.8 Conclusions

This analysis applied EAST to congestion management within road TMCs. Techniques developed through previous work within the area (e.g. Houghton et al., 2006; Stanton, 2014; Stanton et al., 2008; Walker et al., 2010) have been applied to this domain, predominantly as described by Stanton (2014) though some adaption was required due to the domain's characteristics. The three primary networks (task, social and information) were produced directly from observational data and assessed both qualitatively and quantitatively, while combined networks (task and social, information and social, information and task, and integrated) were assessed qualitatively. SNDs were created using association matrixes as in previous work however weightings were based on qualitative assessment of communication link's frequency of use and relevance to the task. This enabled more complete social network analysis, accounting for the nature of the communications occurring within the domain.

The congestion management task process was found to be circular, comprising of seven linear phases, monitoring, contextualisation, prioritisation, personnel allocation, strategy development and selection, strategy implementation, and feedback. There were found to be strict dependencies within the network, each phase having a single output task however the overall network type was found to be a hybrid hierarchical (chain) star archetype, most phases consisting of a number of concurrent tasks.

All social networks were found to be star archetypes with the strategy phases' network exhibiting some hierarchical properties. TMC operators are of course critical and this was represented in high individual metric scores, however surprisingly traffic agents were consistently low scoring, appearing on the periphery of the system despite being the reason for its existence. The social networks show how TMCs must manage interactions with a wide range of internal and external social agents in order to achieve their goals.

The information network exhibits 'small world' properties, in particular a high level of clustering. The combined networks showed how this clustering is based around task phases and how this influenced the distribution of social agents amongst information nodes. It was found that most social interactions occurred at the beginning and end of the task process, information being gathered from a wide range of agents, decisions made internally by operators based on that information, and then implemented, affecting other agents and hence the road network and external environment. Overall performance is therefore reliant on operator's individual performance and the support provided by TMC systems to facilitate interactions between operators and other agents.

While the EAST analysis conducted in this chapter was able to comprehensively assess congestion management within the TMCs visited a question remains as to the transferability of these findings to the wider traffic management domain. Although the four TMCs used in this study represent a reasonable cross-section of urban traffic management in the UK, no very large TMCs, inter-urban control centres or TMCs from other territories were considered. Therefore a significant portion of road traffic management was not accounted for which could be considered in future work to better define those characteristics which are common to all TMCs and those which represent idiosyncrasies of the centres visited.

Further consideration should also be given to the practical applications which could arise from an EAST analysis. This chapter has demonstrated how operational systems can be modelled and insights regarding their structure elicited through the analysis, however the real purpose of such an analysis has to be to generate meaningful design recommendations. To achieve this it would firstly be necessary to quantify performance utilising a specific system configuration. It would then be possible to compare relative performance in other configurations. These alternative configurations could be other examples of a system within the domain, such as the different TMCs visited for this study, or hypothetical configurations. The graphical representations used in EAST are suitable for modelling a theoretically unlimited number of structural configurations so provided a realistic prediction of performance for each configuration can be identified then it would be possible to make recommendations as to which configurations could provide performance improvements.

Finally it is important to consider that the networks produced represent an idealised version of the domain. In reality problems affecting TMCs' operations will occur and hence there is a need to better understand both the impacts and coping mechanisms employed to preserve performance. To this end chapter 4 will conduct further analysis of the domain by using the EAST networks to assess the domains' resilience.

Chapter 4: Investigating Urban Traffic Management Centres' Operational Resilience Using Event Analysis of Systematic Teamwork

4.1 Introduction

A resilient system is intrinsically able to sustain its required operations during both expected and unexpected disruptive conditions (Hollnagel, Paries, Woods, & Wreathall, 2011). Resilience can be considered at all system levels, from specific operational processes and social dynamics, to the organisational factors which support operations, as well as the wider industrial context. Truly resilient systems being able to survive disruptions at all levels by absorbing impacts and adapting or adjusting themselves as needed (McDonald, 2006).

Systems lacking in resilience are unable to respond to the changing demands presented by unexpected situations (Hale & Heijer, 2006) resulting in failures. Paradoxically, accidents resulting from a system's lack of resilience often provide the best insights into their behaviour under disruption, as well as providing the impetus to conduct resilience investigations (Cook & Woods, 2006; Woods, Johannesen, Cook, & Sarter, 1994). Indeed a critical component for achieving high resilience is seen to be continuous learning from events, near-misses and accidents (Weick, Sutcliffe, & Obstfeld, 1999).

The paradox is that gaining the required insights to improve the system first requires an accident to have occurred, which in domains required to be ultra-safe would be unacceptable and lead to the need to radically change the system (Amalberti, 2006). Furthermore, data used in this type of analysis is always out-of-date and does not provide a measure of the system's current performance (Wreathall, 2006). Given that a key purpose of resilience engineering is to enable systems to anticipate and manage risks before they threaten operations (McDonald, 2006), there is a need to assess the resilient qualities of a system before an accident or disaster occurs (Hale, Guldenmund, & Goossens, 2006; Wreathall, 2006).

Resilience is not a static system property but an emergent consequence of its design, thus it is only possible to measure the potential for resilience through continuous monitoring of performance (Hollnagel & Woods, 2006). A key requirement for resilience is that systems must be able to anticipate future developments, threats and opportunities (Hollnagel & Fujita, 2013). Tools used within resilience engineering must therefore be able to accurately assess the performance of existing and potential future system configurations against possible disruptive conditions.

A number of methods have been used to examine resilience with most being qualitative in nature, for example the Critical Decision Method (CDM; Klein & Armstrong, 2005; Mendonca, 2008) the ARAMIS risk assessment method (Hale et al., 2006; Hale et al., 2005), the Functional Resonance Analysis Method (FRAM; Hollnagel, 2004, 2012) and Systems-Theoretic Accident Modelling and Processes (STAMP; Leveson, 2004; Leveson et al., 2006). In each case the goal is to understand how systems function under failure, in contrast to traditional methods such as the use of domino (Heinrich, 1931) or Swiss cheese models (Reason, 1990) which search for causation, and use the knowledge gained to design systems better able to cope with the variability experienced during failures (Rodrigues de Carvalho, 2011).

Quantitative assessment on the other hand is relatively undeveloped, and understandably so given the complexities involved in pinpointing exactly what gives a system resilient characteristics (Mendonca, 2008). Despite the challenges, giving resilience a quantitative basis would have significant benefits, allowing judgement of existing system's sufficiency and hence guiding future improvements as well as enabling comparison between different systems or potential development options (Pasman, Knegtering, & Rogers, 2013) .

Of the quantitative studies that have been conducted, Shirali, Mohammadfam, and Ebrahimipour (2013) applied Principle Component Analysis (PCA; Jolliffe, 1986) to a questionnaire designed to test for six indicators of resilience: top management commitment, just culture, learning culture, awareness and opacity, preparedness and flexibility (see Wreathall, 2006). The PCA approach determined how well the system was perceived to perform against these criteria and identified where it was weak.

Baber, Stanton, Atkinson, McMaster, and Houghton (2013) used a different approach. Social Network Analysis (SNA) and agent-based modelling were used to investigate a search and rescue operation. Failure modes affecting particular nodes were applied to each network configuration, with an impression of resilience being observed through the changes in SNA metrics (see Driskell & Mullen, 2005). This has the advantage of basing the analysis on the system's physical structure, which may be beneficial at an operational level by reducing subjectivity, but may not be able to model the less tangible organisational and industrial context levels of resilience.

In this chapter we consider how use of SNA metrics can be used to take the quantification of a system's resilience further, to assess not only social resilience but the resilience of an entire system using Event Analysis of Systematic Team-work (EAST; Stanton et al., 2008). The method is illustrated through application to road congestion management using the EAST networks developed for four Traffic Management Centres (TMCs) in chapter 3, enabling the process to be explored in more detail.

4.2 Methodology

4.2.1 Event Analysis of Systematic Teamwork

EAST is a systems ergonomics method which considers complex socio-technical systems holistically without favouring either subsystem and enables both quantitative and qualitative analysis based on graphical network diagrams (Stanton, 2014), which themselves have been shown to have advantages over traditional ethnographical approaches (Walker et al., 2010). Temporal aspects of a system can also be modelled effectively (see Griffin et al., 2010). As a method of resilience engineering, EAST can be used to assess the weaknesses and potential points of failure in socio-technical systems (Stanton, 2014).

EAST was originally a multi-method approach (Walker et al., 2006) incorporating a number of established ergonomics methods, including Hierarchical Task Analysis (Annet, 2005), CDM and Coordination Demand Analysis (Burke, 2005), however Stanton (2014) showed that the method's outputs can also be produced directly from observational data.

Systems are considered in terms of the tasks undertaken, social agents involved and information used, each element being depicted graphically through the creation of three primary networks, together providing a detailed view of the system's complexity (Griffin et al., 2010). These primary networks are described below.

- *Task Networks* describe the relationships between tasks and their sequences and interdependences.

- *Social Networks* analyse the organisation of the system and the communications which take place between agents.
- *Information Networks* show the information used and communicated by agents.

This graphical approach enables networks to be assessed qualitatively (e.g. Leavitt, 1951), through visual assessment, and also quantitatively, by calculating SNA metrics (Stanton, 2014; Stanton et al., 2008). Although quantitative analysis has predominately been used to analyse social networks (e.g. Houghton et al., 2006), metrics can be applied to all three primary networks (Stanton, 2014). There are a wide range of metrics that can be calculated for any network, these can be categorised as global, applying to the entire network, and individual, applying to specific network nodes. Metrics taken in isolation describe specific system parameters; however it is also possible to describe its properties by considering the interactions between metrics. These can be depicted graphically using the NATO SAS-050 Approach Space (NATO, 2006), with multiple conditions plotted within a single space to produce what is known as a phase space (Stanton et al., 2012) as shown in Figure 4-1.

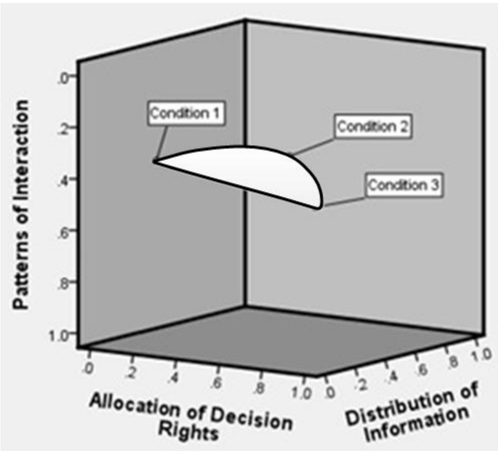


Figure 4-1: A system's phase space showing multiple conditions

4.2.2 NATO SAS-050 Approach Space

The Approach Space enables system structures to be investigated by plotting three critical system properties in a three dimensional space. These are the allocation of decision rights, patterns of interaction and distribution of information. It was shown by Stanton et al. (2012) that each property can be mapped based on SNA metrics as described below.

Allocation of Decision Rights specifies how decision-making is distributed within the network, ranging between 0 (unitary) and 1 (fully distributed). Calculation is based on the proportion of nodes exceeding the mean centrality value (n_{exceed}) compared to the centrality network size ($n_{centrality}$), the number of nodes for which centrality can be calculated (see Equation 4-1). Several methods exist for calculating centrality, the most common being Bevealas-Leavitt (B-L) centrality (Bevelas, 1948; Leavitt, 1951).

Equation 4-1: Allocation of Decision Rights $(x) = \frac{n_{exceed}}{n_{centrality}}$

Patterns of Interaction refers to the network's structure and ranges between ~0 (peer-to-peer) and 1 (hierarchical). It is calculated based on a network's diameter, the geodesic distance between each side of the network (d), relative to the maximum possible diameter for the number of nodes (n) (see Equation 4-2).

Equation 4-2: Patterns of Interaction $(y) = \frac{d}{n-1}$

Distribution of Information is equal to the network's density and ranges between 0 (no connections) and 1 (all-connected network). Density is calculated as the number of links (l) divided by the number of potential links within the system, which is proportional to the number of nodes (n) in the network (see Equation 4-3).

Equation 4-3: Distribution of Information $(z) = \frac{2l}{n*(n-1)}$

Applying these quantitative measures to the approach space enables system's properties to be accurately plotted, allowing comparisons between different network configurations to be conducted. This is a powerful tool because comparisons can be made between different systems within the same domain, different systems in multiple domains or different configurations of the same system.

4.2.3 Measuring Resilience

To investigate a system's resilience its performance must first be considered in different scenarios. If it is assumed that a fully functioning system performs as well as it can then introducing failures should cause an impact to be reflected within the system properties which can be measured using the approach space. These failures can include tasks not being performed, communications links being removed or information not being acquired which can be modelled by systematically removing nodes or links from the fully functioning task, social or information networks as needed (see Baber et al., 2013; Ip & Wang, 2011) . The required network metrics can then be recalculated and used to plot the failure mode's position within the phase space. A measure of the impact upon the system is gained by considering the relative distance between the failure mode's location and that of the fully functioning system (D_{FF}) and of one suffering catastrophic failure (i.e. one plotted at the phase space's origin) (D_{Cat}), which can both be calculated using simple trigonometry (see Equations 4-4 and 4-5).

Equation 4-4: $D_{FF} = \sqrt{\delta x^2 + \delta y^2 + \delta z^2}$

Equation 4-5: $D_{Cat} = \sqrt{x^2 + y^2 + z^2}$

Where x, y and z are the failure mode's allocation of decision rights, pattern of interaction and distribution of information respectively and δx, δy and δz are the changes in properties from the fully functioning system's.

Changes to system properties are likely to be greater in more severe failure modes because the networks become more disturbed from their fully functional state, making D_{FF} increase and D_{Cat} decrease. Considering the proportion of D_{FF} to the total path distance (D_{FF} + D_{Cat}) provides an indication of the impact on system performance, with small D_{FF}'s corresponding to smaller impacts, while large D_{FF}'s produce a greater impact. Hence the system's performance under failure relative to its fully functioning state can be calculated using Equation 4-6.

Equation 4-6: $Performance = 1 - \left(\frac{D_{FF}}{D_{FF}+D_{Cat}}\right)$

EAST is a network of network's approach with the graphical task, social and information networks able to be combined, enabling multiple aspects of the system to be visualised concurrently (see Figure 4-2). Failure modes developed for a specific primary network can thus be applied to the other two. Task, social and information performance can therefore be mapped to a single three dimensional axis (Figure 4-3) with a failure mode's impact on total system performance then calculated by interrogating the distance between the fully functioning network (located at 1,1,1) and catastrophic failure (located at the origin), in which social agents are not communicated with, required information is not obtained and tasks cannot be completed as a result of the failure mode.

Finally, the resilience of the system is defined as its ability to resist disruption caused by failure modes. Using the method described it is possible to consider not only which scenarios are likely to be most disruptive to the system's operation, and in what respect, but to also consider how these risks might be alleviated. This can be achieved by modelling alternative network configurations, real or theoretical, and identifying whether this change provides increased resilience to failure.

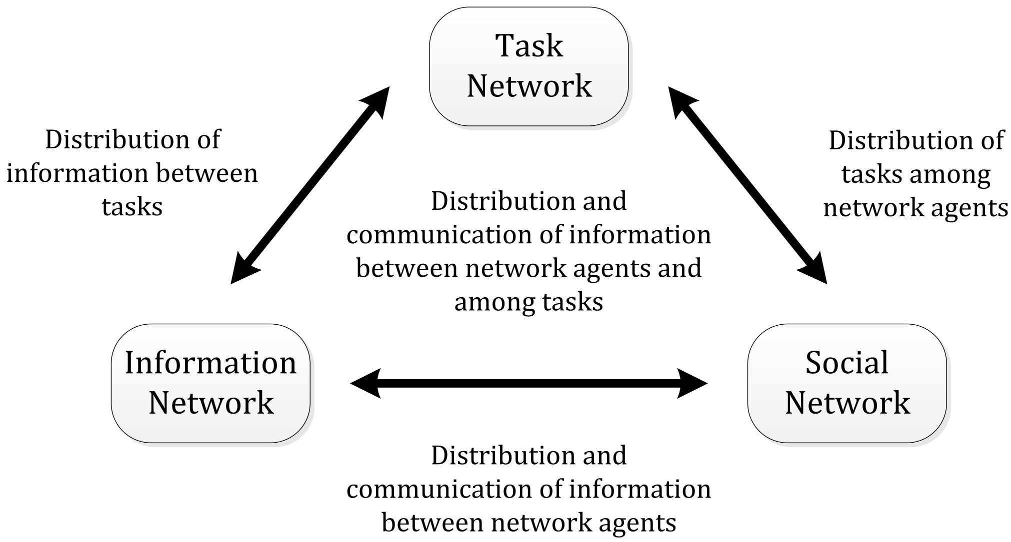


Figure 4-2: Interactions between EAST's primary networks (adapted from (Stanton, 2014))

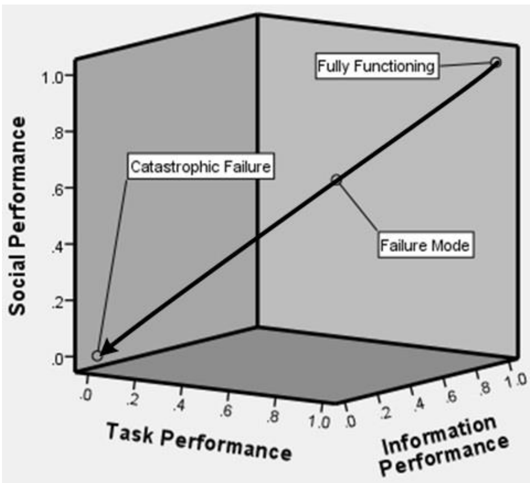


Figure 4-3: Three dimensional visualisation of task, social and information performance

4.3 Resilience of Congestion Management in TMCs

To further investigate congestion management with urban TMCs the above method was applied to the EAST networks developed in chapter 3. The purpose was to increase understanding of how different TMCs cope with failures. To constrain the analysis it was decided to examine only the monitoring processes undertaken. These are critical for identifying scenarios which could cause congestion, enabling them to be managed.

4.3.1 Data Collection and Analysis

Four TMCs were investigated, Bristol, Cardiff, Dorset and Nottingham. All are managed by local authorities, Bristol, Cardiff and Nottingham at a city level with Dorset at county level. Bristol and Nottingham TMCs are of similar size, responsible for the urbanised areas of each city, 40 and 30 square miles respectively. Although Cardiff is a similar sized city its TMC is significantly larger, owing to the amalgamation of police CCTV and public space monitoring control centres into a single location as well as a need to manage the Queen's Gate tunnel twenty four hours a day. Dorset's TMC is responsible for the entire county though management is predominantly focused around the towns of Christchurch, Dorchester and Weymouth; some key trunk routes are also managed. The photographs in Figure 4-4 show views of each TMC.

Figure 4-4: Bristol, Cardiff (BBC News, 2010), Dorset and Nottingham (Nottingham City Council, 2013) TMCs (clockwise from top left)

TMC operations were observed over a working day at each TMC, with informal interviews conducted with the operators on duty when their workloads allowed. Operators came from a range of backgrounds and had varying experience levels; although typically greater than five years some were new to the profession. Several congestion scenarios were observed, including unexpectedly high traffic demand and vehicle breakdowns, which required management. These provided an opportunity to supplement observations with in-depth technical critiques and insights from the Subject Matter Experts (SMEs). Primary EAST networks were produced directly from observational data with SNA metrics calculated using AGNA (version 2.1.1). Combined task and social, and information and social networks were then constructed through interrogation of the primary networks. Microsoft Excel (2010) and SPSS (version 19) were used to conduct the data analysis.

4.3.2 Task Network

The purpose of monitoring is to identify whether a relevant scenario has occurred within the road network, causing the system to change from a state of normal performance to one requiring management. Operators are tasked with using a range of sources to gain information including CCTV, Urban Traffic Management and Control (UTMC) systems (e.g. vehicle counts, incident detection), digital communications (e.g. email, Twitter), internal communications (i.e. discussion between TMC personnel) and analogue communications (e.g. reports by phone). Monitoring is a constant task potentially involving any of these sources. The task process is shown in Figure 4-5, can be described as a hybrid circle-Y archetype and was found to be identical between TMCs.

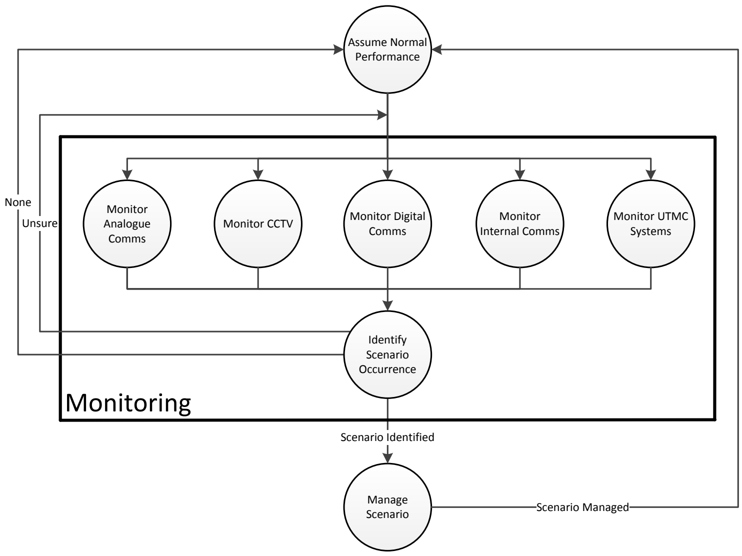


Figure 4-5: Monitoring task network

4.3.3 Social Networks

Social networks are unique to each TMC, however the agents involved are relatively similar, these agents can be grouped by geographical location and are described in Table 4-1.

Table 4-1: Social agent descriptions

Location	Agent	TMC	Description
TMC	TMC Operators	All	Responsible for managing traffic and the domain's SMEs; typically two operators are present although this can vary
	Bus Lane Enforcement Personnel	Bristol Nottingham	Identify and prosecute vehicles illegally using or obstructing public transport infrastructure using CCTV
	Parking Enforcement / Bollard Control Personnel	Cardiff	Monitor CCTV for illegal parking and direct parking enforcement personnel, also responsible for controlling security bollards around the city centre
	Public Space Monitoring Personnel	Cardiff	Monitor CCTV for antisocial behaviour, assisting the police
	Police CCTV Personnel	Cardiff	Monitor CCTV for crime, assisting police operations
	Third Party Representative	Bristol	Acts as a liaison between the TMC and a third party, e.g. public transport providers
	SCOOT Engineer	Cardiff	Responsible for maintaining and upgrading adaptive traffic light systems controlled by SCOOT
	UTMC Application	All	Software used to control traffic monitoring and management equipment, e.g. COMET (Siemens Traffic Solutions, 2009), Argonaut (Cloud Amber, 2012)
	CCTV Application	All	Controls the TMC's CCTV cameras
Road Network	Traffic Monitoring Equipment	All	E.g. CCTV cameras and induction loops
	Traffic Management Equipment	All	E.g. traffic lights and Variable Message Signs (VMSs)
	On-site Monitoring Personnel	All	E.g. parking enforcement personnel

Location	Agent	TMC	Description
Road Network	On-site Management Personnel	All	E.g. traffic management contractors
	Vehicular, Public Transport, Emergency Services, Cyclists and Pedestrians	All	The categories of traffic using (or potentially using) the road network
External	Public Space Monitoring and Emergency Services Control Centres	All	Monitor public areas for criminal activity and manage emergency service operations respectively
	Additional Information Providers	All	Provide extra information to aid decisions such as weather reports (e.g. the Met Office) or wider traffic conditions (e.g. the Highways Agency)
	Radio Stations	All	Distribute information to traffic and other agents
	Traffic Data Distribution	All	Incorporates the dissemination of information to traffic and third parties directly by the TMC and through intermediaries e.g. INRIX
	Other Transport Control Centres	All	Includes other road TMCs as well as public transport control centres (e.g. Bus, Tram)

As discussed in chapter 3 each SND was constructed using qualitative data obtained from operators with weights assigned based on their perception of frequency of use and relevance to the domain. It should be noted that two-way links indicate communication can occur between both agents while one-way links indicate that it is impossible for one agent to communicate back to another, for example a traffic sensor detects vehicles but cannot communicate this information back to them directly.

It can be seen that the social network's for each TMC (Figure 4-6 to Figure 4-9) are relatively similar. Within the TMC there are usually two operators as well as a variety of additional personnel who perform other functions. Here are the greatest differences in social structure, Dorset being a small TMC has no additional personnel constraining activities to those conducted by operators, in contrast Cardiff, the largest TMC, conducts a range of other activities such as public space monitoring and parking enforcement, each of which requires specialist personnel who interact with operators.

Each TMC also employs a variety of technical UTMC and CCTV systems to connect the operators to the on-street equipment.

Outside of the TMC agents can be within the managed road network (e.g. the traffic, on-street personnel) or external (e.g. radio stations, other control centres), this shows how operators must interact with a very diverse range of sources. The network structures are broadly similar across TMCs, some such as Cardiff having greater capability to contact traffic directly due to the tunnel's infrastructure (emergency phones), however all other differences result from the preferences of individual staff, for example some make greater use of additional information providers (e.g. Google traffic reports, TomTom data) than others.

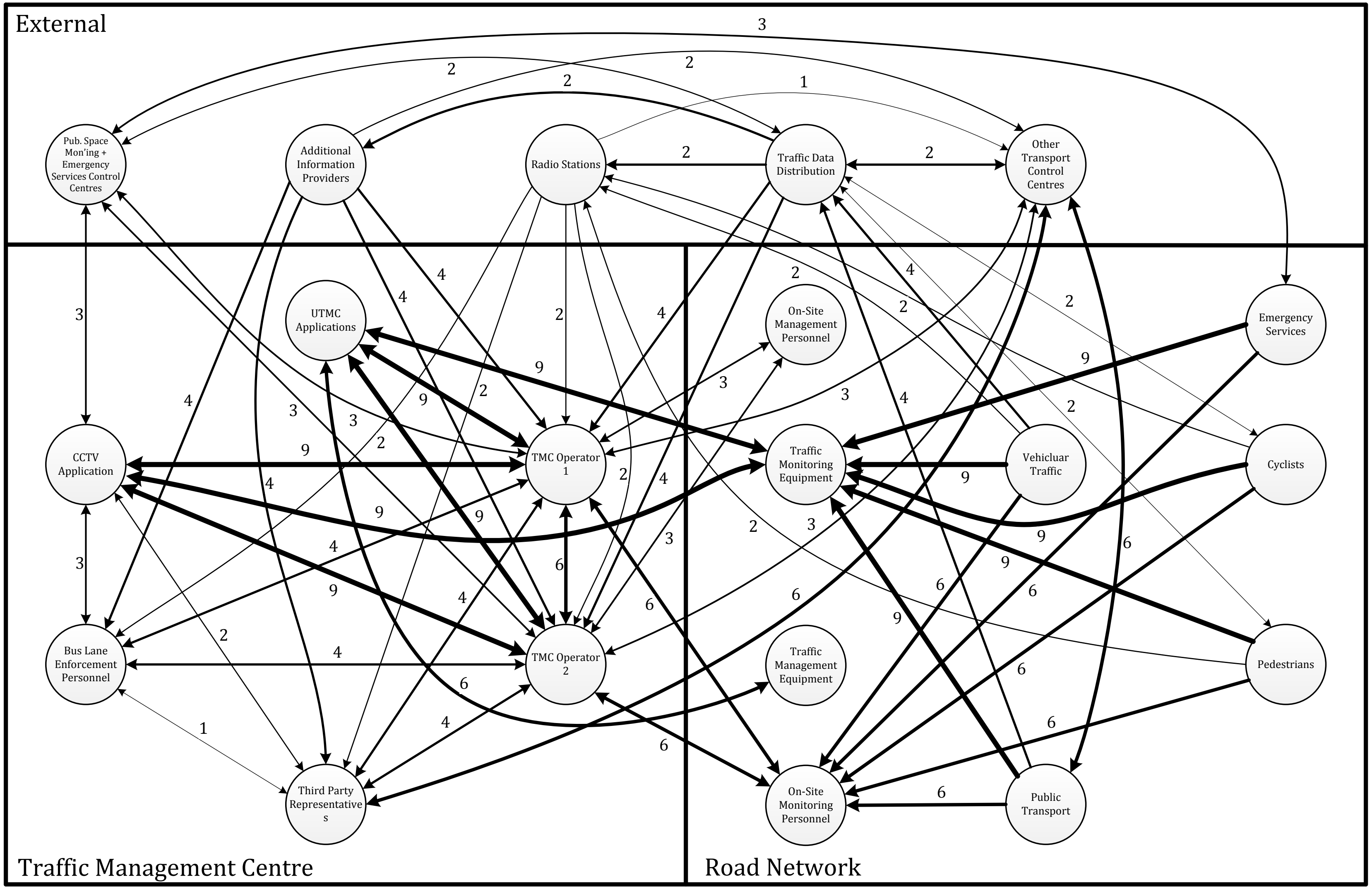


Figure 4-6: Bristol Social Network Diagram

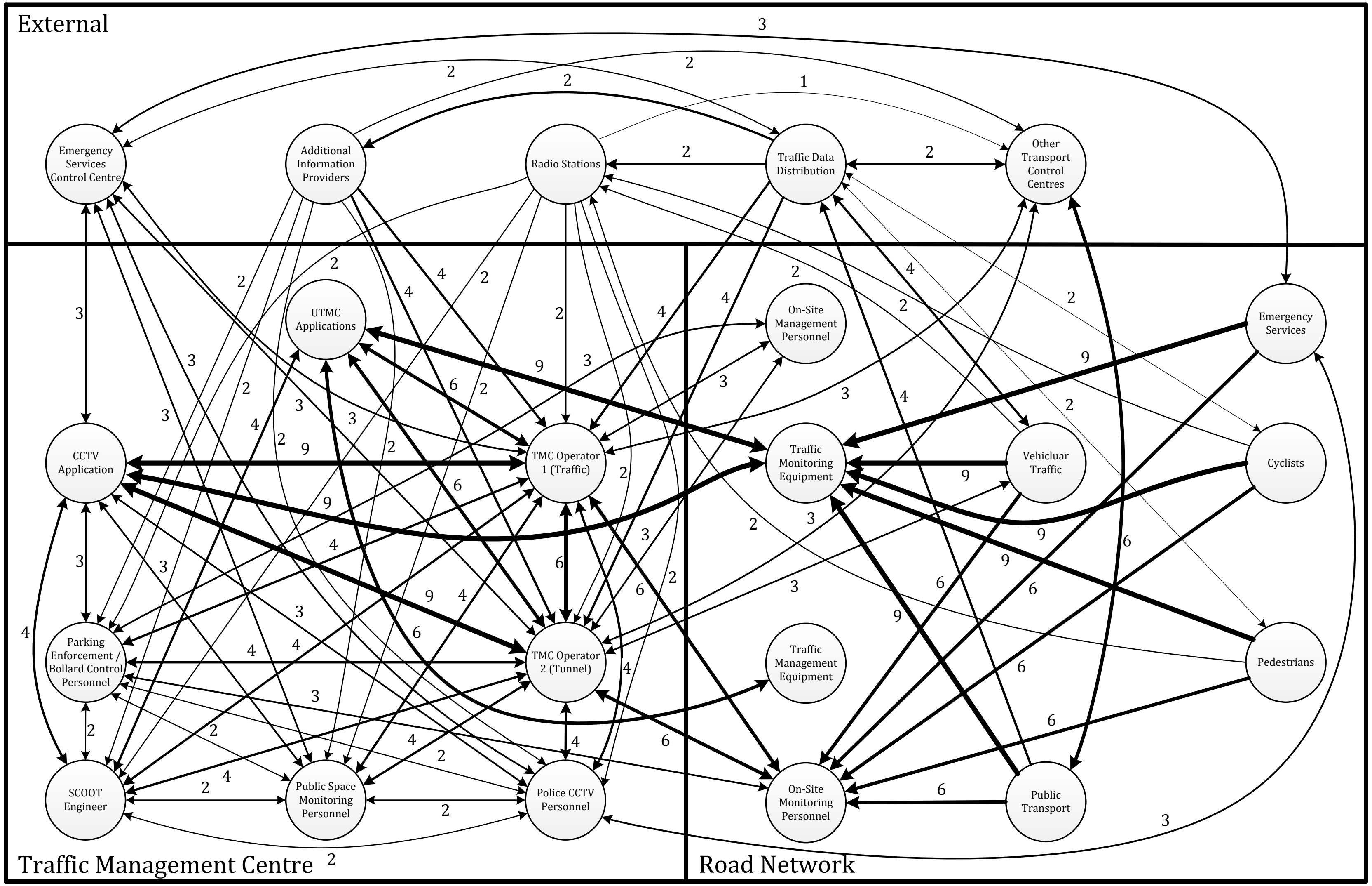


Figure 4-7: Cardiff Social Network Diagram

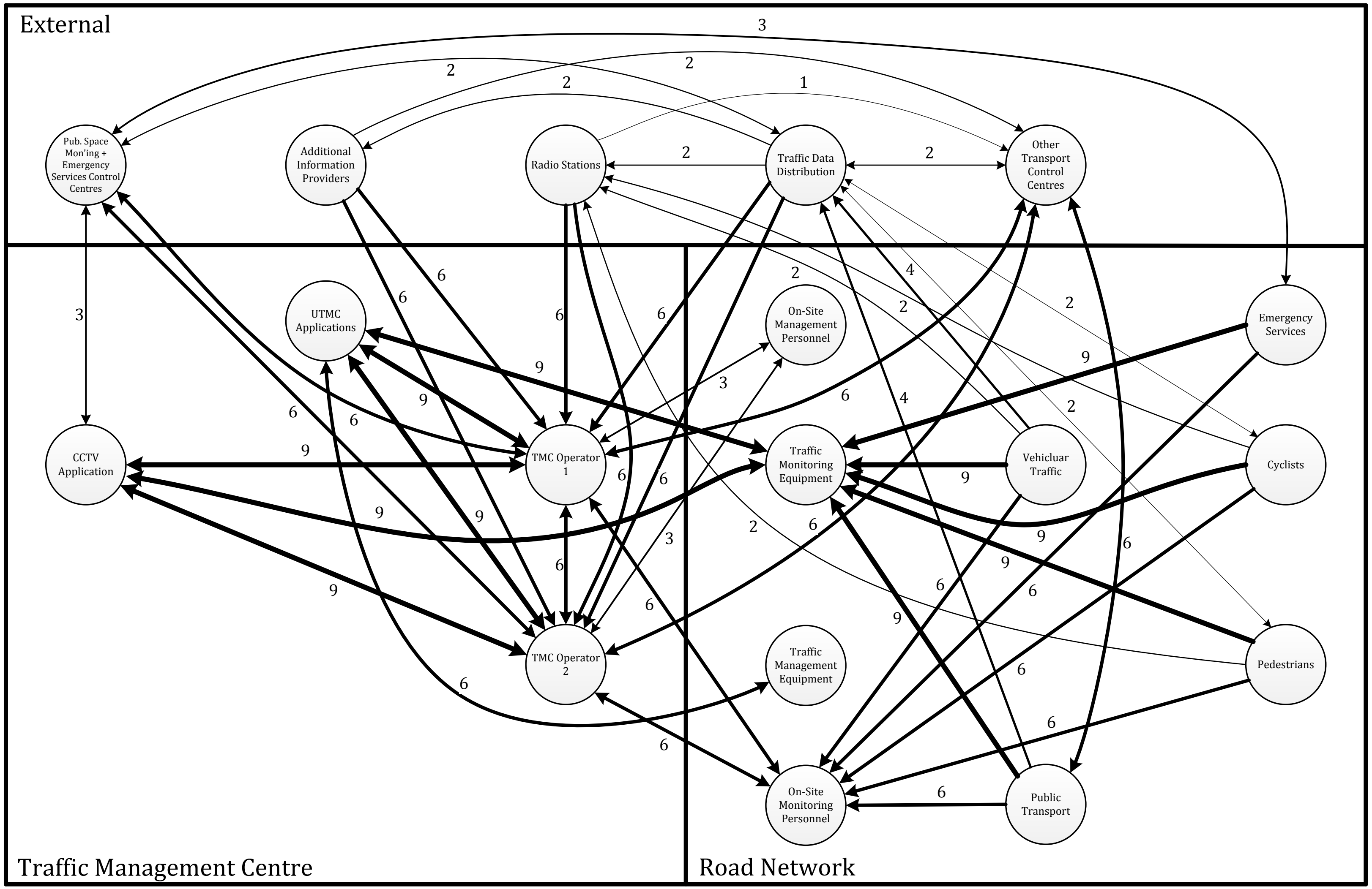


Figure 4-8: Dorset social network

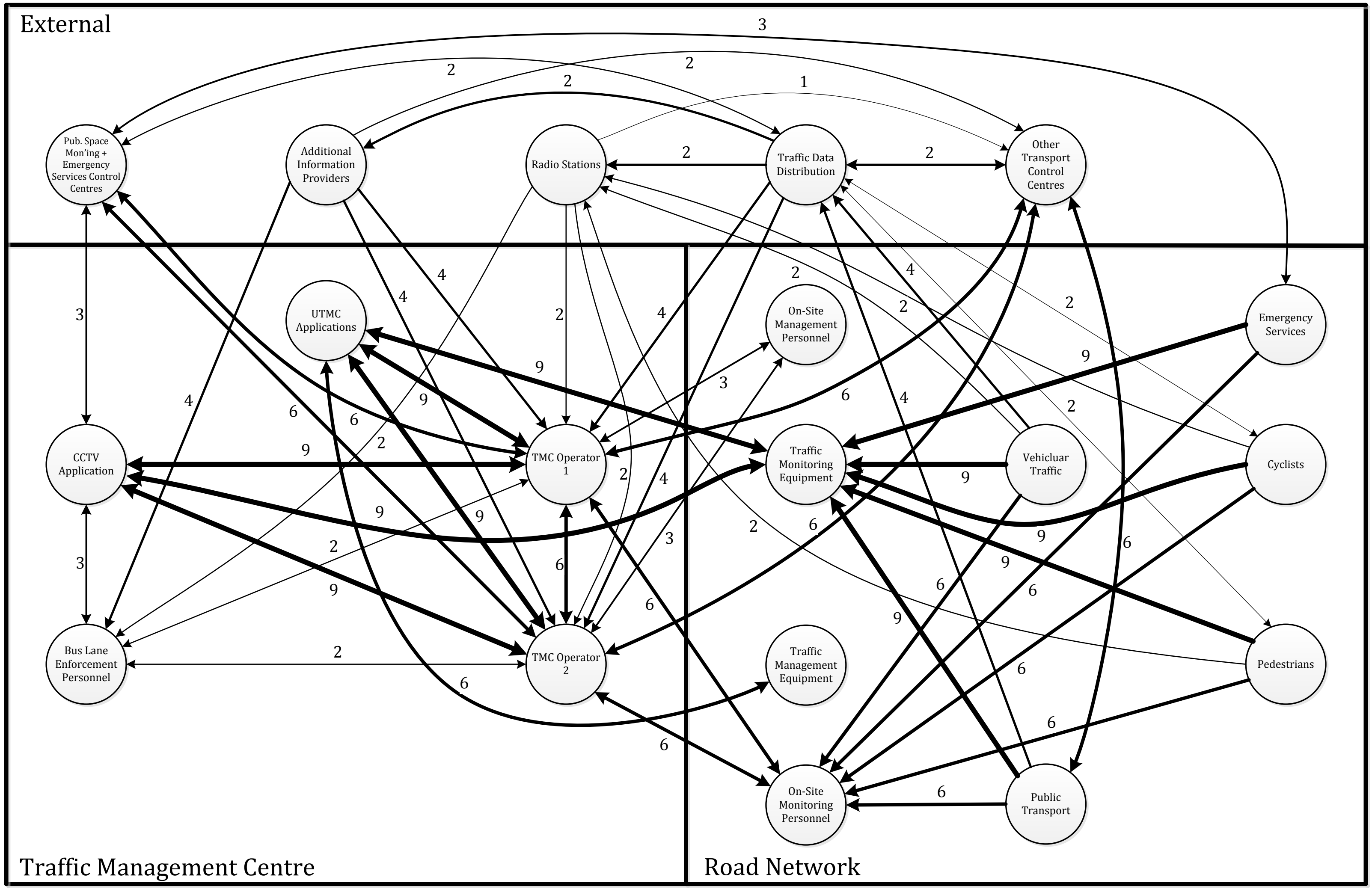


Figure 4-9: Nottingham Social Network Diagram

4.3.4 Information Network

A wide range of information is used throughout monitoring, with the information network (Figure 4-10) identical between TMCs. The key concepts are described below.

- *Affected Traffic* is the subset of traffic directly or indirectly involved with the scenario.
- *Cause* is the reason for the scenario.
- *Exceptional* is the information relating to the exceptional performance state caused by the scenario.
- *Infrastructure* details the physical network components and their capabilities.
- *Location* is where traffic and infrastructure is within the domain.
- *Network Conditions* detail how the network is operating.
- *Traffic* considers the properties of road users, such as speed and route.
- *Traffic Type* includes vehicular, cyclists, pedestrians, public transport and emergency services.
- *Traffic Priority* considers the relative importance of each type of traffic.

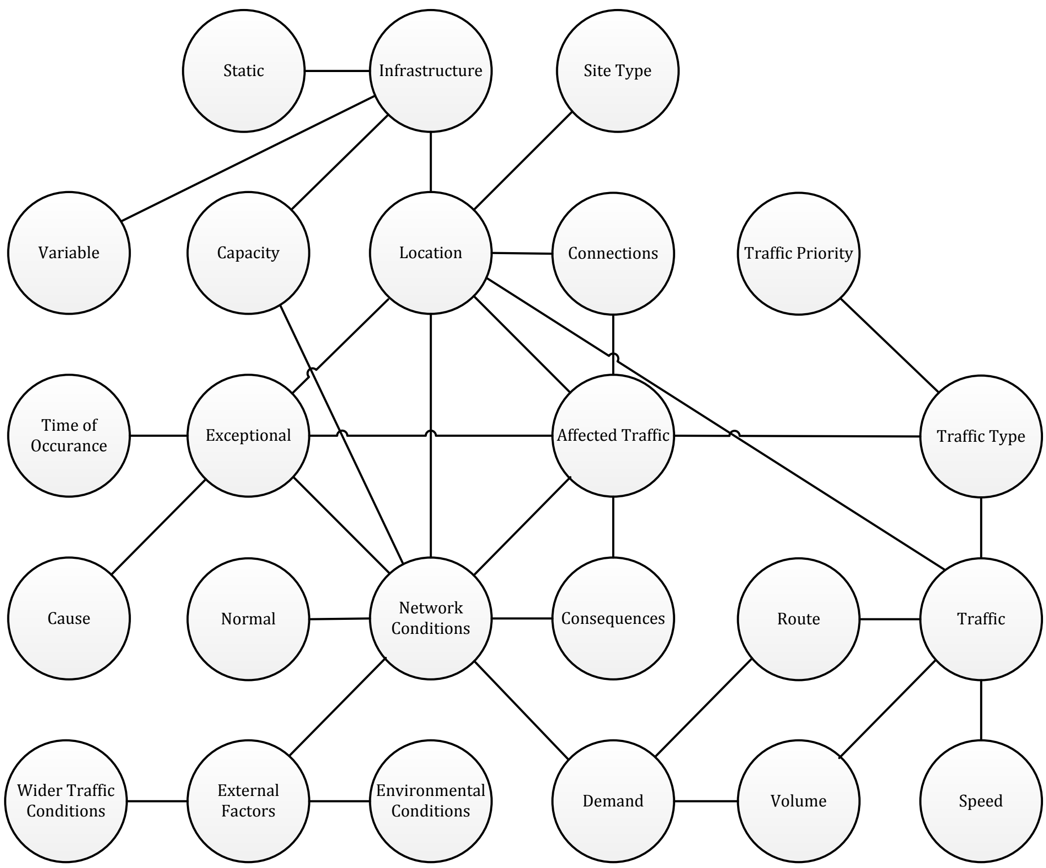


Figure 4-10: Monitoring information network

4.3.5 Combined Networks

Combined networks were produced by shading primary networks according to the social agents involved. For simplicity comparable agents were grouped together as detailed in Table 4-2.

Table 4-2: Social agent grouping

Group	Agents	Shade
TMC Operators	TMC Operators	(red)
Other TMC Personnel	Bus Lane Enforcement Public Space Monitoring Police CCTV Monitoring Third Party Representative	(dark red)
UTMC Application	UTMC Application	(orange)
CCTV Application	CCTV Application	(yellow)
On-site Equipment	Monitoring Equipment Management Equipment	(green)
On-site Personnel	Monitoring Personnel Management Personnel	(light blue)
Traffic	Vehicular Cyclists Pedestrians	(purple)
Third Parties	Radio Stations Traffic Data Distribution Additional Information Providers Public Space Monitoring Control Centre Police Control Centre Other Transport Control Centres	(grey)

<u>Task and Social Network</u>

The task and social network (Figure 4-11) shows which social actors are involved within each task. As may be expected each monitoring task involves a range of agents. Operators are of course involved in every task, although each could also potentially be undertaken by other personnel. Monitoring UTMC and CCTV systems involves their controlling applications as well as the physical equipment on the road, while online and additional communications can be initiated by on-site personnel, third parties, other control centres or the traffic itself (usually through social media e.g. Twitter).

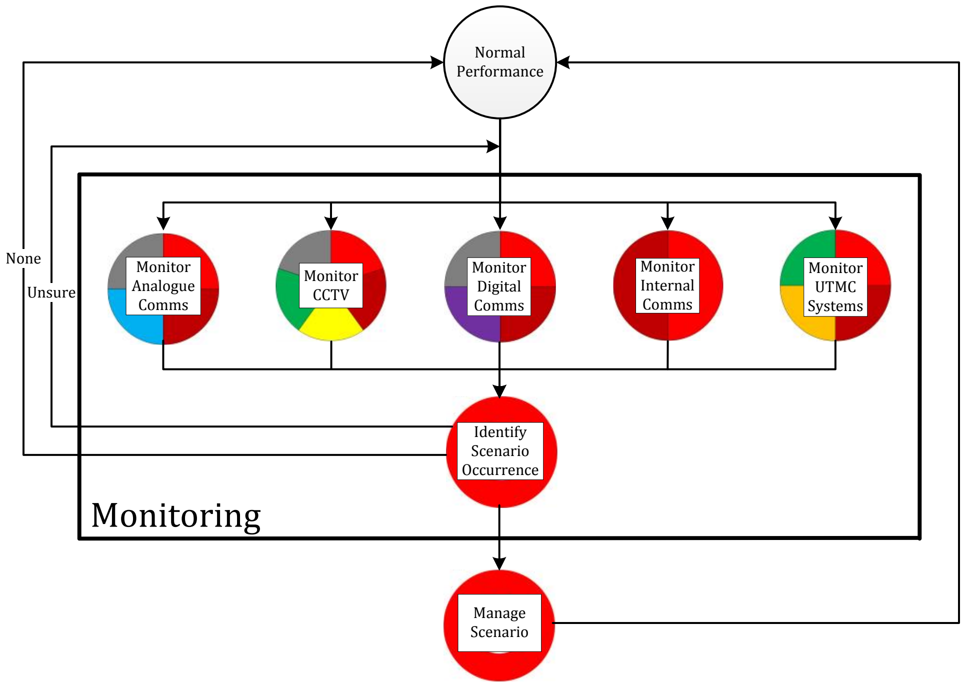


Figure 4-11: Monitoring task and social network

Information and Social Network

From the information and social network (Figure 4-12) it can be seen that the majority of information within the road network is distributed widely amongst social agents. There is also some private information known only to the TMC operators related to their specialised knowledge about the road network and the traffic management process.

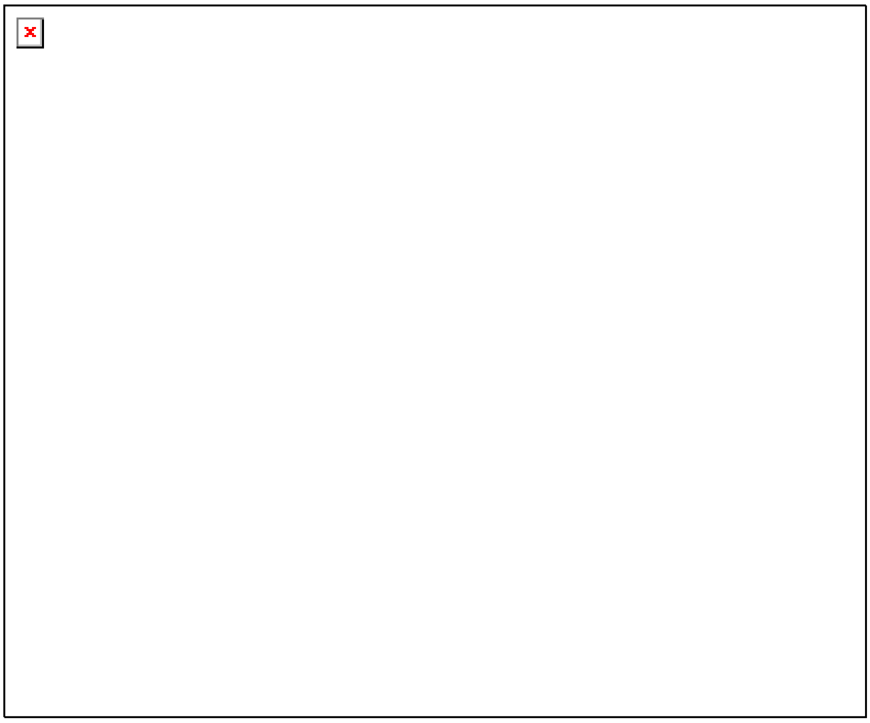


Figure 4-12: Monitoring information and social network

4.3.6 Failure Modes

Failure modes could be developed from any of the three primary networks, either tasks are not conducted, communications between agents are not performed or are impossible, or required information is not obtained. To constrain the analysis for this study only social failure modes linked to physical occurrences within the domain were considered. Each failure mode was identified through interrogation of the SNDs and hence was not attributed to any real scenario but rather what could occur.

Single Node Failures

Ten agents were identified which could fail individually, although not all apply to every TMC, these are presented in Table 4-3.

Table 4-3: Single node failure modes

Failure Mode	Affected TMCs	Code
Lone Operator	All	NS1
No Bus Lane / Parking Enforcement Personnel	Bristol, Nottingham	NS2
No Third Party Representative	Bristol	NS3
No Public Space Monitoring Personnel	Cardiff	NS4
No Police CCTV Personnel	Cardiff	NS5
No SCOOT Operator	Cardiff	NS6
UTMC System Failure	All	NS7
CCTV System Failure	All	NS8
No On-site Monitoring Personnel	All	NS9
No On-site Management Personnel	All	NS10

Compound Node Failures

Compound failures, affecting at least two social agents, were also considered; these are presented in Table 4-4.

Table 4-4: Compound node failure modes

Failure Mode	Affected Nodes	Affected TMCs	Code
Out of Hours	TMC Operators (one at Cardiff) Additional TMC Personnel	All	NM1
No Additional TMC Personnel	Bus lane / parking enforcement, public space monitoring and police CCTV personnel Third party representative SCOOT engineer	Bristol, Cardiff	NM2

Failure Mode	Affected Nodes	Affected TMCs	Code
Technical Systems Failure	UTMC applications CCTV application	All	NM3
No On-site Personnel	On-site monitoring personnel On-site management personnel	All	NM4
No Additional TMC Personnel and Technical Systems Failure	Bus lane / parking enforcement, public space monitoring and police CCTV personnel Third party representative SCOOT engineer UTMC applications CCTV application	Bristol, Cardiff, Nottingham	NM5
No Additional TMC or On-site Personnel	Bus lane / parking enforcement, public space monitoring and police CCTV personnel Third party representative SCOOT engineer On-site monitoring personnel On-site management personnel	Bristol, Cardiff, Nottingham	NM6
Technical Systems Failure and No On-site Personnel	UTMC applications CCTV application On-site monitoring personnel On-site management personnel	All	NM7
No Additional TMC or On-site Personnel and Technical Systems Failure	Bus lane / parking enforcement, public space monitoring and police CCTV personnel Third party representative SCOOT engineer UTMC applications CCTV application On-site monitoring personnel On-site management personnel	Bristol, Cardiff, Nottingham	NM8

Communication Type Failures

A number of communication types are used within TMCs, these are as described in Table 4-5, and were applied to each TMC's SND to produce a Communications Usage Diagram (CUD; Watts & Monk, 1998), an example from Bristol is presented in Figure 4-13.

Table 4-5: Communication types

Communication Type	Description
Data Link	Physical links between on-street equipment and the TMC e.g. fibre optic cables
Face-to-Face	Verbal communications between TMC personnel
Machine Interface	Interface between operators and technical systems
Online Communications	Connects TMC personnel to external agents e.g. email, twitter
Physical Interaction	One agent physically impacts upon another within the road network e.g. on-site management personnel and traffic
Radio / Wireless	Used to communicate between some TMC personnel and on-site personnel e.g. police CCTV personnel and emergency services on the street (Cardiff only)
Telephone	Provides verbal communications between the TMC and external agents
Visual Message	Transfers information from one agent to another within the road network e.g. VMS message to traffic

Not every communication type is capable of failure (e.g. face-to-face), additionally compound failures involving multiple communication types can occur. Potential failure modes are presented in Table 4-6.

Table 4-6: Communication type failure modes

Failure Level	Failure Mode	Affected TMC	Code
Single	Data Link (DL)	All	LS1
	Online Communications (O)	All	LS2
	Radio Communications (R)	Cardiff	LS3
	Telephone Communications (T)	All	LS4
Double	DL + O	All	LD1
	DL + R	Cardiff	LD2
	DL +T	All	LD3
	O + R	Cardiff	LD4
	O + T	All	LD5
	R + T	Cardiff	LD6
Triple	DL + O + R	Cardiff	LT1
	DL + O + T	All	LT2
	DL + R + T	Cardiff	LT3
	O + R + T	Cardiff	LT4
Quadruple	DL + O + R + T	Cardiff	LQ

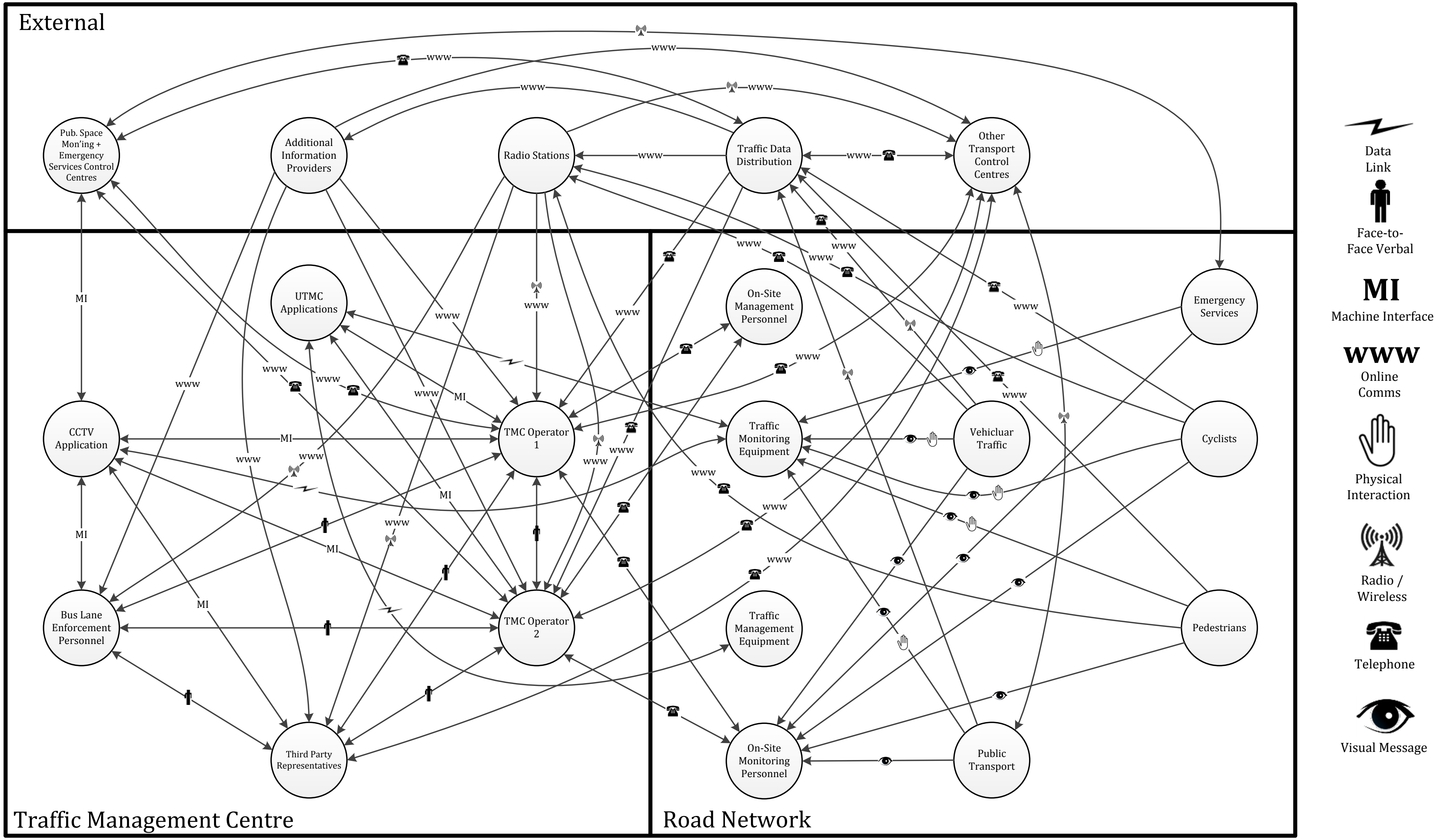


Figure 4-13: Bristol Communications Usage Diagram

4.3.7 Results

Node Failures

The effects of node failure modes on system performance were first considered by failure level and between TMCs (Figure 4-14). Considering the average performance for each failure level shows that as may be expected compound failures ($\overline{x}$ = 85.36%, σ = 0.062) reduce performance more than single failure modes ($\overline{x}$ = 94.40%, σ = 0.025). The performance reductions observed were confirmed significant relative to the fully functioning network using a Mann-Whitney test (n > 20) for both single (z = -3.189, p < 0.01) and compound failures (z = -3.185, p < 0.01) as well as between single and compound failure levels (z = -5.458, p < 0.01). Differences between TMCs were not statistically significant.

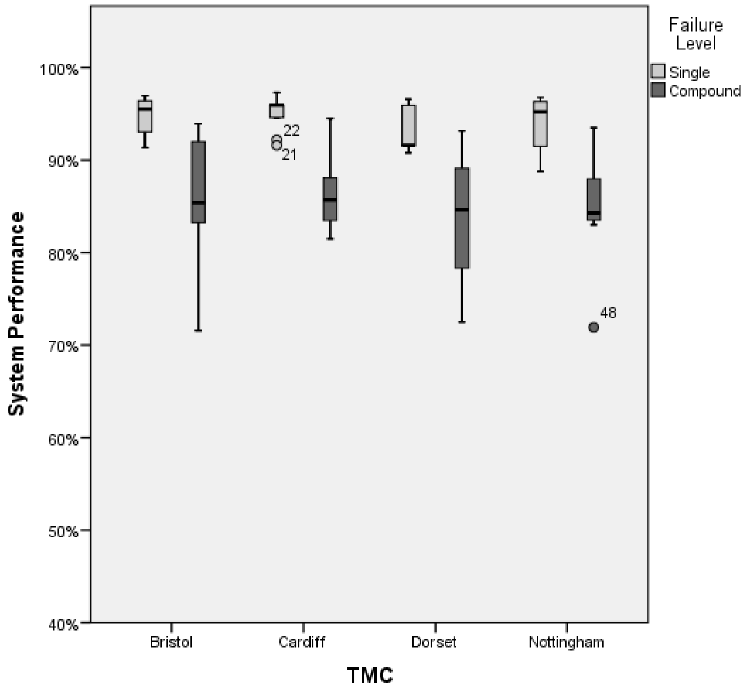


Figure 4-14: Node failure system performance by TMC and failure level

Performance was also considered by failure mode (Figure 4-15) with Figure 4-16 showing how performance reductions are attributed to task, social and information performance. With the exception of technical failures (UTMC and CCTV systems) which impact both social and task networks, TMCs' performance was relatively unchanged due to the loss of any single agent. It could be expected that losing an operator would have the greatest impact on system performance however the redundancy provided through multiple operators ensures that TMCs continue to function effectively in this failure mode, with the probability of both operators failing being sufficiently low to be acceptable.

It can be seen that the greatest performance reduction occurs within the out of hours failure mode. For Bristol, Dorset and Nottingham this entails the loss of all operators as well as other TMC personnel resulting in disruption to all components of system performance. Cardiff's structure means that it is constantly manned, hence while performance is reduced out of normal working hours due to the loss of additional personnel, all key functions are maintained by the lone operator on duty. Of course the occurrence of this failure mode is controlled such that it occurs during the night when traffic demand is low and the probability of scenarios occurring is reduced, hence the performance reduction is unlikely to have any significant impact on the road network. Interestingly, even when the TMCs are not in use the system does not fail completely; showing how TMCs represent only a small aspect of the entire road system with interactions between and within the road network and external environment being an important component of the domain's functionality.

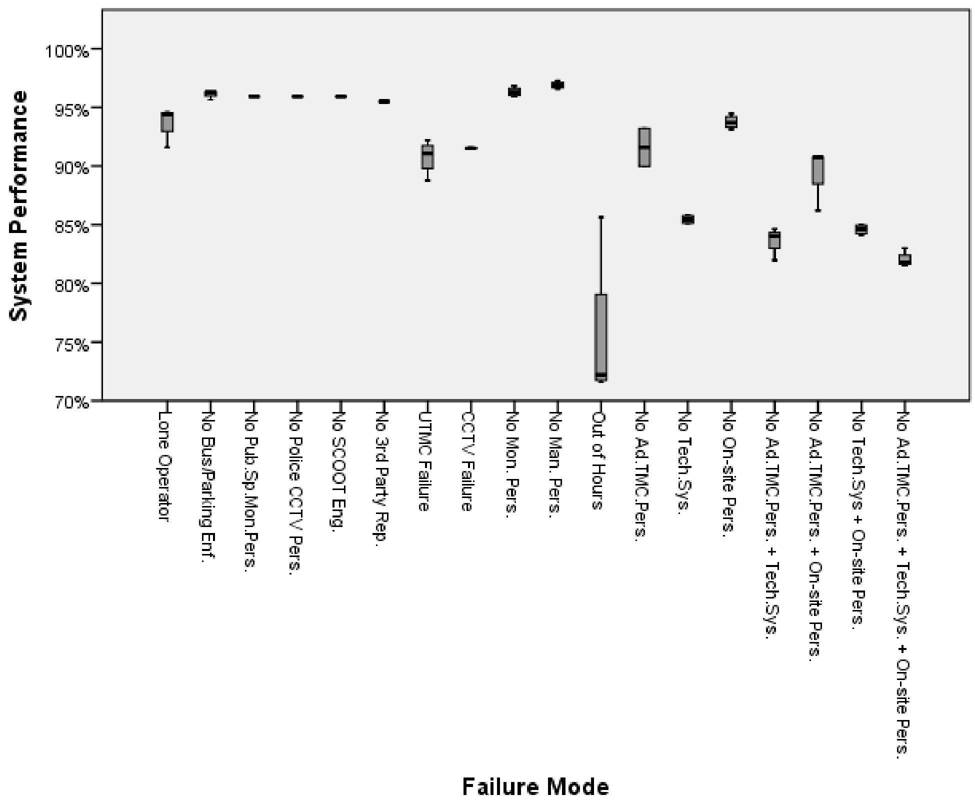


Figure 4-15: Node failure system performance by failure mode

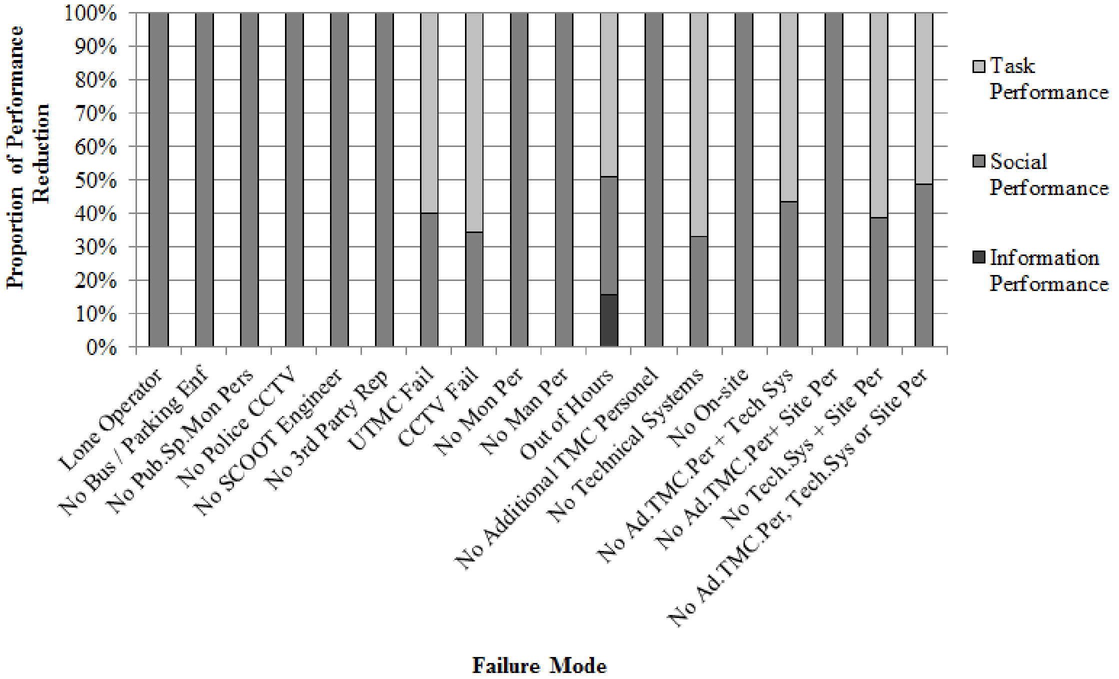


Figure 4-16: Node failure performance reduction composition

Communication Type Failures

The effects of communication type failure modes on system performance were also considered by failure level and between TMCs (Figure 4-17). By considering the average performance for each failure level it can be seen that as the number of failures increases, performance decreases, single failures ($\bar{x}$ = 92.24%, σ = 0.061) having the least impact, quadruple failures having the greatest ($\bar{x}$ = 45.26%, σ = N/A), while double ($\bar{x}$ = 86.60%, σ = 0.048) and triple ($\bar{x}$ = 65.83%, σ = 0.212) failures fall in between. The performance reductions were confirmed significant relative to the fully functioning network using a Mann-Whitney test ($n < 20$) for single ($U = 0$, $p < 0.01$), double ($U = 0$, $p < 0.01$) and triple ($U = 0$, $p < 0.01$) as well as between single and double ($U = 31$, $p < 0.01$), single and triple ($U = 2$, $p < 0.01$) and double and triple ($U = 15$, $p < 0.01$) failure levels. Statistics could not be calculated for the quadruple failure level because it only has one data point, however the performance observed was lower than the triple failure level as expected. Similarly to node failures differences between TMCs were not statistically significant.

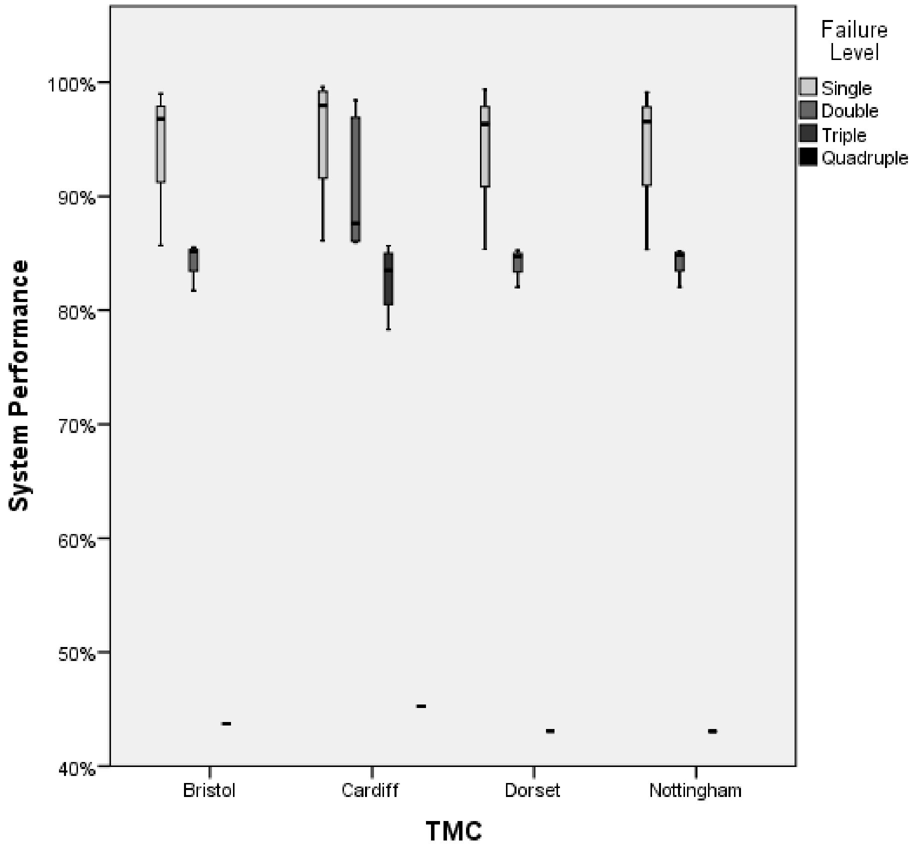


Figure 4-17: Communication type failure system performance by TMC and failure level

Performance was also considered by failure mode (Figure 4-18) with Figure 4-19 showing how performance reductions are attributed to task, social and information performance while Table 4-7 details these impacts for each failure mode in the three dimensional phase space detailed in section 4.2.3. Unlike node failures, the majority of failure modes have both social and task impacts, although with the exception of data link failures the task network is unaffected by single level failures. Information impacts were only observed in compound failure modes, the range of communication types and prevalence of links employing several types restricting these impacts.

Data link failure has the greatest impact for single failures, these communications are critical for connecting the TMC to the specialist on-street equipment, and hence their failure means operators must rely on other potentially less reliable sources. Compound failures create greater impacts on system performance, with failures of all communication types, predictably, having the greatest impact. This entails the loss of data link, online and telephone communications at Bristol, Dorset and Nottingham, with the addition of radio communications at Cardiff. The addition of this communication type reducing the impact of the most disruptive failure modes found within the other TMCs, for example online and telephone communications failure.

One potential issue is the relationship between online and telephone communications, it can be seen that combined failure produces a far greater impact than either failing individually, affecting all elements of the system. While the probability of multiple failures is far less than any individual failure, if the sub-systems are linked, as could occur in this case, failure becomes much more likely. This risk is however easily averted by physically separating the sub-systems or providing backups, for example mobile phones, which would be unaffected by a landline failure.

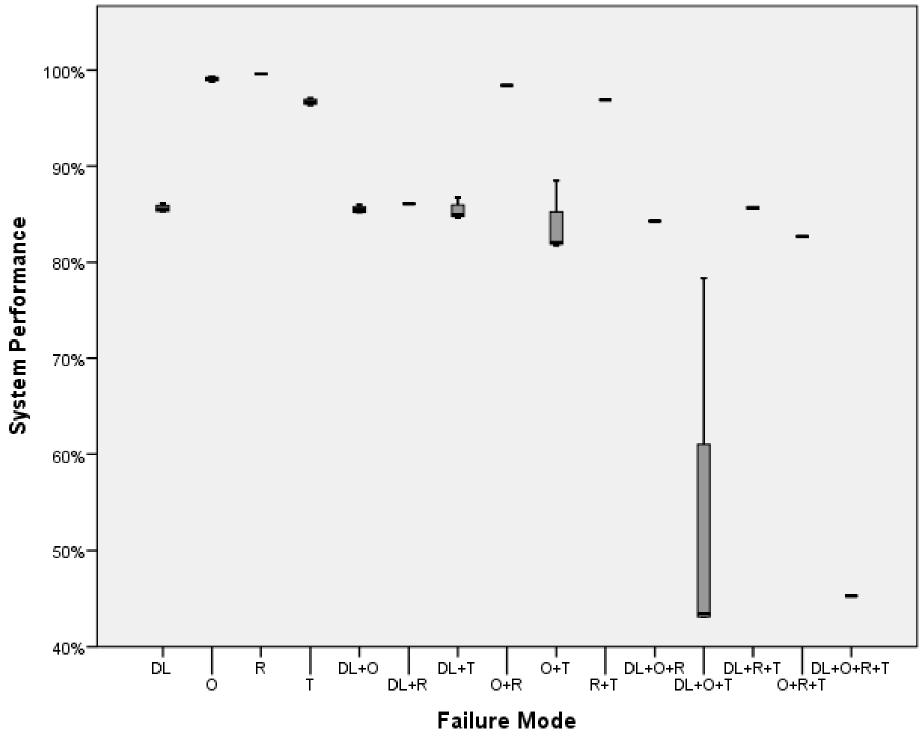


Figure 4-18: Communication type failure system performance by failure mode

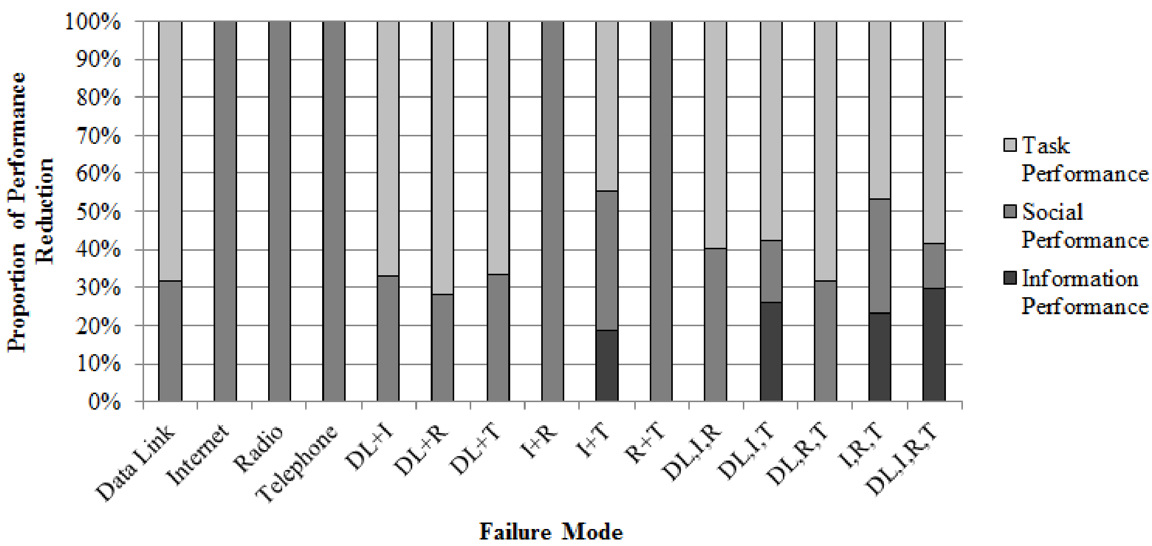
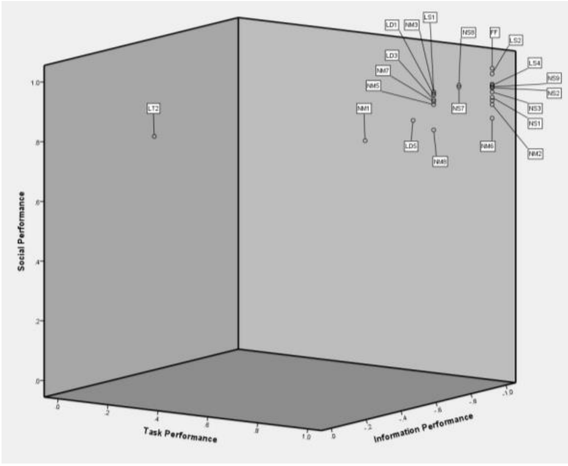
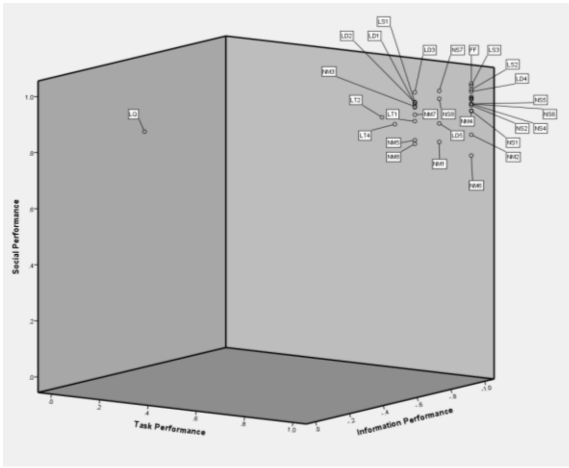
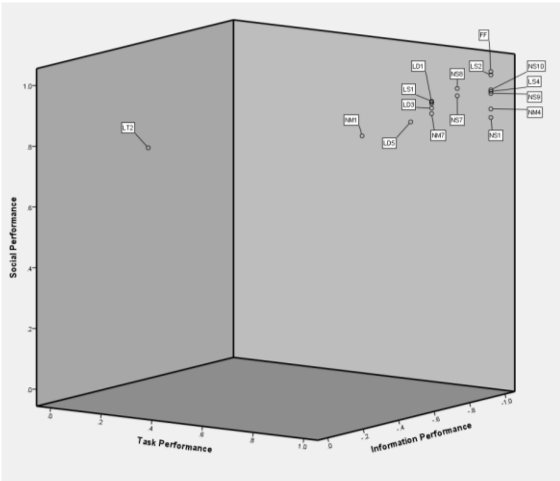
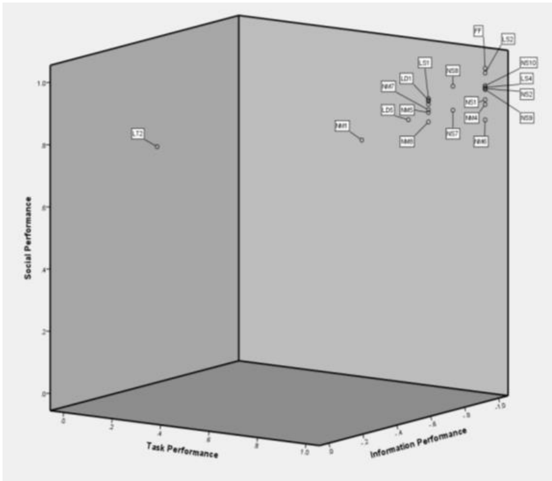


Figure 4-19: Communication type failure performance reduction composition

Table 4-7: 3D representations of failures' task, social and information impacts

Bristol	Cardiff
	
Dorset	**Nottingham**
	

4.4 Discussion

Practical application of resilience engineering requires systematic methods to assess resilience and guide system design to ensure resilient qualities. This is challenging given the emergent nature of resilience and the need to assess the effects of unexpected conditions (Hollnagel et al., 2011) . A range of qualitative methods have been utilised (e.g. ARAMIS, FRAM and STAMP) which provide insights into system behaviour under failure, however quantitative assessment has been limited despite the potential benefits, in particular the ability to compare system configurations and planned developments (Mendonca, 2008; Pasman et al., 2013) .

EAST provides a comprehensive model from which to conduct quantitative analysis using SNA metrics at an operational level. With networks based on the physical structure of the system, failure modes can be derived independently from observed events, going some way to addressing the paradox that accidents often provide the greatest insights into resilience (Cook & Woods, 2006; Woods et al., 1994). By observing failure mode's impacts the consequences for system operation can be anticipated, enabling remedial measures to be taken before operations are threatened. This is a key purpose of resilience engineering (McDonald, 2006), and critically enables measures to be based not on the probability of occurrence, but on the probability of survival, a consideration often overlooked in system design (Hollnagel & Fujita, 2013).

A consequence of resilience being an emergent phenomenon is that it is only possible to measure the potential for resilience, through performance monitoring, and not resilience itself (Hollnagel & Woods, 2006). The analysis conducted within TMCs examined system performance under each failure mode relative to the fully functioning condition, but to what extent can traffic management be considered resilient?

The fundamental requirement for resilience is that the system must be able to sustain its operations through both expected and unexpected conditions, by responding to the changing demands presented (Hale & Heijer, 2006; Hollnagel et al., 2011). For a TMC's monitoring processes to be successful operators must be able to make a decision regarding the occurrence of a scenario. The analysis has shown that it is relatively difficult to disrupt the task process, with most failure modes having limited or no impact on the task network. The reason for this is that information is distributed throughout the domain with a range of sources available to access it, hence even when failure affects a particular source others can be used by operators to maintain their situational awareness. This is an example of the system's flexibility, a characteristic thought to contribute towards resilience (Woods, 2006).

Resilient systems must also be able to absorb the impacts of failure (McDonald, 2006), with the degree of disruption able to be absorbed without a fundamental performance breakdown referred to as the system's buffering capacity (Woods, 2006). The amount of disruption which can be considered acceptable is of course subjective, however the analysis does provide an indication of which failure modes are likely to have the greatest impact on the system's operation. The lowest performance level was calculated as the out of hours node failure which is controlled and therefore not of concern. Even within this scenario the system does not fail completely, traffic management being a cognitively distributed domain which may provide it with resilient qualities (Weick & Sutcliffe, 2001). The next most disruptive conditions required relatively unlikely compound failures, with single failures having a limited impact on overall performance. Hypothetically the loss of an operator would be the most disruptive single failure; however this threat is alleviated through provision of redundancy in the form of multiple operators. The loss of technical systems would also be disruptive however the prevalence of other monitoring options would prevent catastrophic failure.

It is worth noting that the method assumes that if a task can be completed even under failure then task performance is equivalent to the fully functioning state, although impacts will be reflected within social and information networks this still represents a simplification because the task is likely to be more difficult even if it is possible. Therefore it may be that while the system appears theoretically resilient to a particular failure mode the reality may be different, to address this discrepancy further investigations into the validity of resilience predictions produced by the method are required.

4.5 Conclusions

Quantitative analysis within resilience engineering is relatively undeveloped but potentially powerful, enabling systematic assessment and comparison of existing system's strengths and weaknesses, as well as guiding the development of future systems. In this chapter it has been demonstrated how EAST can be used to model a system and develop failure modes independently from any event that may or may not have occurred in reality. Applying SNA metrics to the networks enabled quantification, describing system properties and revealing the impacts of failure on the system, which provided an indication of operational resilience.

Road TMCs were found to have resilient qualities, most failure modes having a relatively small impact on system performance, with the greatest impacts requiring complex and unlikely compound failures. This resilience can be attributed to a flexible task process, wide information distribution, an abundance of information sources and redundancy of critical agents.

Similarly to chapter 3 it is important to remember that the TMCs visited do not represent a complete cross-section of road traffic management, not incorporating very large TMCs, inter-urban control centres of TMCs from other territories. Therefore further investigations are required to identify how transferable these findings are to the wider traffic management domain and what represents idiosyncrasies of the TMCs visited. Furthermore this analysis was limited to the impacts of social (e.g. physical) failures and therefore represents assessment of only one aspect of resilience. Further insights could be gained by deriving failure modes from the task and information networks and through consideration of potential failure responses, this being a critical component of resilience engineering (Hollnagel & Fujita, 2013), in order to obtain a fuller picture of the system's resilience.

While useful insights have been produced there are several questions to be addressed before EAST can be considered a useful tool in resilience engineering. Firstly, how can the validity of the predictions be evaluated empirically? The method relies on production of possible failure modes and modelling their impacts on the domain, therefore consideration must be given to how these theoretical impacts compare to real failures. Secondly, can the insights provided be used to influence system design? The work presented served to model the traffic management domain and thus infer its resilient qualities, however to be useful the method must go beyond this theoretical evaluation to produce useable design guidance. This could be achieved by demonstrating that a system is less resilient as compared to its contemporaries or a theoretical alternative. Thirdly, can it be empirically validated that application of design guidance resulting from the method elicits improved resilience? This last question is perhaps the most important because resilience engineering can only be considered to be effective if real improvements can be demonstrated.

Chapter 5: Assessment of SCOOT Validation with PC SCOOT using Cognitive Work Analysis

5.1 Introduction

A key component of many urban road networks is the use of Split Cycle Offset Optimisation Technique (SCOOT; Hunt et al., 1981) to optimise traffic signals in order to maximise capacity and minimise delays. SCOOT considers a road network as connected nodes (junctions or pelican crossings) and links (roads) within a region, adjusting the amount of green for each link (Split), time allowed for all of a node's links (Cycle time) and the time between adjacent nodes (Offset) using real-time data from detectors and a traffic model (see Siemens, 2011). A graphical depiction of SCOOTs traffic model is shown in Figure 5-1 (Siemens, 2015). In simple terms the roads leading to a junction controlled by SCOOT are monitored by traffic detectors upstream from the junction which provides a real-time flow profile of the traffic approaching the junction. The traffic model's purpose is then to predict what happens to the traffic between the detector and leaving the junction. To do this it assumes each vehicle travels through the junction at cruising speed, potentially joins the back of a queue if the light is red which then discharges at a constant rate known as the 'saturation flow rate' once the light turns green.

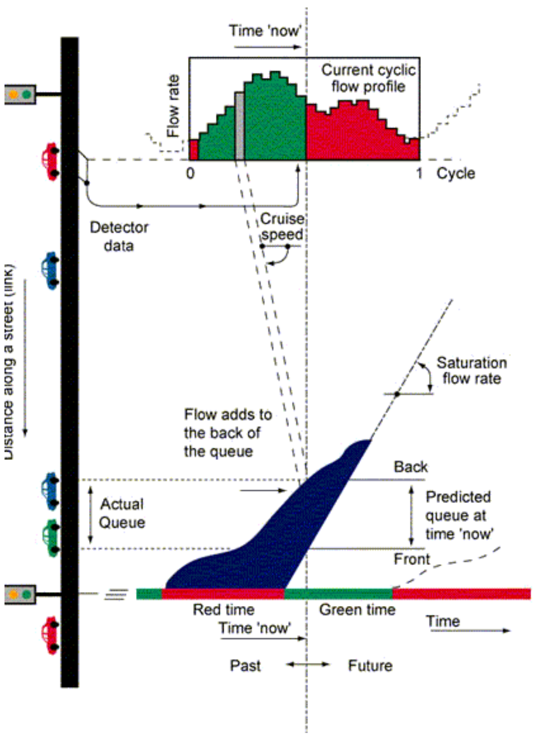


Figure 5-1: Graphical representation of SCOOT's traffic model (Siemens, 2015)

For SCOOT to operate effectively it is important that its traffic model accurately reflects on-street conditions. To achieve this SCOOT systems must be validated, giving consideration to the performance of the region as a whole, specific nodes, their component links and individual detectors. This process is conducted by human validators who are required to check each of the parameters used by SCOOT against values empirically measured on street to ensure the model is accurate.

Validation is facilitated through Siemens' Urban Traffic Control (UTC) system called PC SCOOT, which uses a predominantly text based interface to present each SCOOT parameter and enables validators to make changes as necessary. Siemens believe that PC SCOOT's current interface may inhibit performance because of its historical limitations which could be addressed using contemporary interface design techniques. To address these concerns this chapter is concerned with analysing the validation process with an aim of guiding the future development of PC SCOOT (Siemens, 2013). To constrain the analysis it was necessary to consider validation only up to node level.

Analysis of complex socio-technical systems (Walker et al., 2010) is a key concern of the ergonomics discipline with studies previously being undertaken within all transport domains including aviation (de Carvalho, Gomes, Huber, & Vidal, 2009; Harris & Stanton, 2010), road and rail (Stanton et al., 2013; Stanton & Salmon, 2011). For this domain Cognitive Work Analysis (CWA; Rasmussen, 1986) was chosen as the analysis method having been developed specifically to analyse complex socio-technical systems.

CWA enables the constraints acting upon a domain as well as the work's key features to be identified (Stanton & Bessell, 2014). Utilising a semi-structured framework guides consideration of the various constraint levels and how they affect work within the system. This addresses the challenges presented within complex socio-technical systems such as the interrelations between social and technical subsystems, interactions between potentially numerous system components and that these systems often operate within dynamic, ambiguous and often safety-critical domains (Jenkins, Stanton, Walker, & Salmon, 2009; Rasmussen, 1986; Vicente, 1999).

CWA consists of five phases, each focussing on a particular set of constraints and thus presenting a different perspective on the system, Figure 5-2 illustrates these phases including an indication of the type of constraint being analysed and the forms of representation provided. A key benefit of CWA is its flexibility and the range of domains to which it has been applied (Durugbo, 2012), however relatively few have utilised all five phases, those which have conducted a full analysis include simulated air traffic control (Kilgore, St-Cyr, & Jamieson, 2009), communications planning within military aviation (McIlroy & Stanton, 2011) and submarine operations (Stanton & Bessell, 2014).

It is worth reiterating that this point in the thesis marks the change in focus onto the second of Siemens key business challenges as illustrated in chapter 1. This change is also the justification for changing the method used. While EAST is suited to modelling the cognitive distributed traffic management domain, the challenge with SCOOT validation is to go beyond the existing system and ultimately produce tangible alternative designs. While EAST could have been used for this part of the project, CWA's formative nature and intimate link to the Ecological Interface Design (EID) technique make it more suitable for this stage of the project and the desired outcomes. This chapter therefore presents a comprehensive assessment of SCOOT validation which will be used to identify the key activities undertaken and inform selection of those areas which could be better supported by technical systems through more detailed analysis and design in chapter 6 .

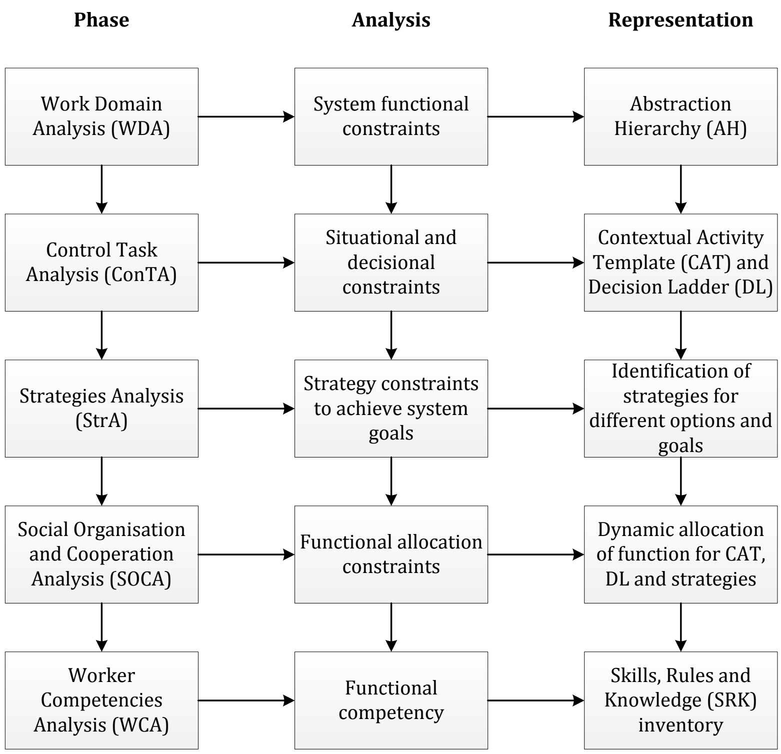


Figure 5-2: The five phases of CWA adapted from Vicente (1999)

5.2 Data Collection

The SCOOT validation process was introduced through meetings with five Subject Matter Experts (SMEs), experienced Siemens SCOOT validators, who described their experiences of the validation process. Additionally a technical demonstration of PC SCOOT was given. The CWA outputs were produced following the procedures described by Jenkins et al. (2009) and used in Jenkins, Stanton, Salmon, Walker, and Young (2008), with the aid of the Human Factors Integration Defence Technology Centre's (HFI-DTCs) CWA software tool (Jenkins et al., 2007). Each output was refined, amended and validated through subsequent meetings with SMEs. Analysis of each phase is presented over the following five sections.

5.3 Work Domain Analysis

Work Domain Analysis (WDA) is the first phase of CWA and is used to describe the system in terms of the environment in which it operates, identifying the fundamental constraints which shape the system's activities (McIlroy & Stanton, 2011). An AH (Figure 5-7) is used to describe the system at a number of levels, from its functional purpose at the top to physical objects on the bottom. Relationships between levels are specified using means-ends links (Burns & Hajdukiewicz, 2004) in what is known as the why-what-how triad, with connected nodes above a particular element describing why it exists and the nodes below how it is achieved, for example the object-related process 'depict site layout' is required to assess the site and is achieved using a node site plan.

5.3.1 Functional Purpose and Values and Priority Measures

The functional purpose of SCOOT validation is to enable SCOOT to optimise traffic flow. The values and priority measures specify how this objective can be achieved. Specifically by ensuring unbiased validation, correct detector set-up and accuracy of the SCOOT model compared to street conditions, including the parameters on which the model is based.

5.3.2 Purpose-related Functions

The central layer, purpose-related functions, are the general system functions which link the purpose-independent processes of the physical objects and the object-independent functions used to measure system performance (Stanton & Bessell, 2014). Functions are grouped according to the corresponding values and priority measures and also appear to be focused at a specific level of the SCOOT hierarchy. At node level, assessment and preparation of the site is used to prevent bias while staging validation provides accuracy of the SCOOT model. SaTuration OCcupancy (STOC) validation provides model accuracy at link level with measurement of the SCOOT parameters JourNeY Time (JNYT), Queue Clear Maximum Queue (QCMQ), Start LAG (SLAG), End LAG (ELAG) and the initial STOC estimates relating to assumption accuracy. Finally at detector level verification of association and validation of accuracy ensures correct detector setup.

5.3.3 Object-related Processes

This layer captures the affordances of the physical objects in the system, which are independent of the overall system goals (Stanton & Bessell, 2014), for example a node site plan affords the depiction of the site layout and definition of equipment locations. The full list comprises, from left to right, 'ensure stage demand', 'isolate node', 'clear node settings', 'context within region', 'depict site layout', 'define equipment location', 'detect vehicle presence', 'indicate sensitivity', 'output detector readings', 'control and reply bits', 'saturation level', 'congestion level', 'link red/green state', 'model queue', 'model queue clear time', 'STOC estimate', 'input parameters', 'define association', 'stage plan', 'traffic demand', 'assist parameter calculation', 'visual traffic detection', 'time traffic', 'vehicle storage' and 'direct traffic'.

5.3.4 Physical Objects

The system's physical objects are listed in the lowest level of the AH and consist of, from left to right…

DEMand All (DEMA) command: forces all stages to run

(X)SCOOT command: removes or reinstates a node from/to SCOOT control.

Other SCOOT commands (see Siemens, 2011)*:* can alter how SCOOT manages a node and must not bias validation.

Region diagram: specifies how nodes are connected within a SCOOT region.

Node site plan: specifies the site layout and location of equipment.

Detector: any equipment used to detect vehicle presence; common types include induction loops, radar and Bluetooth sensors.

Detector card: interfaces between detectors and node controllers, dictates detector sensitivity and provides visual confirmation of detection.

DIsplay Plan Monitor (DIPM): PC SCOOT screen used to display node's control and reply bits, plan information and used to validate staging (Figure 5-3).

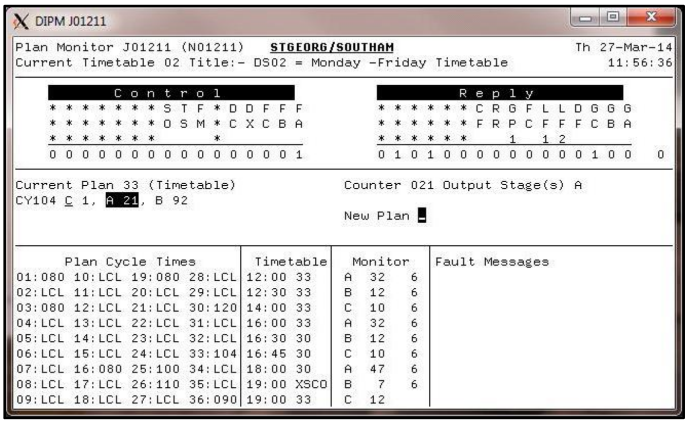


Figure 5-3: DIPM screen

MONItor (MONI) display: PC SCOOT screen which displays node's control and reply bits, used to validate staging (Figure 5-4).

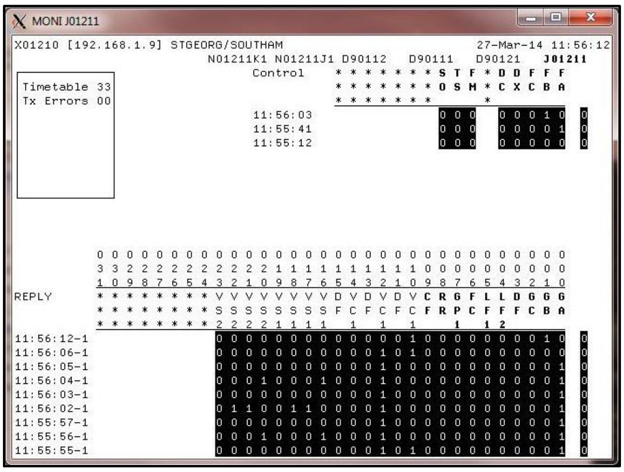


Figure 5-4: MONI screen

Node Fine Tuning Display (NFTD): PC SCOOT screen which displays information for all links in a node, used to validate at node level (Figure 5-5).

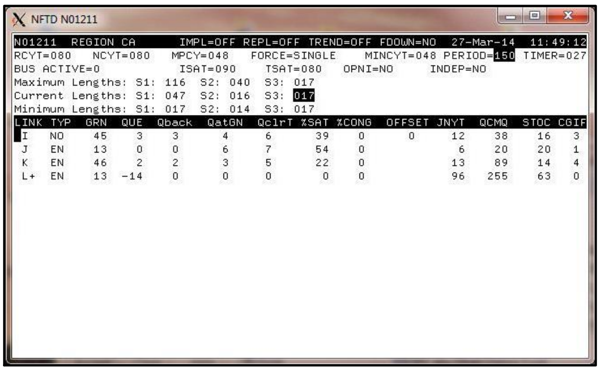


Figure 5-5: NFTD screen

Link VALidation (LVAL) display: PC SCOOT screen used to input parameters and provide the model output (Figure 5-6).

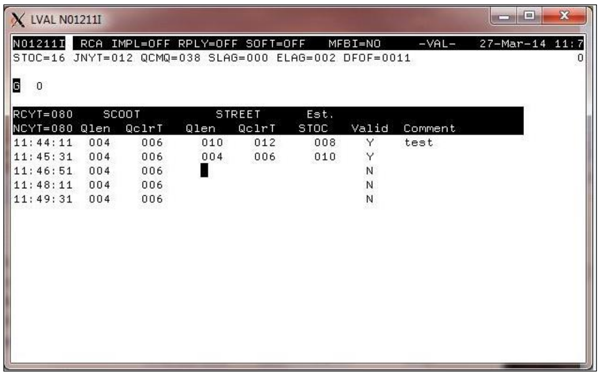


Figure 5-6: LVAL screen

TR2500: form which details traffic phase and stage operation, specifying factors including minimum green and intergreen timings, and phase maximums, extensions and delays.

SCOOT database: defines how the SCOOT system is set up including details about the region, node and link, staging and detector information. It is critical that information within the SCOOT database accurately reflects the on-street configuration.

Vehicles: provide demand for links, SCOOT aims to optimise their travel.

Stationary: used to note down and calculate parameters.

CCTV: can be used to validate a node when it is not desirable to conduct on-site validation.

Observer: monitors traffic and clear times

Stopwatch: used to time traffic for the calculation of SCOOT parameters.

Lanes: store and direct traffic.

Traffic lights: control traffic flow.

Stop line: controls traffic and is the end cue for most parameter timings.

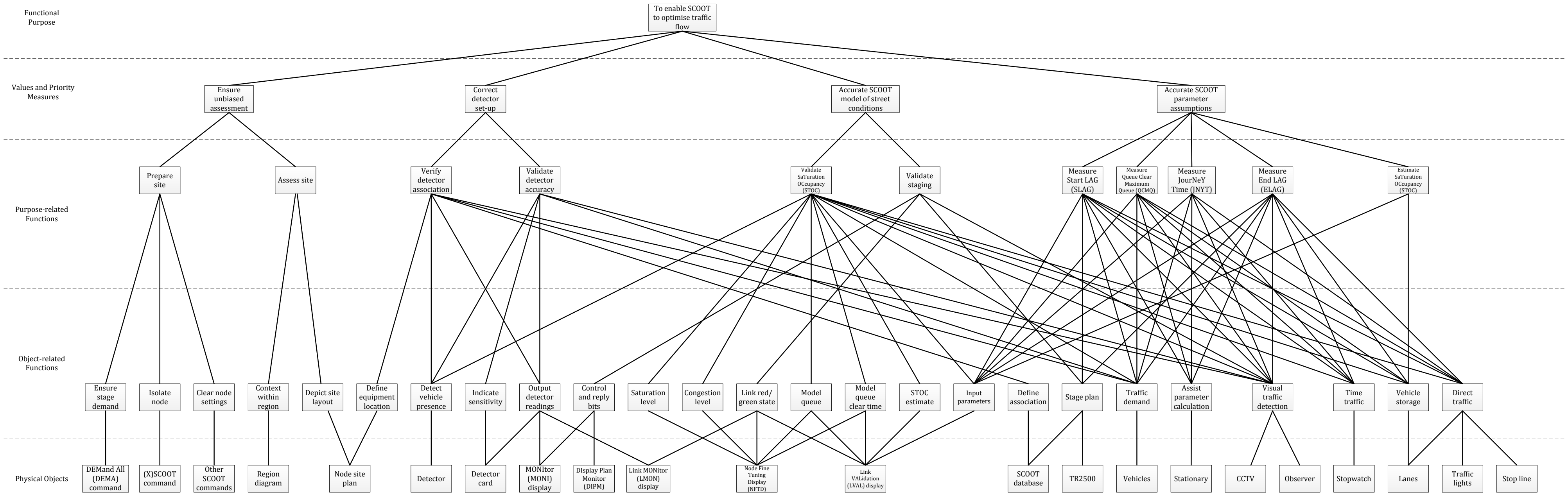


Figure 5-7: Abstraction Hierarchy

5.4 Control Task Analysis

Control Task Analysis (ConTA) is the second phase of CWA and is used to identify constraints associated with the recurring situations which can be encountered (Stanton & Bessell, 2014). A Contextual Activity Template (CAT; Figure 5-8) is used to represent the system in terms of work situations and functions. Situations can be distinguished temporally, through recurring schedules, or spatially, through differing locations. The CAT shows where functions can potentially be carried out, marked by the dotted circles, and where they are typically conducted, marked by circles and whiskers.

There are three temporal situations occurring within SCOOT validation, preparation, data collection and validation. Each can be subdivided spatially by considering activities which are undertaken from the office and on-site.

Functions were identified from the AH's purpose-related function level. Preparation functions consist of assessing the site to plan its validation and preparing it for validation by isolating the node, ensuring stage demand and clearing any disruptive settings. Each can be conducted in both spatial situations however, as most validation occurs in the field, site preparation is usually carried out on-site. Data collection includes the measurement of all SCOOT parameters and the initial STOC estimate, these activities are typically undertaken on-site, owing to the need for good situational awareness of the area, however may be office based when remotely validating via CCTV. Validation functions include verifying detector association and validating detector accuracy, STOC and staging, all of which can be conducted in either spatial condition, however where possible validators are encouraged to verify detector association and validate detector accuracy and staging from the office in order to minimise time exposed on-site, conversely the situational awareness required for STOC validation means it is recommended that this takes place on-site.

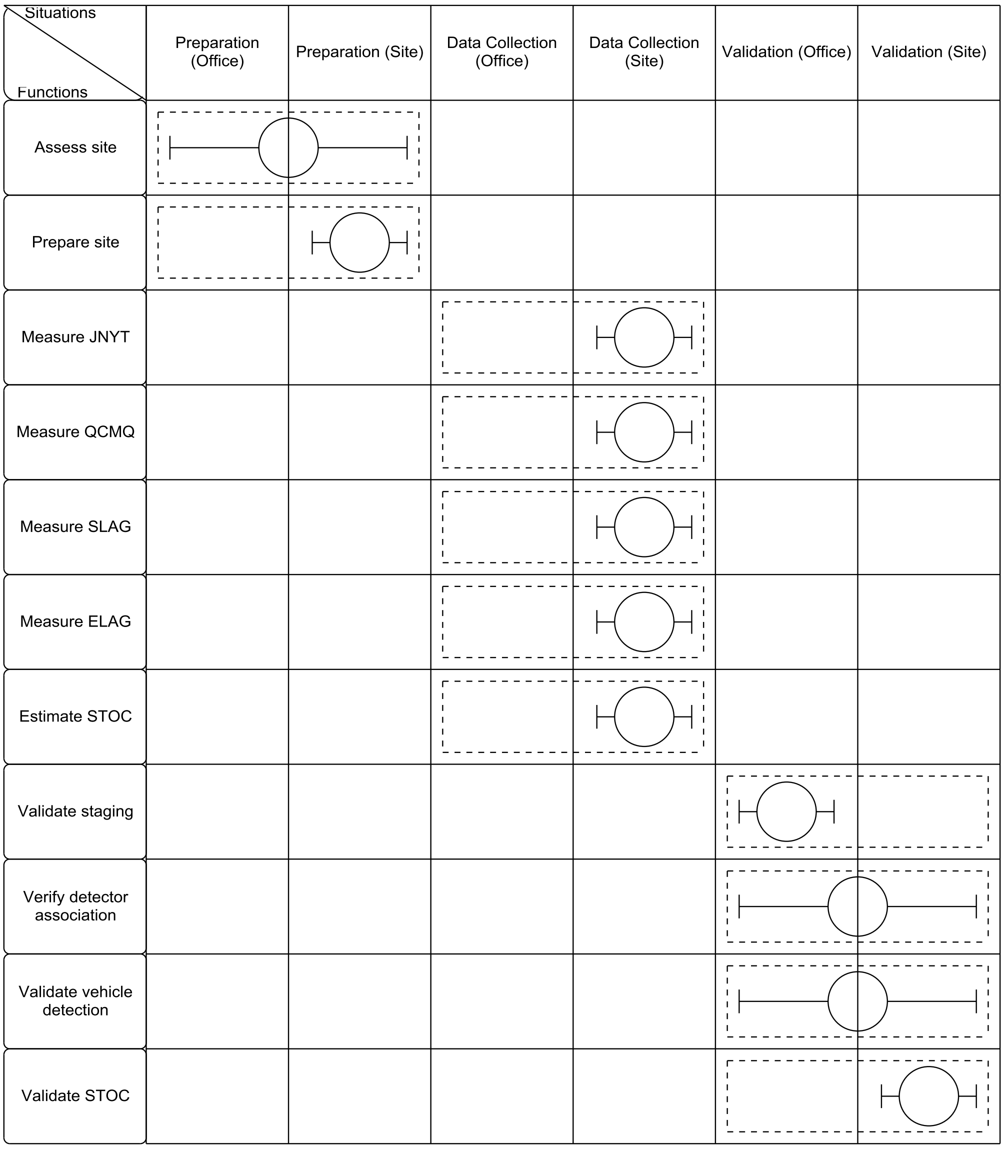


Figure 5-8: Contextual Activity Template

5.4.1 Decision-making Analysis

Decision ladders (DLs; Rasmussen, 1974; Vicente, 1999) provide further insights within ConTA by considering activity in decision-making terms (McIlroy & Stanton, 2011). Ladders are formed of two types of node, rectangular boxes represent information-processing activities and circles represent the resulting states-of-knowledge. The left side consists of observation and information gathering activities used to identify the system state, while the right side represents the planning and execution of tasks and procedures in order to achieve a target state. Linking each half are activities concerned with option selection in order to meet a desired goal (Stanton & Bessell, 2014).

The ladder considers levels of expertise and novelty of decision processes, with novice users expected to follow the ladder linearly, while experts use short-cuts to connect each half. Rule-based short-cuts can be shown in the centre of the ladder, where information observation and diagnosis of the system state can immediately signal a procedure to execute (McIlroy & Stanton, 2011). The top of the ladder represents effortful Knowledge-Based Behaviour (KBB), where goal evaluation is required to determine the executable procedure (Stanton & Bessell, 2014). Short-cuts consist of 'shunts' where an information processing activity is connected to a state of knowledge (rectangle to circle) and 'leaps' connecting two states of knowledge (circle to circle) without requiring further information processing (Jenkins et al., 2009).

A DL for SCOOT validation was produced through discussion with SMEs where validation scenarios they had encountered where described; these were developed into a prototypical DL for the activity (Figure 5-9) which shows how multiple factors influence the decisions required to determine whether validation has been completed.

The overall goal of SCOOT validation is to manipulate the SCOOT model so that local traffic objectives are achieved. Two constraints act upon this goal, to either match the SCOOT model accurately to street conditions allowing it to optimise traffic flow, or to adapt the model to account for other factors, for example to bias towards particular links. These constraints are in conflict and hence there are two goal choices.

The alert to commence validation may be directly received from a client via the validator or notification through PC SCOOT that a node is un-validated and therefore not performing optimally under SCOOT. When validation is undertaken a range of information is gathered including what stage plan is, or should be, in operation, how the detectors are, or should be, associated and what their outputs are, how traffic is actually behaving, measurement or estimation of the model parameters and information regarding local traffic objectives. This is used by the validator to judge whether the node is performing correctly, considering whether its staging and detectors (including association) are correct, whether local traffic objectives have been met and the validity of the data used by the model.

When validation is incomplete, the node not meeting its objectives, several options are available, making adjustments to the SCOOT database, on-street equipment, assumption parameters (JNYT, QCMQ, SLAG, ELAG) or STOC (see section 5.5.3). The right-hand side of the ladder is then concerned with deciding which of these options should be undertaken and how to implement them.

Several expert leaps were identified by SMEs, firstly diagnosis of certain system states or observation of particular conditions will trigger an immediate procedure or task process by experts, for example if the model's queue doesn't clear within a green inaccurately then STOC has been set too low and must be reset higher before further validation can take place. In less clear cut cases knowledge-based diagnosis of the problem may be required but once a target state has been decided upon experts will leap to the required procedure. In all cases validation is an iterative process, having to be repeated until the validator decides that the settings are optimum for the local traffic objective, judgement of this is critical within the validation process, the criteria for when a node has been effectively validated being a cause for debate.

The DL can be further assessed to establish how its elements (information, system states, tasks etc.) relate to one another, these relationships can provide an understanding of what contributes to each element and can be considered for both legs of the DL (Jenkins, Stanton, Salmon, & Walker, 2011). A relationship only means that an element 'could' influence another but not that it 'does', this is useful because it provides an insight into how information is required to determine system states and inform option selection, and how goals lead to target states and their associated tasks (Stanton & Bessell, 2014).

Considering the information and system state elements of the left leg (Table 5-1) shows how states require differing amounts of information, for example to determine correct staging requires knowledge of the planned and implemented staging, while diagnosing whether objectives have been met requires some or all of: the planned and implemented staging, detector readings, assumption parameters and knowledge of local objectives.

In addition mapping system states and options shows how there is a split between states with a single option and more complex states with multiple variables, for example if the detector is deemed to be inaccurate the only option is to adjust the on-street equipment, while when the data is deemed to be invalid a decision must be made as to whether equipment, assumption parameters or the estimated STOC must be adjusted or some combination of these.

Analysis of the right leg (Table 5-2) shows that the chosen goal has a limited impact on the target state, with only adjusting equipment settings being unsuitable for adapting the SCOOT model to account for other factors. Tasks are highly proceduralised, each being attributed to a single target state, for example when adjusting assumption parameters it is possible to change JNYT, QCMQ, SLAG or ELAG, however this will not aid in achieving any other target state.

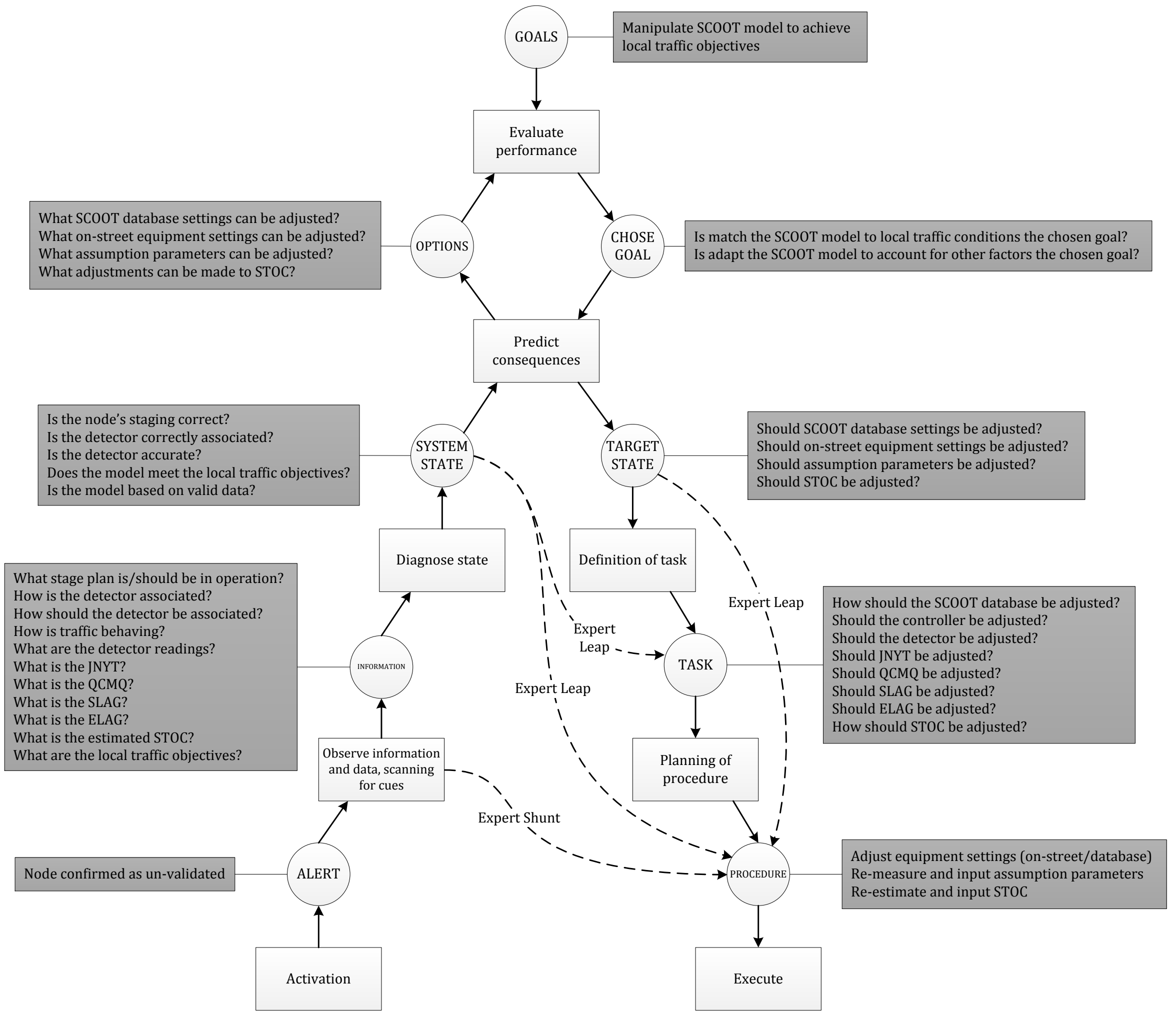


Figure 5-9: Decision Ladder

Table 5-1: Left leg of decision ladder linking system states to options and information

Options					Information										
What SCOOT database settings can be adjusted?	What on-street equipment settings can be adjusted?	What assumption parameters can be adjusted?	What adjustments can be made to STOC?	**System States**	What stage plan is/should be in operation?	How is the detector associated?	How should the detector be associated?	How is traffic behaving?	What are the detector readings?	What is the JNYT?	What is the QCMQ?	What is the SLAG?	What is the ELAG?	What is the estimated STOC?	What are the local traffic objectives?
■				Is the node's staging correct?	■										
■	■			Is the detector correctly associated?		■	■	■	■						
	■			Is the detector accurate?				■	■						
■	■	■	■	Does the model meet the local traffic objectives?	■			■	■	■	■	■	■	■	■
	■	■	■	Is the model based on valid data?				■	■	■	■	■	■	■	

Table 5-2: Right leg of decision ladder, linking target states to chosen goal and tasks

Chosen Goal			**Tasks**							
Is match the SCOOT model to local traffic conditions the chosen goal?	Is adapt the SCOOT model to account for other factors the chosen goal?	**Target States**	How should the SCOOT database be adjusted?	Should the controller be adjusted?	Should the detector be adjusted?	Should JNYT be adjusted?	Should QCMQ be adjusted?	Should SLAG be adjusted?	Should ELAG be adjusted?	How should STOC be adjusted?
■	■	Should SCOOT database settings be adjusted?	■							
■		Should on-street equipment settings be adjusted?		■	■					
■	■	Should assumption parameters be adjusted?				■	■	■	■	
■	■	Should STOC be adjusted?								■

5.5 Strategies Analysis

Strategies Analysis (StrA) is CWA's third phase and identifies how the system activities identified in ConTA are conducted (McIlroy & Stanton, 2011). StrA is used to describe all of the possible ways to complete an activity, recognising that there are often multiple ways to achieve an objective with choices being variable both between and within agents (Stanton & Bessell, 2014), depending on context. Alternative strategies can be effectively presented using flow diagrams (Ahlstrom, 2005) to show the potential action sequences linking a start and end state. Strategy flowcharts have been developed for each of the functions identified within the ConTA's CAT.

5.5.1 Site Assessment

Before validation commences the site must be assessed, the strategy to achieve this is shown in Figure 5-10. Consideration is given to the site's layout particularly where to park and conduct observations while remaining safe and not biasing the validation process. The site's context within the region is also considered in order to establish the factors which may affect validation and to plan the overall process.

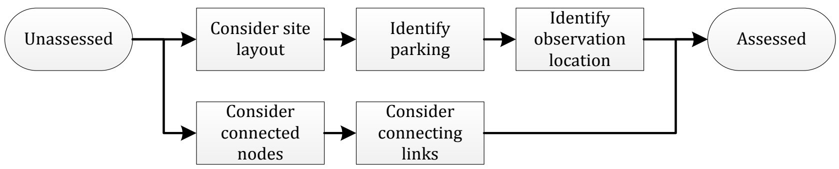


Figure 5-10: Site assessment strategy

5.5.2 Site Preparation

To prevent bias each validation site must be prepared, the strategy to achieve this is shown in Figure 5-11. Node's settings can be accessed through PC SCOOT. Before validation all stages must be called, the node must be isolated from SCOOT and any other settings should be set to default, each of which is achieved individually and hence potentially inefficiently, with the appropriate PC SCOOT commands.

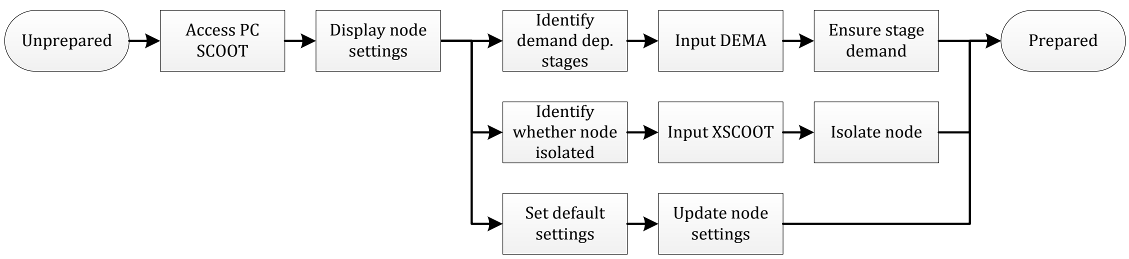


Figure 5-11: Site preparation strategy

5.5.3 Parameter Measurement

The SCOOT model is based on several parameters (see Siemens, 2011) each being measured as follows.

JourNeY Time (JNYT): Time for a free-flowing vehicle in the centre of a platoon to travel from the detector to the stop line. This determines when the model believes a vehicle arrives at the stop line.

Queue Clear Maximum Queue (QCMQ): Time for a full queue to clear, determining how quickly a queue can be cleared. This can be measured for short links however longer links must be estimated based on the time for a known number of vehicles to clear using equation 5-1, where L is the link's length (m), Q is the queue clear time for a known number of vehicles (x). For very long links where a full queue cannot discharge fully this may produce an overestimate which must be multiplied by equation 5-2, where "cycle time" is the node's largest likely cycle time and "green time" is the corresponding average green time given to the link, to get a fair value.

Equation 5-1: $QCMQ = \frac{L*Q}{6x}$

Equation 5-2: $\frac{cycle\ time}{cycle\ time+green\ time}$

Start LAG (SLAG): Time from a SCOOT stage starting (usually indicated by the previous phase losing right of way) to vehicles crossing the stop line and accounting for intergreen time and area start lag, acts as a timer for calculating when a queue will begin to discharge.

End LAG (ELAG): Time from a SCOOT stage ending to traffic ceasing to cross stop-line and accounting for area end lag, acts as a timer for calculating when traffic ceases to discharge.

Measurement of each parameter follows the strategy illustrated in Figure 5-12 both when conducted on-site and via CCTV. In each case the start and end cue for measurement is identified and the appropriate timing is conducted, the validator must then judge whether the measurement is valid (e.g. if a car stalled it is not representative) and average as many valid results as necessary to gain a fair representation of the parameter. LVAL in validation mode (1 in Figure 5-12) is then used to input each parameter (2 in Figure 5-12) and automatically updates the SCOOT model accordingly. The most complex task is identifying start cues for the measurement of SLAG and ELAG because of their variability and the impact caused by phase delays, with the required diagnosis information not readily available within the system.

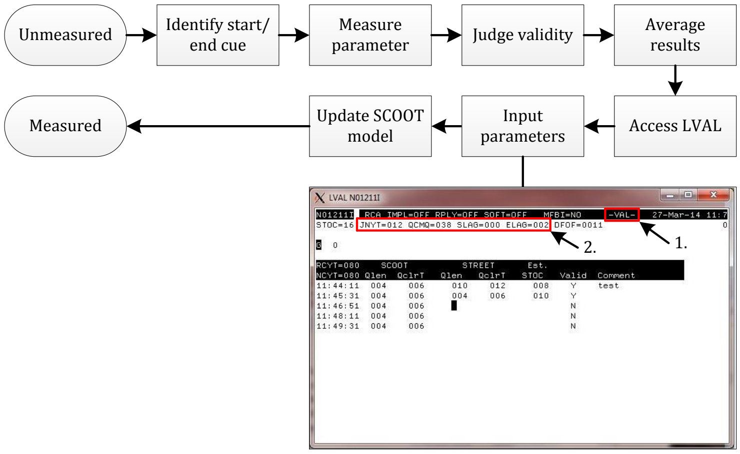


Figure 5-12: Parameter measurement strategy

5.5.4 STOC Estimation

STOC is simply a link's discharge rate measured in link profile units (see Siemens, 2011) per second (lpu/sec), hence as STOC increases so does the number of vehicles discharged. Before validation can commence an initial STOC value must be estimated by the validator and input into the system, the strategy to achieve this is shown in Figure 5-13. The estimation is usually based on the number of lanes a link has, the validator will then adjust this value based on the site's context, accounting for whether there is a positive or negative gradient, the local environment (e.g. schools, crossings) and local traffic behaviours (e.g. are lanes used equally). LVAL in validation mode (1 in Figure 5-13) is then used to input the desired STOC value (2 in Figure 5-13), which then automatically updates the SCOOT model.

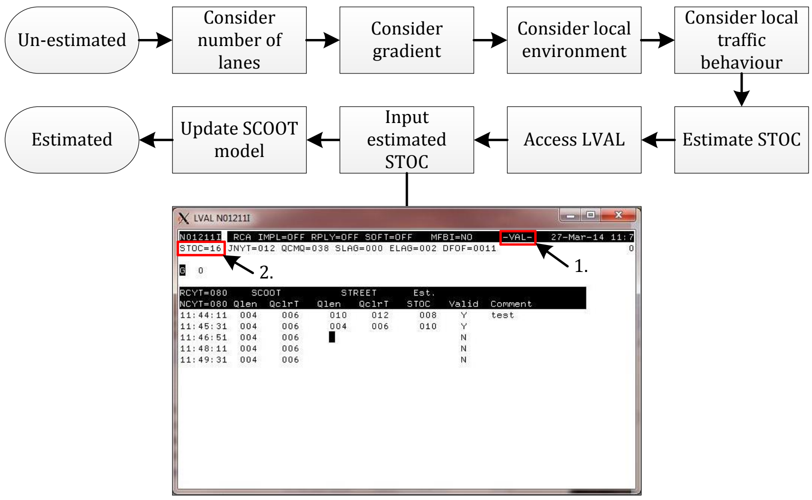


Figure 5-13: STOC estimation strategy

5.5.5 Staging Validation

Staging validation is carried out to ensure that the implemented stages match those planned and hence the junction operates as designed, the strategies to achieve this are shown in Figure 5-14. The validator must first identify the designed stage plan from the SCOOT database or TR2500 form, either by cross checking the control and reply bits with phase movements, or through a stage diagram. There are then three potential strategies for stage validation. Firstly, the traffic signals can be observed and compared to the plan. Secondly, the NFTD screen can be used to display when each link is green (1 in Figure 5-14) and compared to the plan, this is useful when it is not possible or easy to observe all traffic signals. Thirdly, the control and reply bits in operation can be displayed on either DIPM (2 and 3 in Figure 5-14) or MONI (4 and 5 in Figure 5-14) and compared to the plan.

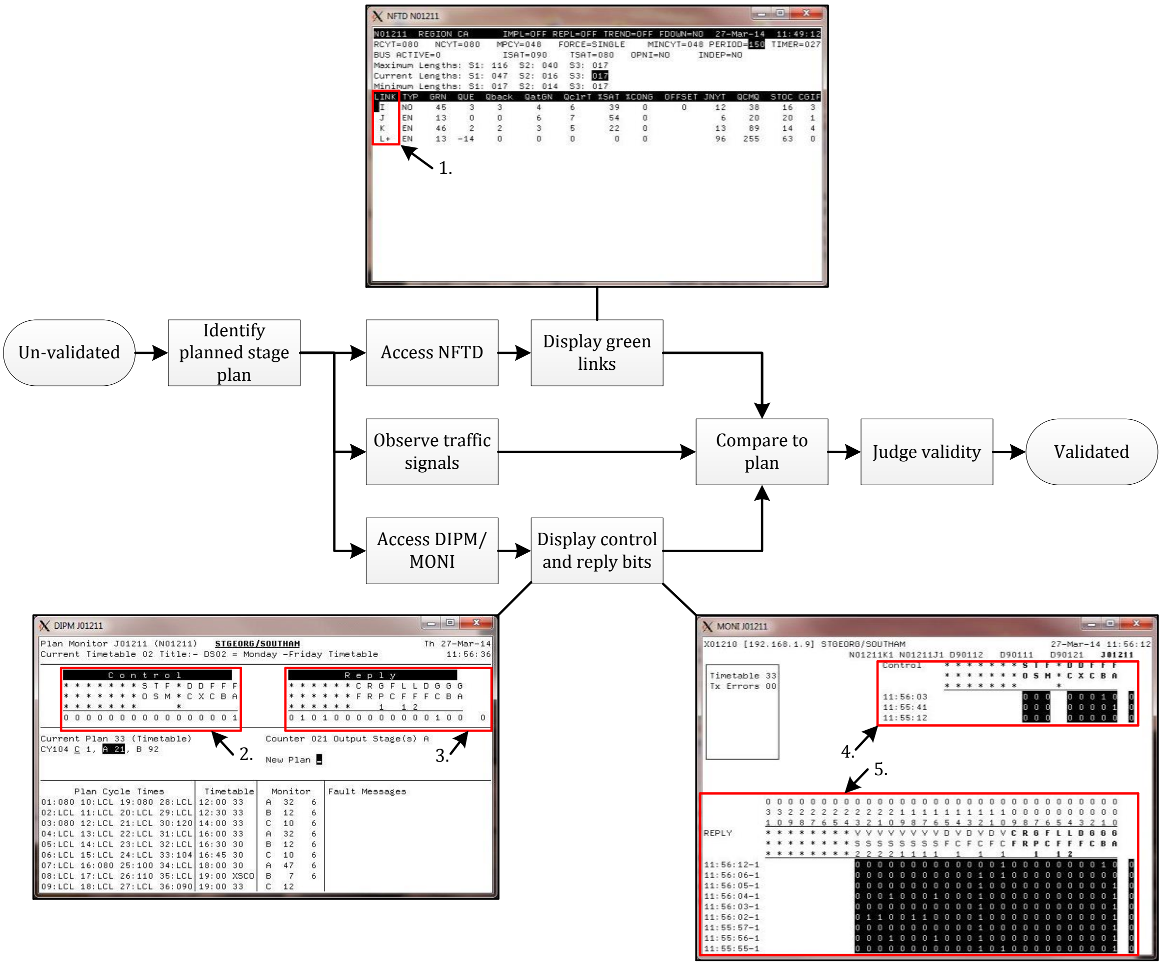


Figure 5-14: Staging validation strategies

5.5.6 Detector Association Verification

Detector association verification is conducted to check that links are monitored by the correct detector; the strategy for achieving this is illustrated in Figure 5-15. First the desired detector must be physically located on-site and its intended association must be identified from the SCOOT database. The detection output is then monitored using LMON and compared to the expected traffic flow based on observation. LMON provides a binary output (1 in Figure 5-15) of when the detector is active. If detection matches the observed flow the detector is likely correctly associated. A potential issue is when traffic flow is similar across multiple detectors, leading to potential errors.

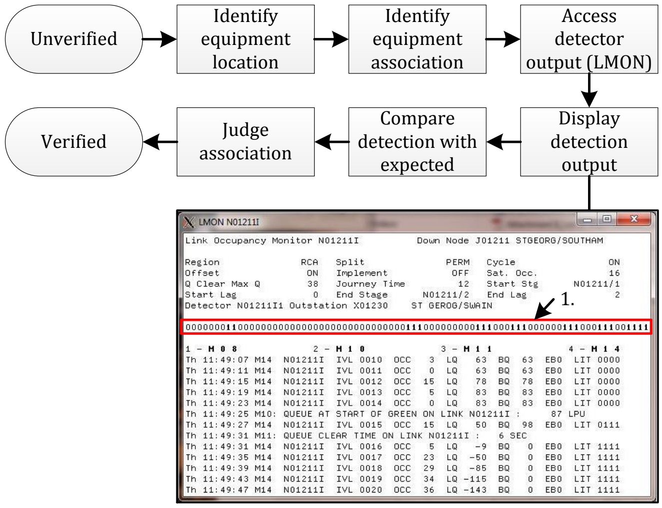


Figure 5-15: Detector association strategy

5.5.7 Vehicle Detection Validation

Detectors must be validated to ensure that detection is accurate; the strategies to achieve this are shown in Figure 5-16. In all cases the detector's sensitivity settings must be checked in the controller cabinet, ensuring detection is phased out after the appropriate amount of time. There are then three options for completing validation. Firstly, LMON can be used to display a binary output (1 in Figure 5-16) of when the detector is active in ¼ second pulses, similarly to association verification this output is compared to observed traffic flow however in this case the degree of detection per vehicle must be considered, typically ¾ second representing a single car. Secondly, LMON also outputs M14 messages (2 in Figure 5-16) every four seconds which specify queue length in lpu. This value must be converted by the validator into vehicles and compared with the observed queue. Thirdly, NFTD can be used to display queue, saturation and congestion levels for each link in a node (3 in Figure 5-16), these figures can be compared by the validator to the observed conditions. Congestion is calculated based on the proportion of time a detector is activated in relation to the cycle time, saturation is the ration of demand to the discharge rate (STOC) for the duration of effective green time (Siemens, 2011). Multiple strategies may be employed when one is not sufficient to validate accuracy.

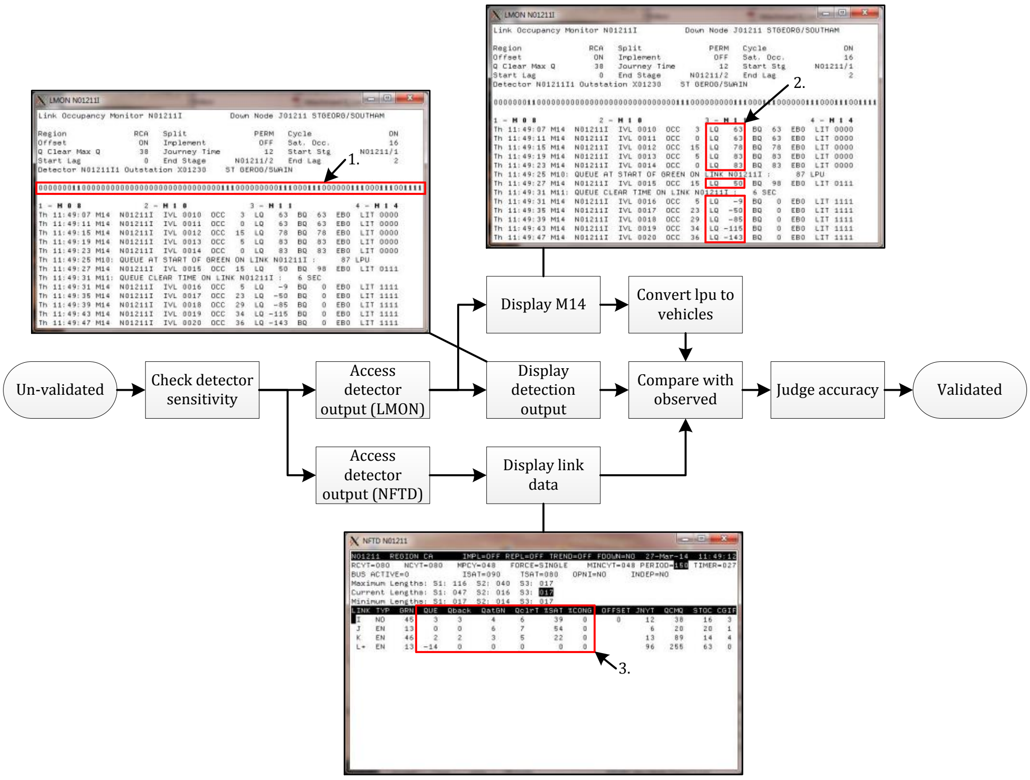


Figure 5-16: Vehicle detection validation strategies

5.5.8 STOC Validation

The STOC validation process is illustrated in Figure 5-17. This function makes extensive use of LVAL in validation mode (1 in Figure 5-17), validators must first measure queue length and clear time for a number of cycles inputting these parameters into LVAL (2 in Figure 5-17). LVAL also displays the modelled queue length and clear time based on the assumption parameters (3 in Figure 5-17) as well as a graphical depiction of the queue length (4 in Figure 5-17) The validator must then judge whether the iteration was valid (5 in Figure 5-17) and whether STOC has converged to the correct amount by comparing the modelled and observed data, if not STOC is adjusted based on the validator's intuition or by using an automated estimate produced by PC SCOOT (6 in Figure 5-17) utilising equation 5-3, through LVAL (7 in Figure 5-17) and the model is updated for the next iteration.

Equation 5-3: $New\ STOC = \frac{sum\ of\ valid\ street\ queue\ clear\ times}{sum\ of\ valid\ model\ queue\ clear\ times} * Old\ STOC$

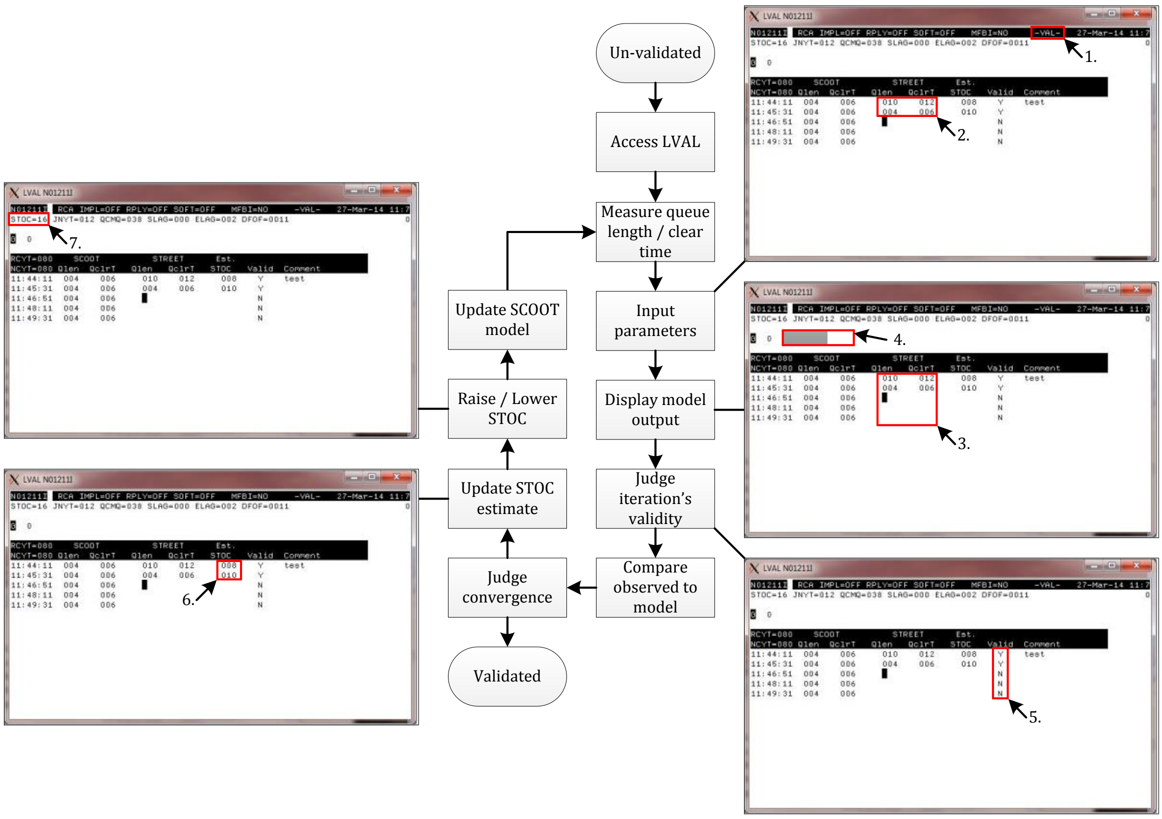


Figure 5-17: STOC validation strategy

5.6 Social Organisation and Cooperation Analysis

CWA's fourth phase Social Organisation and Cooperation Analysis (SOCA) investigates the cooperation between actors within a system, addressing the constraints imposed by organisational structures or specific actor roles and definitions (McIlroy & Stanton, 2011). SOCA can be used to determine how the social and technical elements of a socio-technical system can work together to enhance performance and supports the development of flexible systems with dynamic function allocation, whereby the situation dictates agents' roles (Stanton & Bessell, 2014).

SOCA is achieved by colour coding the previous phase's outputs according to potential agent roles. Two agents are utilised within SCOOT validation the human validator and the technical system PC SCOOT. Colour-coding (Table 5-3) has been applied to the CAT and DL from ConTA and each strategy flow chart from StrA to show how these agents are utilised.

Table 5-3: Colour coding for the key roles analysed in SOCA

	Validator
	PC SCOOT

5.6.1 Contextual Activity Template

From Figure 5-18 it can be seen that the majority of functions involve both the validator and PC SCOOT regardless of the situation, with the exception of site assessment which can only be carried out by the validator. On-site access to PC SCOOT through a remote terminal is clearly highly beneficial throughout the validation process.

5.6.2 Decision Ladder

The DL can also be used in SOCA with the information processing activities (boxes) and the resultant states of knowledge (circles) being colour coded by social agent (Figure 5-19). It is clear that the majority of decision-making within SCOOT validation is performed by the validator, in particular the high level activities such as goal evaluation, system state diagnosis and target state definition.

Use of PC SCOOT is predominantly focused on the ladder's left leg, able to provide much of the information required to validate as well as potentially acting as the alert to begin validation based on information in the SCOOT database. PC SCOOT's congestion supervisor tool has a limited capacity to diagnose node's performance and suggest potential problems including with assumption parameters or STOC values. In addition PC SCOOT is capable of estimating how STOC should be adjusted, this represents the only use of PC SCOOT on the ladder's right leg. The reason for this is that the majority of task options can be highly site specific, for which the intelligence of the current system is not sufficient to replace the human validator.

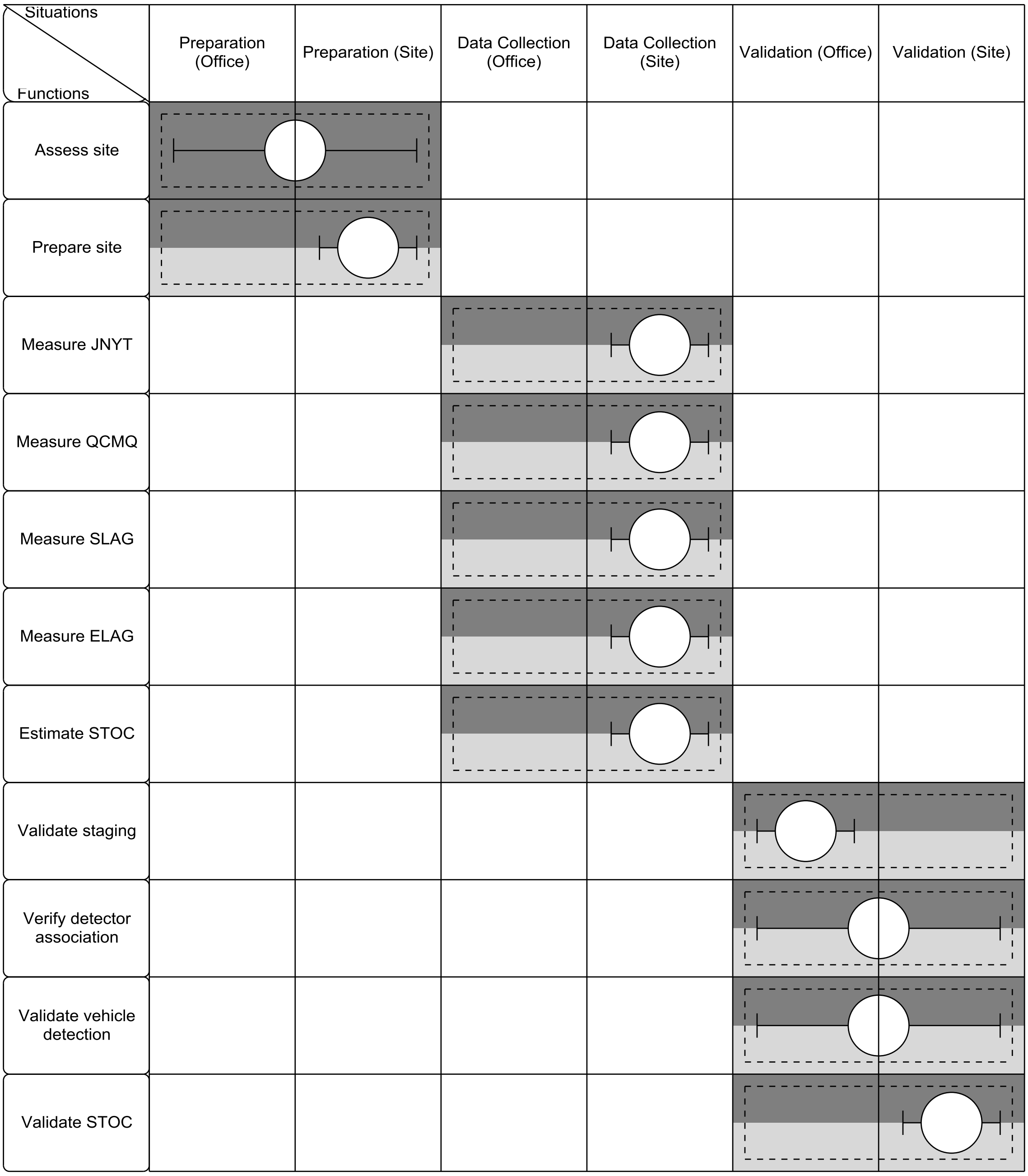


Figure 5-18: SOCA-CAT

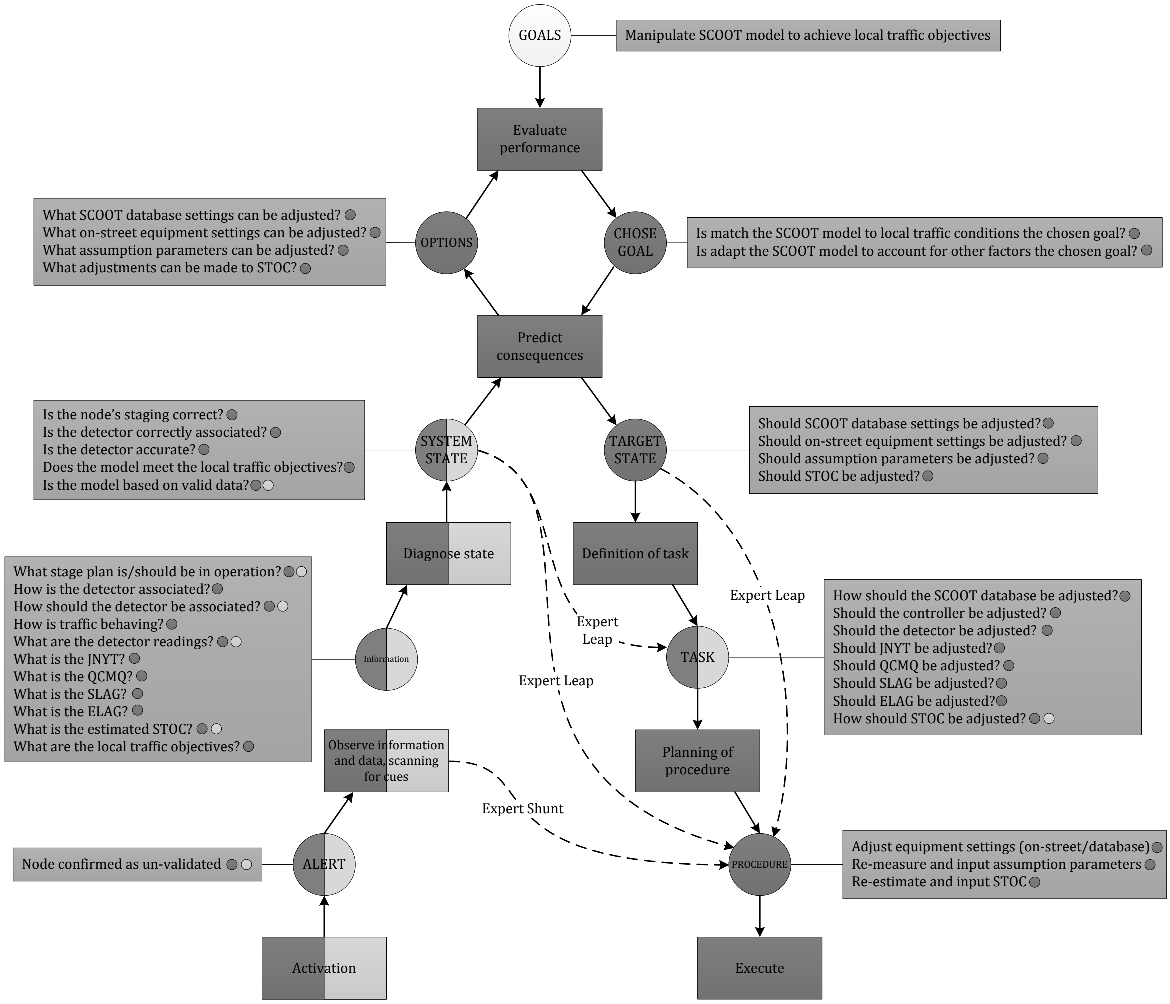


Figure 5-19: SOCA-DL

5.6.3 Strategy Flowcharts

Finally by considering the flowcharts produced in StrA it is possible to identify how agents are utilised in each function strategy.

5.6.3.1 Site Assessment

Site assessment (Figure 5-20) is exclusively conducted by the validator, technical systems not being intelligent enough to perform this function.

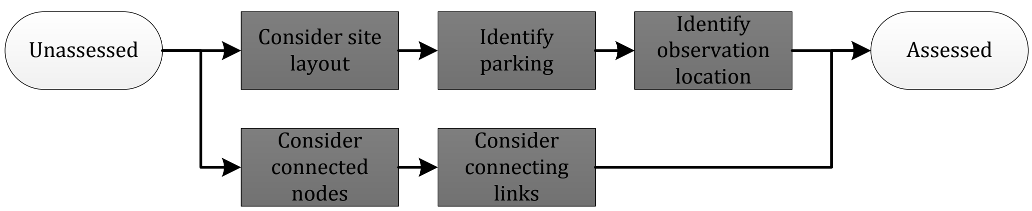


Figure 5-20: Site assessment SOCA strategy

5.6.3.2 Site Preparation

The site preparation process (Figure 5-21) utilises PC SCOOT to provide required information and implement changes to the node. Decision's regarding how settings must be adjusted to prevent bias remain the validator's concern.

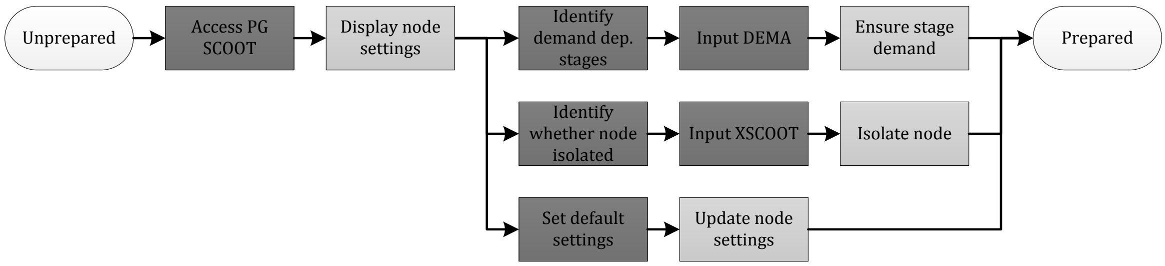


Figure 5-21: Site preparation SOCA strategy

5.6.3.3 Parameter Measurement

Figure 5-22 shows how parameter measurement is performed almost exclusively by the validator. PC SCOOT provides a mechanism to input the measured parameters into the system through the LVAL screen and hence update the SCOOT model, accurate measurement is entirely dependent on the skill and training of the validator.

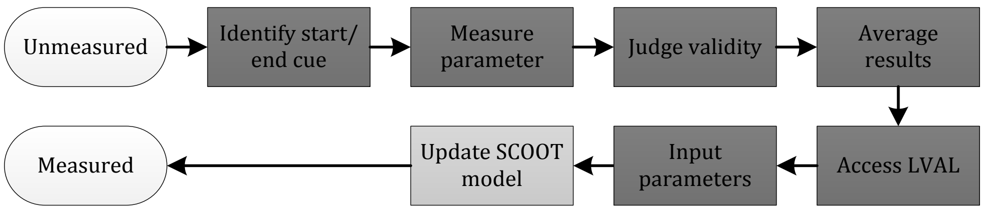


Figure 5-22: Parameter measurement SOCA strategy

5.6.3.4 STOC Estimation

Figure 5-23 shows how consideration of the factors impacting STOC is carried out by the validator, who either estimates STOC directly or makes use of PC SCOOT's wizard, which can be useful for novices. Once estimated STOC is input similarly to the other validation parameters through LVAL and PC SCOOT updates the model accordingly.

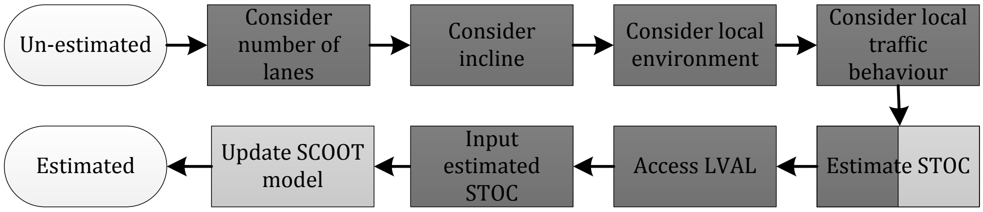


Figure 5-23: STOC estimate SOCA strategy

5.6.3.5 Staging Validation

In the current system the required plan information is held outside of the technical system leading to potential inefficiencies. PC SCOOT is involved in two of the three strategies for validating staging (Figure 5-24), with the NFTD screen displaying which links are green, while the DIPM and MONI screens display the control and reply bits in operation, in both cases the comparison with the plan is conducted by the validator who ultimately judges whether the observed staging matches the plan. Similarly to other functions PC SCOOT is used simply to provide information to the validator.

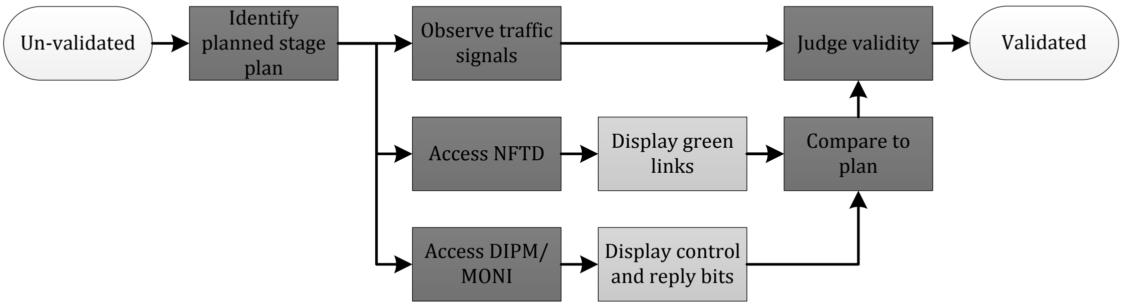


Figure 5-24: Staging validation SOCA strategies

5.6.3.6 Detector Association Verification

For verifying detector association (Figure 5-25) PC SCOOT displays the detector's outputs through the LMON screen, the validator is responsible for identifying the correct set-up and judging whether this has been achieved through comparison of detection and expected traffic conditions.

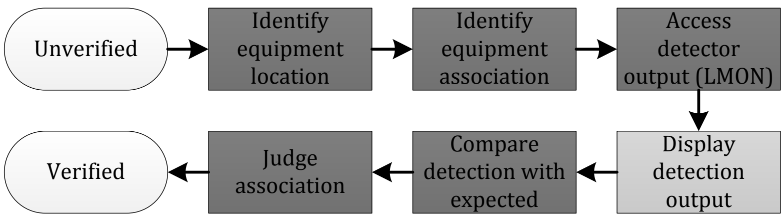


Figure 5-25: Detector association verification SOCA strategy

5.6.3.7 Vehicle Detection Validation

Similarly to association verification, for vehicle detection validation PC SCOOT is used to display the detector's output (Figure 5-26), whether through the LMON or NFTD screens. The task of comparing detection with the observed traffic, including any necessary conversions (lpu to vehicles) is then carried out by the validator who judges the detector's accuracy accordingly.

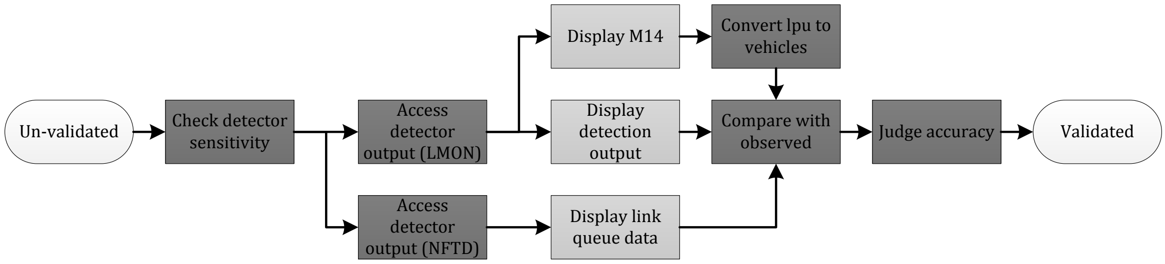


Figure 5-26: Vehicle detection validation SOCA strategies

5.6.3.8 STOC Validation

For STOC validation PC SCOOT performs three functions (Figure 5-27). Firstly, it displays the model queue and clear time output through LVAL. Secondly, it can provide an estimate for what STOC should be, based on equation 5-3, if the validator decides not to estimate directly. PC SCOOT is also able to calculate multiple queue clear times based on a range of STOC values to assist the operator. Thirdly, LVAL is used to update the SCOOT model whenever the STOC value is changed. All other tasks are performed by the validator.

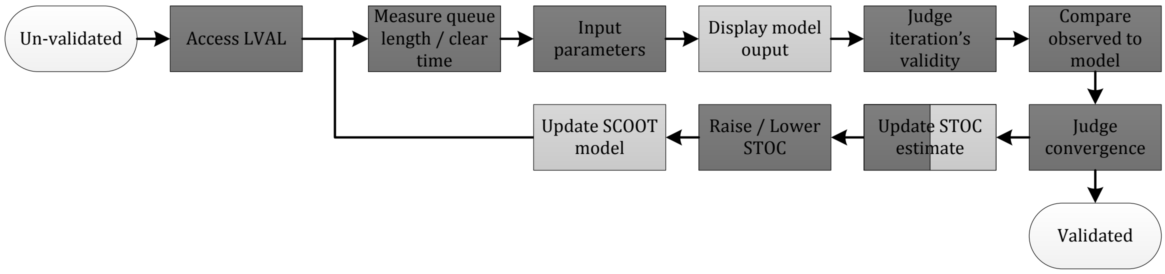


Figure 5-27: STOC validation SOCA strategy

5.7 Worker Competencies Analysis

Worker Competencies Analysis (WCA) is the final CWA phase and addresses the constraints of agent skill within different functions, investigating the behaviour required by both humans and automation through application of Rasmussen's (1985)

Skills, Rules and Knowledge (SRK) Taxonomy (Stanton & Bessell, 2014). WCA was originally based on the information processing steps taken from the DL, however several recent examples (McIlroy & Stanton, 2011; Stanton & Bessell, 2014) instead base the analysis on the CAT in order to be consistent with CWA's functional outputs.

The SRK framework describes three levels of cognition, described most recently within the context of CWA by Stanton and Bessell (2014), Skill-Based Behaviour (SBB) consists of automated actions in response to environmental cues and events, and requires little or no conscious effort, this behaviour is acquired through practice and is usually found within experts. Rule-Based Behaviour (RBB) utilises stored rules and procedures acquired through experience or learned from other agents which guide behaviour but require cognitive processing. Knowledge-Based Behaviour (KBB) is used when advanced reasoning is required, commonly during novel and unanticipated events, it is characterised as slow and effortful, requiring conscious attention to the system's governing principles.

The WCA analysis is presented as a SRK inventory (Table 5-4) showing the SBB, RBB and KBB which applies to each function. The inventory can be formed through interrogation of WDA's AH and hence requirements can be determined even with no existing interface. To maximise performance it is important that each of these behaviours is supported for each function (Kilgore & St-Cyr, 2006), ensuring that both novice and expert behaviour is accommodated (Rasmussen, 1983). The inventory can also inform function allocation, through description of the required behaviours for each function with suitability for automated or human allocation identified.

SBB in all functions is centred around the validator performing the function intuitively based on their knowledge and experience of the domain, for example an initial estimate for each parameter is made based on assessment of local conditions and then adjusted, rather than individually measured. RBB is accommodated extensively within PC SCOOT, the proceduralised nature of the domain enabling relatively simple logic rules to be developed for each function. KBB is focused on understanding how each model factor can impact on the traffic and vice versa.

PC SCOOT's screens are relatively rigid; having been developed around the domain's proceduralised tasks. While these interfaces may support RBB well there is a lack of support for both KBB and SBB, which could impede performance especially in more complex scenarios. Development of PC SCOOT should ensure all three behaviours are supported across all functions to improve validator's performance at varied skill and experience levels. This could be achieved through application of EID (Burns & Hajdukiewicz, 2004; Vicente & Rasmussen, 1992) for each function. EID having been shown to provide performance improvements in other domains (e.g. Lau, Jamieson, Skraaning, & Burns, 2008; Lau, Veland, et al., 2008).

Table 5-4: SRK inventory for SCOOT validation

Function	Skill-Based Behaviour	Rule-Based Behaviour	Knowledge-Based Behaviour
Assess site	Ensure validation is undertaken at the correct time(s) of day, minimises disruption/bias and is undertaken safely	IF traffic levels vary over the day THEN identify when validation must take place IF validation is undertaken on-site THEN ensure personnel are safe and do not bias traffic	Understand the need for and how to achieve unbiased and accurate validation as well as the potential dangers of on-site validation and how to manage them
Prepare site	Ensure the node being validated is removed from SCOOT control, demand is provided for all stages and settings for the node and any connections do not bias the process.	IF the node is under SCOOT control THEN place it under local control IF any links are demand dependent THEN ensure demand IF any node settings could introduce bias THEN set to default IF node is within a region THEN ensure other node/link's settings do not bias validation	Understand the factors which may cause validation to be biased and how to correct for them
Measure JNYT	Intuitively estimate JNYT based on road geometry, local environment and traffic behaviour	IF the platoon is free-flowing THEN time a central vehicle between the detector and stop-line IF the result is not representative THEN discard REPEAT UNTIL sufficient valid results have been obtained, covering a range of vehicle types and take the mean as JNYT	Understand that JNYT is used to determine vehicle arrival at the stop-line by the SCOOT model, the factors which may influence vehicle's behaviour and change's impacts on the SCOOT model

Function	Skill-Based Behaviour	Rule-Based Behaviour	Knowledge-Based Behaviour
Measure QCMQ	Intuitively estimate QCMQ based on road geometry, local environment and traffic behaviour	IF link is short THEN time from when light turns green until vehicle stopped on the detector crosses the stop-line IF link is long THEN use equation 1 to calculate QCMQ IF link is too long for a full queue to discharge in a single green THEN multiply the calculated QCMQ by equation 2 IF results are not representative THEN discard REPEAT UNTIL sufficient valid results have been obtained, and take the mean as QCMQ	Understand that QCMQ is used to calculate how quickly a queue will clear by the SCOOT model, the factors which may influence vehicle's behaviour and change's impacts on the SCOOT model
Measure SLAG	Intuitively estimate SLAG based on road geometry, local environment and traffic behaviour	IF the relevant SCOOT stage has commenced THEN time until the first vehicle crosses the stop-line and subtract the default SCOOT intergreen (5s) and area start lag (~2s) IF results are not representative THEN discard REPEAT UNTIL sufficient valid results have been obtained, and take the mean as SLAG	Understand what causes the commencement of a SCOOT stage and that SLAG is used as a timer for calculating when the queue will begin to discharge once a SCOOT stage starts, the factors which may influence vehicles and the impacts of changes on the SCOOT model

Function	Skill-Based Behaviour	Rule-Based Behaviour	Knowledge-Based Behaviour
Measure ELAG	Intuitively estimate ELAG based on road geometry, local environment and traffic behaviour	IF the relevant SCOOT stage has terminated THEN time until vehicles cease to cross the stop-line and subtract area end lag (~3s) IF results are not representative THEN discard REPEAT UNTIL sufficient valid results have been obtained, and take the mean as ELAG	Understand what causes a SCOOT stage's termination and that ELAG is used as a timer for calculating when traffic ceases to discharge after a SCOOT stage finishes , the factors which may influence vehicles and the impacts of changes on the SCOOT model
Estimate STOC	Intuitively estimate STOC based on road geometry, local environment and traffic behaviour	IF the link has multiple lanes STOC will be higher IF the link has a positive/negative gradient STOC is likely to be lower/higher IF traffic does not use lanes optimally STOC may be reduced	Understand that STOC is a link's discharge rate (lpu/s) and how it can be affected by road geometry, the local environment and traffic behaviour
Validate staging	Check node's staging arrangement and that links are green at the correct times	IF the control/reply bits match the plan AND the SCOOT database is correct AND links are green when expected THEN staging has been implemented correctly	Understand staging's importance and how to test for correct implementation

Function	Skill-Based behaviour	Rule-Based Behaviour	Knowledge-Based Behaviour
Verify detector association	Identify how a detector should be associated and verify by comparing observed traffic flow with the detector's output	IF the detection output matches the observed traffic flow THEN detector is likely correctly associated IF detection output does not match observed traffic flow THEN detector is likely incorrectly associated	Understand the importance of correct association, how to identify planned association and how detector outputs can be used to test association
Validate vehicle detection	Check detector's sensitivity and validate detector's accuracy by comparing its output to observed traffic flow	IF the detection output matches observed traffic flow THEN detector is likely to be accurate	Understand the importance of accurate detection , how to use the detector output to test accuracy and how to check detector sensitivity
Validate STOC	Quickly converge to the correct STOC value based on a few readings	IF the model queue does not clear within a green inaccurately THEN set a high STOC to reset and start again IF the link is green THEN identify the queue length and time until the last delayed vehicle crosses the stop line IF results are not representative THEN discard REPEAT UNTIL sufficient valid results have been obtained IF the model queue and queue clear times are lower/higher than that observed THEN reduce/increase the STOC estimate and recalculate UNTIL the model matches observed then STOC has converged correctly	Understand that STOC is a link's discharge rate (lpu/s), is used to determine how quickly vehicles discharge when the link is green and the impacts of STOC being too high/low

5.8 Conclusions

This chapter has applied an entire CWA to the SCOOT validation process. Each phase has provided insights into how the process operates and several development areas for the existing technical system, PC SCOOT, can be identified.

An AH was constructed in the WDA phase to identify the functions required in SCOOT validation, how they are achieved and why they exist. The AH showed how each function is conducted to achieve a specific value and priority measure, either preventing bias, correct detector setup or accuracy of the assumption parameters or SCOOT model, and so the system can be described as proceduralised. In addition functions are focussed at a particular system level, node, link or detector as illustrated in Table 5-5, it is suggested that they are grouped accordingly in any future developments of PC SCOOT.

Table 5-5: SCOOT validation functions by value and priority measure and system level

		Value and Priority Measure			
		Prevent bias	Correct detector setup	Accuracy of assumption parameters	Accuracy of SCOOT model
System Level	Node	Assess site Prepare site	N/A	N/A	Validate staging
	Link	N/A	N/A	Measure parameters	Validate STOC
	Detector	N/A	Verify detector association Validate detector accuracy	N/A	N/A

ConTA considered the impacts of temporal and spatial recurring scenarios through production of a CAT. It was established that all validation functions can be carried out either on-site or from the office when extensive CCTV coverage is available; however it is recommended that parameter measurement and STOC estimation and validation functions are conducted on-site owing to the need for sufficient situational awareness potentially not provided remotely.

The DL provided further insights into the decision-making process. The ladder's left leg highlighted how system states differed in complexity both in terms of the information required to diagnose them and the options available to manage them. Considering the right leg, two potential goals were identified, to match the SCOOT model to on-street conditions or to adjust it to account for other local factors (e.g. political directives). Goal selection has a limited impact on the possible tasks however task processes are highly proceduralised being linked to a specific target state. Several expert leaps were identified linking a system state or target state to a task or procedure, explaining how experienced validators will intuitively know the correct strategy to employ once the system or target state is identified.

Strategies analysis was conducted for each of the functions identified within the CAT. The majority of these were found to be inflexible, having set procedures. Staging and detector accuracy validation on the other hand each have multiple strategies mostly linked to the particular PC SCOOT screen used by the validator. The rigidity of the task processes arise from the way SCOOT operates and hence it is unlikely that they can be changed, future improvements are therefore likely to arise from enabling validators to do the existing tasks more effectively.

SOCA was applied by colour-coding the other phases' outputs by social agent, the validator or PC SCOOT. From the CAT almost all functions involve both agents; in particular this shows the importance of having on-site access to PC SCOOT through a remote terminal. Considering the DL, all high-level decision-making is conducted by the validator with PC SCOOT activities being focused on the left leg, specifically in providing the information required to diagnose system states, it also has limited capacity to help estimate STOC, the only right leg activity owing to a lack of intelligence. Finally, the strategies analysis reinforces the prevalence of activities conducted by the validator and that PC SCOOT is used to provide information for most functions and undertake technical processes such as updating the SCOOT model. Given that it is unlikely PC SCOOT's intelligence can be radically increased at least in the short-term, development should focus on enabling validators to make decisions and complete functions more accurately and efficiently.

An SRK inventory for WCA identified the SBB, RBB and KBB required for each function, it was found that the existing technical system is based around procedural RBB with limited support for SBB or KBB. It is argued that improving support for these behaviours would lead to performance improvements.

The following areas were identified throughout the analysis as development opportunities.

1. *Site preparation* – improve the efficiency of setting up a node correctly for validation, ensure all commands acting upon a node can be identified and adjusted easily.
2. *Parameter measurement* – in addition to direct parameter input, aid validator's understanding of how each parameter should be calculated, in particular start/end cues and the potential for automated assistance.
3. *Ecological interface development* – redesign staging validation, detector association verification, detector accuracy validation and STOC validation interfaces to support all behaviours as identified in the SRK inventory through EID.

Through consultation with Siemens it was decided that the third of these options represented the greatest potential benefit. By considering each function's importance, relative difficulty and level of support provided by PC SCOOT it was decided that STOC Validation represented the best candidate for further development; hence this function is the subject of further analysis, design and evaluation in chapters 6 through 8.

Chapter 6: Using Cognitive Work Analysis to Design an Ecological STOC Validation Tool

6.1 Introduction

Ecological Interface Design (EID; Rasmussen & Vicente, 1989; Vicente & Rasmussen, 1992) represents an important Human Factors design technique which could be applied to address some of the issues identified with traditional SCOOT validation displays, with extensively documented impacts achieved through its application (Vicente, 2002) including within aviation (e.g. Ellerbroek, Brantegem, van Paassen, & Mulder, 2013), medicine (e.g. Effken, 2006) and power generation (e.g. Lau & Jamieson, 2006; Lau, Jamieson, et al., 2008) domains to name a few.

The premise of EID is a theoretical framework for designing interfaces which support rapid detection and interpretation of information in complex systems (Burns & Hajdukiewicz, 2004) by accounting for the domain's fundamental constraints and specific agent behaviours. In particular all three levels of cognitive control identified by the Skills, Rules and Knowledge (SRK) taxonomy (Rasmussen, 1983; Vicente, 2002) should be supported through application of the principles described by Vicente and Rasmussen (1992), encouraging use of the most appropriate level to improve consistency, reliability and predictability (Vicente & Rasmussen, 1992) and supporting users' skill acquisition (Rasmussen & Vicente, 1989).

1. Skill-Based Behaviour (SBB) – automatic actions supported through direct action on the interface while displaying information consistently with the part-whole structure of movements.
2. Rule-Based Behaviour (RBB) – associating perceived cues with stored rules requiring consistent one-to-one mapping between constraints and interface cues.
3. Knowledge-Based Behaviour (KBB) - analytical problem solving supported by providing an externalised mental model of the domain.

Central to the EID process is use of Cognitive Work Analysis (CWA; Jenkins et al., 2009; Rasmussen et al., 1994; Vicente, 1999) to formatively assess domains from multiple perspectives and levels of detail. While completion of all CWA phases is not always justified (Stanton et al., 2013) representations from each phase can inform EID, most attention being given to Work Domain Analysis (WDA) and Worker Competencies Analysis (WCA), in particular construction of an Abstraction Hierarchy (AH; Rasmussen, 1985) and application of the SRK taxonomy (Rasmussen, 1983). Although consistent with EID's original description it has been argued that Control Task (ConTA), Strategies (StrA) and Social Organisation and Cooperation (SOCA) Analyses can also contribute (e.g. Sanderson, Anderson, & Watson, 2000), however very few studies have utilised a complete CWA in an EID context (see McIlroy & Stanton, 2015).

While road transport is represented within the EID literature (e.g. Hilliard & Jamieson, 2007; Lee, Nam, & Myung, 2008; Mendoza, Angelelli, & Lindgren, 2011; Seppelt et al., 2005) most of these studies have focussed on in-vehicle driver assistance systems rather than the macro systems associated with traffic management. In this chapter EID is applied to SCOOT validation with particular focus given to how each CWA phase contributes to the EID process.

6.1.1 SCOOT Validation

Traffic signals are an integral part of any road environment providing control over vehicles in order to meet demands imposed by road users and governments, such as maximising capacity and safety while minimising delays (Folds et al., 1993). Signals' timings can be predetermined based on observed traffic flows (e.g. TRANSYT; Robertson, 1969) however in many urban networks adaptive control systems such as Split Cycle Offset Optimisation Technique (SCOOT; Hunt et al., 1981) are used to increase efficiency with improvements in excess of ten percent reported over traditional fixed-time plans (e.g. Jhaveri, Perrin, & Martin, 2003; Nottingham Traffic Control Centre, 1997). Light controlled junctions and pelican crossings controlled by SCOOT are known as nodes, with the interconnecting roads termed links. Real-time traffic data from detectors and a traffic model are used to adjust the length of green for a specific link (split), time allowed for all of a node's links to complete a green period (cycle time) and the offset time between adjacent nodes (see Hunt et al., 1981).

To be effective the model must accurately reflect on-street conditions and so its parameters must be validated which is both time consuming and reliant on validators' experience and domain knowledge (Siemens, 2011). This is problematic given the limited number of qualified validators in contrast to the amount of SCOOT systems in operation worldwide and the difficulty of training novices to use the historically developed textual interface of the current validation tool within Siemens' PC SCOOT

Urban Traffic Control (UTC) system (Siemens, 2013). It is proposed that development of an alternative ecological interface could overcome this difficulty and potentially lead to performance improvements.

Time constraints meant that only a single SCOOT validation parameter could be developed. Reiterating from chapter 5, SaTuration OCcupancy (STOC) validation was chosen because it is critical to SCOOT's effectiveness and it is perceived to be relatively difficult to do with PC SCOOT providing limited support. This chapter is concerned firstly with assessing STOC validation using PC SCOOT with these findings used to inform the development of an alternative ecological interface, evaluation of this interface will then be conducted in chapters 7 and 8.

6.2 Data Collection

Descriptions of the STOC validation process were obtained from individual interviews with five Subject Matter Experts (SMEs), SCOOT validators with experience ranging from five to thirty years, and a technical demonstration of the Link VALidation (LVAL) tool used to validate STOC was provided. The CWA outputs were produced following the procedures described by Jenkins et al. (2009) and used in Jenkins et al. (2008), with the aid of the Human Factors Integration Defence Technology Centre's (HFI-DTCs) CWA software tool (Jenkins et al., 2007) and Microsoft Visio. Each output was refined, amended and verified during subsequent meetings with the SMEs.

6.3 Work Domain Analysis

WDA describes the system in terms of the environment in which it operates by identifying the fundamental constraints which shape activities (McIlroy & Stanton, 2011). An Abstraction Hierarchy (AH; Rasmussen, 1985) describes the system at multiple levels (see Naikar, Hopcroft, & Moylan, 2005; Reising, 2000) from its functional purpose at the top to physical objects on the bottom. The relationships between levels are specified using means-ends links in what is known as the why-what-how triad, with connections above a particular node describing why it exists and those below how it is achieved (Burns & Hajdukiewicz, 2004).

For EID the AH serves to identify information requirements, with nodes showing what needs to be displayed while means-ends links guide organisation such that the connections between physical components are reflected. These principles serve to provide an externalised domain model which supports knowledge-based reasoning (Vicente, 1996). Within the AH for STOC validation (Figure 6-1) the purposes, values, functions and processes directly related to the validation tool have been colour-coded dark grey while those of associated technical subsystems are coded light grey, non-technical subsystems are white.

6.3.1 Functional Purpose, Values and Priority Measures and Purpose-related Functions

The functional purpose, or reason for the system's existence, is to ensure a link's STOC value is accurate. Values and priority measures define the criteria against which achievement of the functional purpose can be measured, in this case by accurately measuring street conditions, identifying model outputs and minimising its error. The central purpose-related functions specify how these measures are achieved. The parameters queue length and queue clear time are measured from observed conditions and also estimated and output by the model, adjustments are made by altering the STOC value used.

6.3.2 Object-related Processes and Physical Objects

The AH's lowest level depicts the system's technical and natural physical objects, with their affordances, or capabilities, captured in the object-related processes layer (Naikar et al., 2005). Objects include vehicles, infrastructure to control and observe traffic and a stopwatch to measure the street queue clear time. Technical objects include the traffic model used to calculate the model parameters, detectors and traffic controllers which provide information to the model as well as the validation tool itself.

6.3.3 Validation Tool Functions

The means-end relationships between object-related processes, physical objects and purpose-related functions are shown for the validation tool and other technical subsystems in Table 6-1. It can be seen that the detector, traffic controller and traffic model subsystems are concerned solely with the calculation of model outputs while the validation tool is utilised in all five purpose-related functions. The primary functions of the validation tool are as follows.

1. *Input measured parameter* – street clear time is measured by validators and recorded using the tool.

2. *Input STOC value* – to enable model queue clear times to be calculated.
3. *Output modelled parameters* – model queue length and clear time are output having been calculated by the traffic model using inputs from the detector, traffic controller and STOC value.
4. *Provide clear time comparison* – to facilitate STOC value adjustment, if the modelled clear time is consistently faster than observed STOC must be reduced and vice versa.
5. *Enable data validity assessment* – to ensure the model provides sensible outputs the source data must be valid, specifically the queue must be long enough to produce a meaningful clear time and it must have been detected accurately.

Table 6-1: AH means-ends analysis

Purpose-related Function						**Physical Object**			
Street Queue	Street Queue Clear Time	Model Queue	Model Queue Clear Time	Adjust STOC	**Object-related Process**	Detector	Traffic Controller	Validation Tool	Traffic Model
					Physical Detection				
					Light Status				
					Calculated Queue				
					Calculate Queue Clear Time				
					Input Measured Parameter				
					Input STOC Value				
					Output Modelled Parameters				
					Compare Clear Times				
					Assess Data Validity				

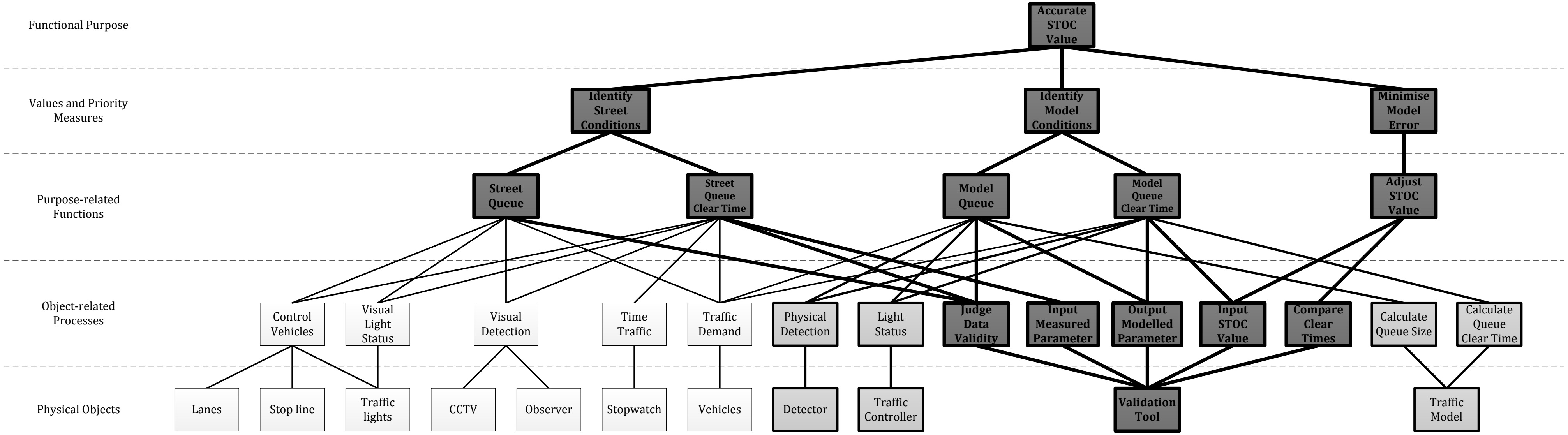


Figure 6-1: Abstraction Hierarchy

6.4 Temporal and Spatial Constraints

A system's temporal and spatial constraints are considered using a Contextual Activity Template (Naikar, Moylan, & Pearce, 2006) as part of CWA's ConTA phase, by identifying where and when the functions identified in WDA could be (dashed box), or typically are (circles and whiskers) performed. By colour-coding the CAT according to which agent, human or technical, conducts each task the constraints imposed by organisational structure and agent role are revealed (McIlroy & Stanton, 2011; Naikar, 2011; Vicente, 1999), this is conducted in the SOCA phase as shown in Figure 6-2. Use of a CAT output in the EID literature has been limited (McIlroy & Stanton, 2015) although they have been used to inform other design techniques (e.g. Stanton & McIlroy, 2012). It has been argued that task analysis provides a basis for prioritising, clustering, filtering or sequencing how an interface presents information (Jamieson, Reising, & Hajdukiewicz, 2001) as well as revealing further domain constraints (Seppelt et al., 2005).

Temporally, functions can be divided into those concerned with data collection, calculation of model parameters and projection of the node's likely performance. Three agents can be considered, the human validator, traffic model (with its associated technical subsystems e.g. the detector) and the validation tool, corresponding colour-codes are shown in Table 6-2. Two function groups concern validators and hence are a priority for design, data collection through measurement and input of the required parameters, and projection through consideration of the outputs to judge data validity and adjust STOC based on clear time comparison. The traffic model also collects information relating to the traffic queue independently of the validator and processes this information to output the model queue and clear time via the validation tool in a form which enables comparison.

Spatially STOC validation takes place predominantly on the roadside at the link being validated; any validation tool must therefore be portable and able to interact with on-street equipment, interface design should also reflect available input/output equipment (e.g. direct interaction through a touch screen could be more appropriate than requiring use of a mouse). Where comprehensive CCTV coverage is available it is possible to validate from an office environment (typically a traffic control room), although this does not otherwise impact either the functions undertaken or agent roles.

Table 6-2: SOCA agent colour codes

Colour	Agent
	Validator
	Traffic Model
	Validation Tool

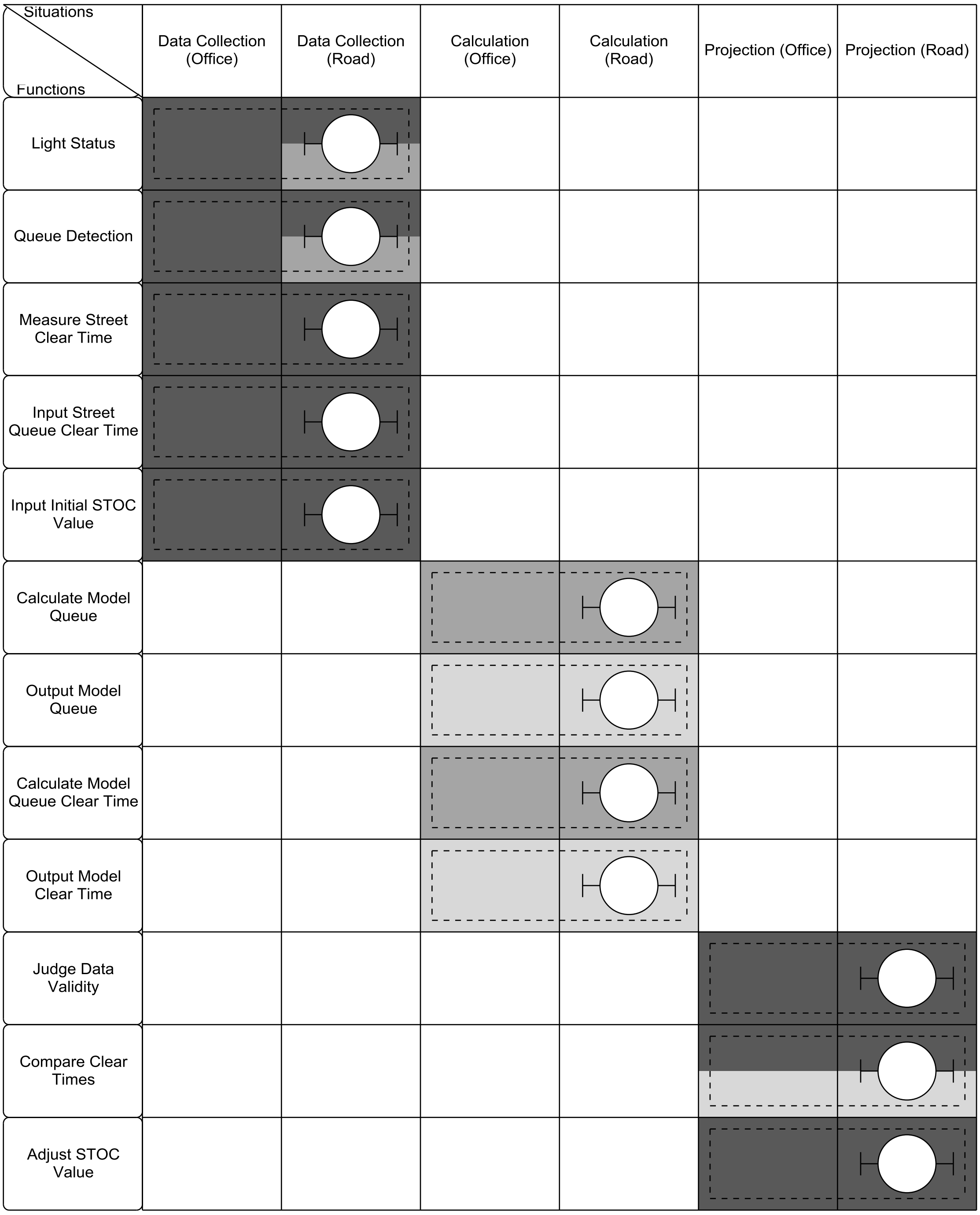


Figure 6-2: SOCA - Contextual Activity Template

6.5 Decision-making Constraints

Decision-ladders (DLs; Rasmussen, 1974) are a further output of ConTA and consider system activity in decision-making terms (McIlroy & Stanton, 2011), similarly to the CAT they can be colour-coded by social agent through SOCA. The purpose within EID is to identify how an interface should provide decision support to users through the task process (Effken, 2006). A DL was produced for STOC validation (Figure 6-3) and colour-coded similarly to the CAT in the previous section (see Table 6-2); however the traffic model has been excluded because all interactions with the validator are via the validation tool.

A DL is formed of two types of node, rectangular boxes represent information-processing activities and circles represent the resulting states-of-knowledge. The left side consists of observation and information gathering activities used to identify the system state, while the right side represents the planning and execution of tasks and procedures in order to achieve a target state, linking each half are activities concerned with option selection in order to meet a desired goal (Elix & Naikar, 2008; Rasmussen, 1974; Rasmussen et al., 1994; Vicente, 1999)

The ladder considers levels of expertise and novelty of decision processes, with novice users expected to follow the ladder linearly while experts use short-cuts to connect each half. Rule-based short-cuts can be shown in the centre of the ladder where information observation and diagnosis of the system state can immediately signal a procedure to execute (McIlroy & Stanton, 2011; Rasmussen, 1974). The top of the ladder represents effortful KBB, where goal evaluation is required to determine the executable procedure (Rasmussen, 1974; Stanton & Bessell, 2014). Short-cuts consist of ‘shunts’ where an information processing activity is connected to a state of knowledge (rectangle to circle) and ‘leaps’ connecting two states of knowledge (circle to circle) without requiring further information processing (Jenkins et al., 2009; Rasmussen, 1974; Vicente, 1999).

STOC validation’s goal is to ensure that the traffic model consistently matches observed conditions, with the options concerning this how to adjust the STOC value in respect to whether the modelled queue’s clear time must be increased or decreased. The range of information required to validate is apparent on the left leg of Figure 6-3, including knowledge of how traffic behaves in reality, gathered by the validator, and the model outputs communicated by the validation tool. Higher level decision-making concerning judgement of data validity, model convergence and STOC adjustment are undertaken entirely by the validator when using LVAL. On the right leg of Figure 6-3 the validation tool can provide suggestions on the degree to which STOC could be adjusted, however the decision is ultimately made by the validator who implements any changes.

Several expert leaps were identified in Figure 6-3, firstly diagnosis of the system state (i.e. to what degree the valid model matches observed conditions) can cause experts to immediately recognise the required course of action to rectify discrepancies, with potentially no conscious consideration given to the specific degree to which STOC must be adjusted. More complicated scenarios may require deliberation of whether an adjustment should be made (e.g. if the cycle's validity is in question) however the task of deciding how to adjust STOC is automatic. Additionally an expert shunt from observing information to a procedure is possible, for example if the validator recognises that a cycle is not valid (e.g. insufficient queue size) triggering the procedure to continue validation at the current STOC value.

The DL can provide further insight into how the validation tool's functions are used by considering which elements (information, system states, tasks etc.) relate to each function; these relationships are shown in Table 6-3. The functions input street clear time and output model queue length / clear time are concerned only with the transfer of quantitative information between the validator and model and hence do not involve decision-making per se. Although input of the STOC value is functionally as simple, how the value is determined is more complicated. The initial value is based on validator's intrinsic knowledge of probable STOC values accounting for the link's physical properties (e.g. number of lanes, gradient) and how the traffic is perceived to behave on the link (e.g. are all lanes used equally), while subsequent changes are in effect the outcome of the validation process.

The most complex functions are enabling data validity judgement and clear time comparison, both being required to diagnose the system state and define the target state. In the first case validators must identify whether sufficient traffic was present to validate accurately (based on experience) and whether the model is accurate (by comparing street and model queues), resulting in a decision to use the cycle's data for validation or collect more. In the second case comparison of model and street clear times determines whether STOC requires adjustment higher or lower and by how much. The relative complexity of these tasks suggests that it is in these areas where the interface most needs to support validators.

6.6 System Requirements

To achieve the key EID tenet that the three levels of cognitive control, SBB, RBB and KBB should be supported and use of the most appropriate level encouraged (Rasmussen, 1983; Vicente, 2002) the method must account for how these behaviours are exhibited within the domain. This is achieved through the final CWA phase WCA which addresses the constraints of agent skill within each function, investigating the behaviour required by either humans or automation through application of Rasmussen's (1983) Skills, Rules and Knowledge (SRK) Taxonomy (Stanton & Bessell, 2014). WCA was originally based on the information processing steps taken from the DL, however several recent examples (e.g. McIlroy & Stanton, 2011; Stanton & Bessell, 2014) instead base the analysis on the CAT in order to be consistent with CWA's functional outputs.

As previously discussed the SRK framework describes three levels of cognition, SBB consists of automated actions in response to environmental cues and events requiring little or no conscious effort, this behaviour is acquired through practice and is often demonstrated by experts. RBB utilises stored rules and procedures acquired through experience or learned from others which guide behaviour but requires cognitive processing. KBB is used to enable advanced reasoning, primarily during novel and unanticipated events, it is characterised as slow and effortful, requiring conscious attention to the domain's governing principles.

The WCA analysis is presented as a SRK inventory showing the SBB, RBB and KBB which applies to each function. To maximise performance it is important that each of these behaviours is supported (Kilgore & St-Cyr, 2006) ensuring that both novice and expert behaviour is accommodated (Rasmussen, 1983). In the original description of EID while an AH is used to identify what content is required within an interface, the SRK taxonomy informs how it is presented (McIlroy & Stanton, 2015).

The SRK inventory presented in Table 6-4 has been limited to the most complex validation functions, clear time comparison and data validity judgement. Both functions, and the validation process as a whole, are highly proceduralised, hence there are clearly defined rules concerning how to adjust the STOC value and identify invalid data based on the information provided. SBB is characterised through immediate recognition of data validity based on observed conditions and a reasonably accurate STOC estimate which is then refined over a short series of cycles. KBB is concerned with understanding the mechanics of how the traffic model works and the potential consequences of validation decisions (e.g. using an incorrect STOC value or basing validation on invalid data).

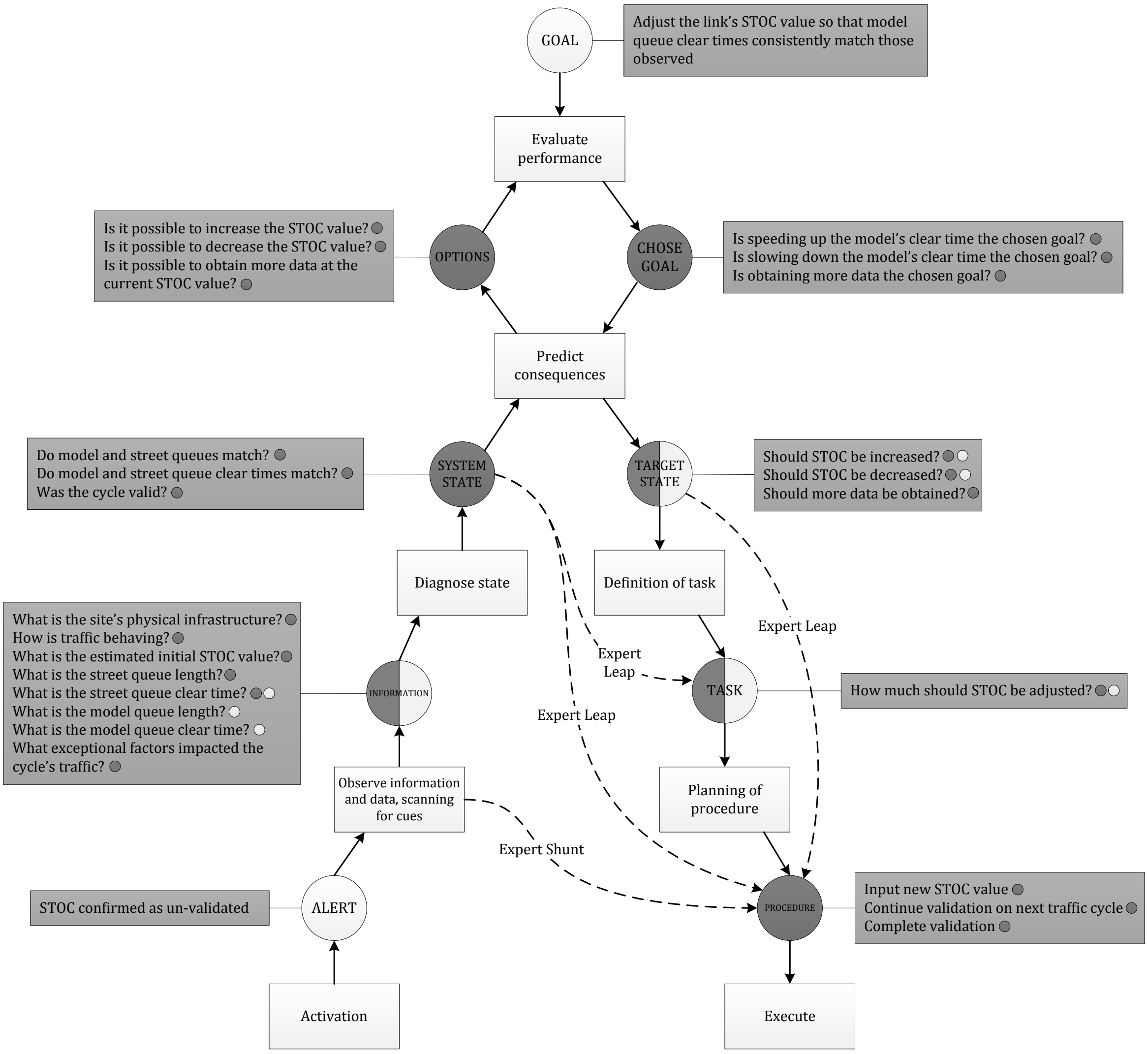


Figure 6-3: SOCA - Decision Ladder

Table 6-3: Validation tool decision-making analysis

Information								System State				Target State			Task
What is the site's physical infrastructure?	How is traffic behaving?	What is the estimated initial STOC value?	What is the street queue length?	What is the street queue clear time?	What is the model queue length?	What is the model queue clear time?	What exceptional factors impacted the cycle's traffic?	Do model and street queues match?	Do model and street queue clear times match?	Was the cycle valid?	**Validation Tool Functions**	Should STOC be increased?	Should STOC be decreased?	Should more data be obtained at the current STOC?	How much should STOC be adjusted?
				■							Input street clear time				
■	■	■									Input STOC value				■/□
					□						Output model queue				
						□					Output model queue clear time				
				■/□		□			■		Provide clear time comparison	■	■	■	■/□
			■	■/□	□		■	■		■	Enable data validity assessment			■	

Table 6-4: SRK Inventory

Validation Tool Function	Skill-based behaviour	Rule-based behaviour	Knowledge-based behaviour
Compare Clear Times	Select a reasonably accurate initial STOC value and converge to the correct value within a few cycles	IF the model queue and queue clear times are lower/higher than that observed THEN reduce/increase the STOC estimate and recalculate UNTIL the model consistently matches that observed	Understand that STOC is a link's discharge rate (lpu/s), is used to determine how quickly vehicles discharge when the link is green and the impacts of STOC being too high (real queue not identified) or low (phantom queue modelled) resulting in inefficient traffic light timings
Judge Data Validity	Quickly identify whether a cycle's data is valid from the observed traffic conditions and consistency of model outputs	IF the link is green THEN identify the queue length and time until the last delayed vehicle crosses the stop line IF traffic levels are insufficient OR results are not representative THEN discard cycle IF the model queue length doesn't correlate to observed THEN investigate detector equipment problems	Understand what constitutes invalid data and how its use in validation could result in an inaccurate STOC value and the impacts this could cause on traffic light timings

6.7 Analysis of LVAL

To understand how the existing tool is used within the domain a strategies analysis has been undertaken. This is conducted in CWA's third phase, StrA, and identifies how the previously identified system activities are conducted (McIlroy & Stanton, 2011). Flow diagrams (Ahlstrom, 2005) showing potential action sequences are used to describe all of the possible ways to complete an activity, recognising that there are often multiple ways to achieve an objective (Stanton & Bessell, 2014).

Use of StrA within EID has been limited in the past, most applications serving only to describe the process rather than utilise formal outputs (McIlroy & Stanton, 2015). It has been argued that this phase can be used to specify the interface's structure by considering the types of information representation required to support a strategy (Drivalou, 2005) and to identify gaps in system functionality (Seppelt et al., 2005). By modelling the validation process using the existing tool, and colour-coding each task by the social agent responsible (see Table 6-2), the mechanisms by which LVAL achieves its goal and the resulting constraints imposed upon the domain can be identified. It is then possible to consider how well the current interface supports the required activities as identified within WCA and how it could be improved.

The validation process is detailed in Figure 6-4 with the corresponding components of LVAL's interface shown in Figure 6-5. To commence validation the validator accesses LVAL for the relevant link (from a PC or remote terminal at the roadside) and inputs a value for STOC by typing it in (1, in Figure 6-5) Over a cycle they observe the queue length (in number of vehicles) which builds while the light is red and measure the queue clear time (in seconds) using a stopwatch, both values are then input into the tool, again by typing (2, in Figure 6-5). Simultaneously the traffic model derives the arrival profile of cars from the traffic detector (usually an induction loop) and discharge rate as specified by the STOC value, using this information to calculate the queue length (in link profile units (lpu; see Siemens, 2011) or converted into vehicles) and clear time (in seconds), these values are output by LVAL (3 and 4, in Figure 6-5) once the cycle is complete.

To judge data validity the validator considers the queue size during the cycle and whether the model queue size matches (5 and 6, in Figure 6-5) by comparing values. If the data is invalid the record is marked as such (7, in Figure 6-5) and the process is repeated for the next cycle until valid data is obtained. Consideration is then given to how well the model and street queue clear times match (8 and 9, in Figure 6-5) by comparing the values. If the model is deemed to accurately model the street conditions, by providing accurate clear times over a number of cycles, then validation is complete. If the model does not match then the validator is required to update their estimate of the STOC value, potentially using LVAL's STOC estimation feature (10, in Figure 6-5), and repeat the process with a new STOC value until the model converges. Cycle times can be up to four minutes (Siemens, 2011) hence validation can be a time consuming process.

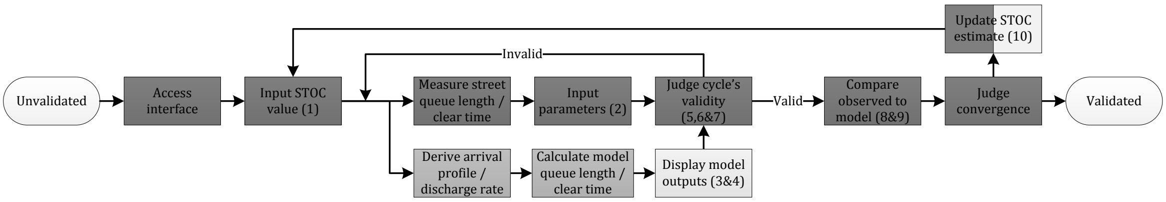


Figure 6-4: LVAL SOCA-Strategy Analysis

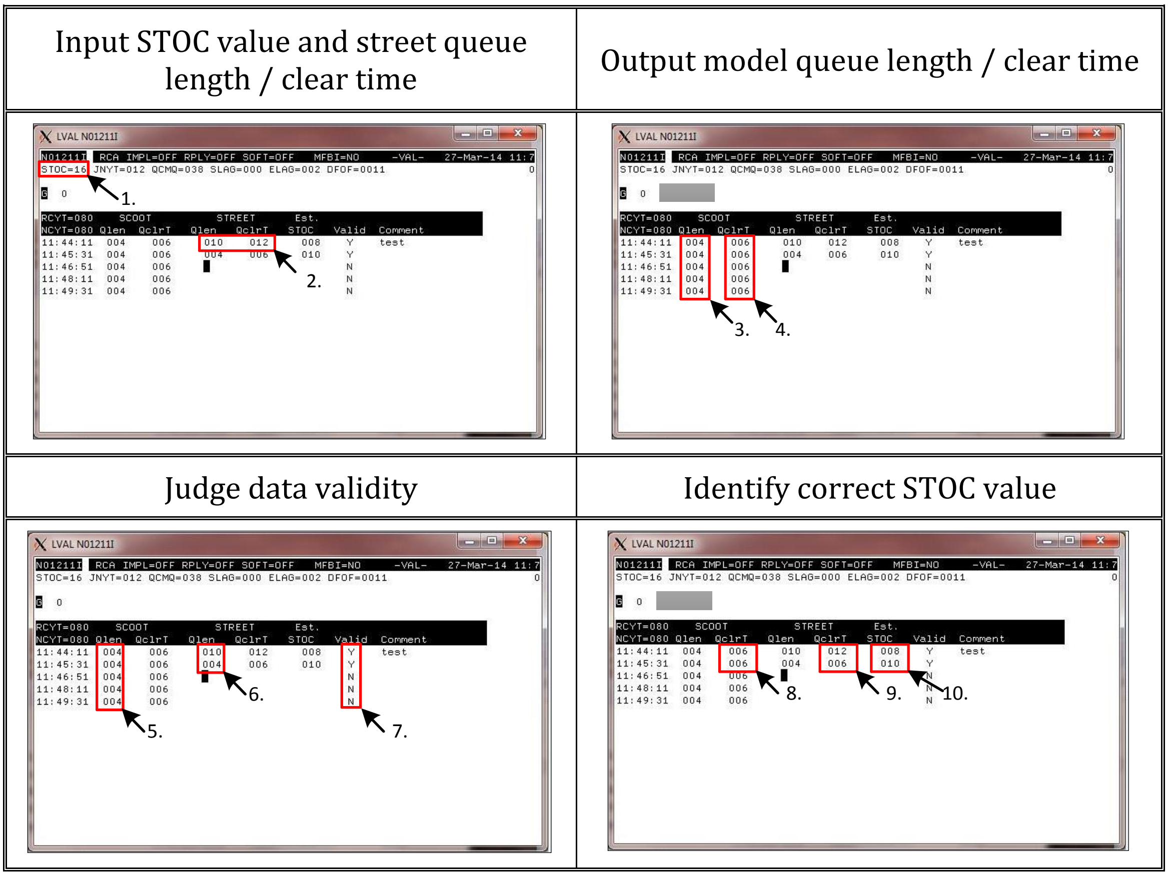


Figure 6-5: Validation functions using LVAL

6.7.1 Interface Support

LVAL provides validators with all of the information required to validate (e.g. model/street queue length and clear time) as identified in preceding sections and presents it textually due to historical technical constraints during its development. While sufficient to enable validation it appears to rely considerably upon validator's tacit knowledge of the validation process and mechanics of the SCOOT system as a whole and hence performance is likely to be dependent on the validator's skill and experience.

Both key functions are concerned with the comparison of a modelled and observed value, although it is simple to see whether they match the presentation method is disconnected from the domain's mechanics and governing rules, hence it is assumed that the validator will be able to diagnose the cause of any discrepancy and take appropriate action. Only limited support is provided in the form of a STOC estimation tool. This calculates a new STOC value based on valid observed and modelled clear times at the current value. In principle, the estimate should produce an improved matching and at the least indicates in which direction STOC needs to be adjusted, however several cycles of data at a single STOC value are required to produce a reasonable estimate, the validity of which must still be consciously considered by the validator.

6.8 Design of an Ecological Interface

The validation tool's role is to provide the outputs from the traffic model, enabling comparison with reality such that data validity and model accuracy can be assessed. Although functional, the existing LVAL interface fails to provide the behavioural support advocated by the EID approach (Burns & Hajdukiewicz, 2004; Vicente, 2002; Vicente & Rasmussen, 1992), which is achieved through adherence to the following:

1. SBB – enable direct action on a display to support interaction via time-space signals and structure information isomorphic to the part-whole structure of movements.
2. RBB – provide consistent one-to-one mapping between work domain constraints and the cues or signs provided by the interface.
3. KBB – represent the domain in the form of an abstraction hierarchy to serve as an externalised mental model.

A graphical display that makes constraints and affordances explicit is required to provide these levels of support, externalising the relationship between the chosen STOC value, the model queue clear time and observed clear time. Through interrogation of the AH it can be seen that the model parameters are calculated based on the traffic count from a detector, traffic light status from a traffic controller and the assumed discharge rate from the inputted STOC value. The modelled queue is simply the quantity of vehicles remaining after those assumed to have discharged while the light is green has been subtracted from those known to have arrived at the link. The model queue clear time is then the point in the cycle at which the queue size reaches zero. The detector output (in lpu) and discharge rate (in lpu/s) are in comparable units, hence each parameter can be plotted on a graph of traffic vs time, with the model clear time read from the 'x axis' adjacent to the parameter's intercept and then compared to the observed value.

This representation provides the detailed information required to understand the domain, in particular how changes to the STOC value are reflected within the traffic model. More comprehensive assessment of data validity is also provided by outputting the arrival profile in near-real time enabling its comparison with observed conditions for the entire cycle rather than final queue lengths alone. In effect the mechanics of the domain are displayed within the interface enabling it to serve as an externalised mental model in support of KBB.

To support RBB all of the domain's constraints must be represented within the interface, in addition to the parameters already discussed a comparison between the model and street clear times must be provided, this being critical to the rules governing STOC adjustment. By inputting the street clear time the difference in values can be plotted, highlighting whether the model is discharging traffic too quickly or slowly at the current STOC value.

Support for SBB can be provided by enabling direct adjustment of the STOC value within a cycle, the resulting changes to the traffic model then shown within the interface. This significantly alters the task process because by eliminating the constraint of only being able to model a single STOC value per cycle it is possible to find the most accurate value regardless of what is initially chosen. The best STOC value for the link then becomes whichever value minimises the model's error across as many cycles as is deemed necessary by the validator. To detail this alternative task process an additional strategies analysis is presented in Figure 6-6 with the corresponding components of the proposed interface shown in Figure 6-7.

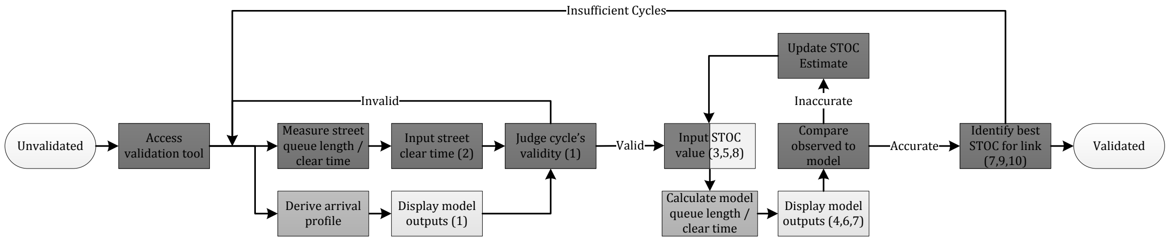


Figure 6-6: Ecological tool SOCA Strategy Analysis

On commencement of validation the interface would display the arrival profile of vehicles from the detector (1, in Figure 6-7) including the state of the traffic lights in near real-time, this output would be used by the validator to judge the cycle's validity through comparison with the observed conditions. After the cycle is complete the street clear time is input into the tool and marked on the graph's 'x axis' (2, in Figure 6-7) by typing in the value or dragging the slider. If the cycle is deemed invalid it must be discarded and further data must be collected otherwise a STOC value is input (3, in Figure 6-7) by typing or dragging the slider, plotting the discharge rate on the graph, with the resulting model queue clear time displayed on the graph's axes (4, in Figure 6-7). If the model does not match, STOC is adjusted by dragging the discharge rate line as required (5, in Figure 6-7) resulting in a theoretically correct STOC value for that cycle (6, in Figure 6-7). The validator must then decide if the value is appropriate for the link, which requires the model to reasonably match observed values over several cycles. As further cycles of data are obtained model comparisons are displayed together (7, in Figure 6-7) with the STOC value persisting across cycles (8, in Figure 6-7), which may be adjusted as necessary throughout the process to minimise the model's error (9 and 10, in Figure 6-7), the effects on model clear times of changing the STOC value are immediately reflected within the interface for all cycles of data. Once a STOC value is identified which is perceived to minimise the error over sufficient cycles validation is complete.

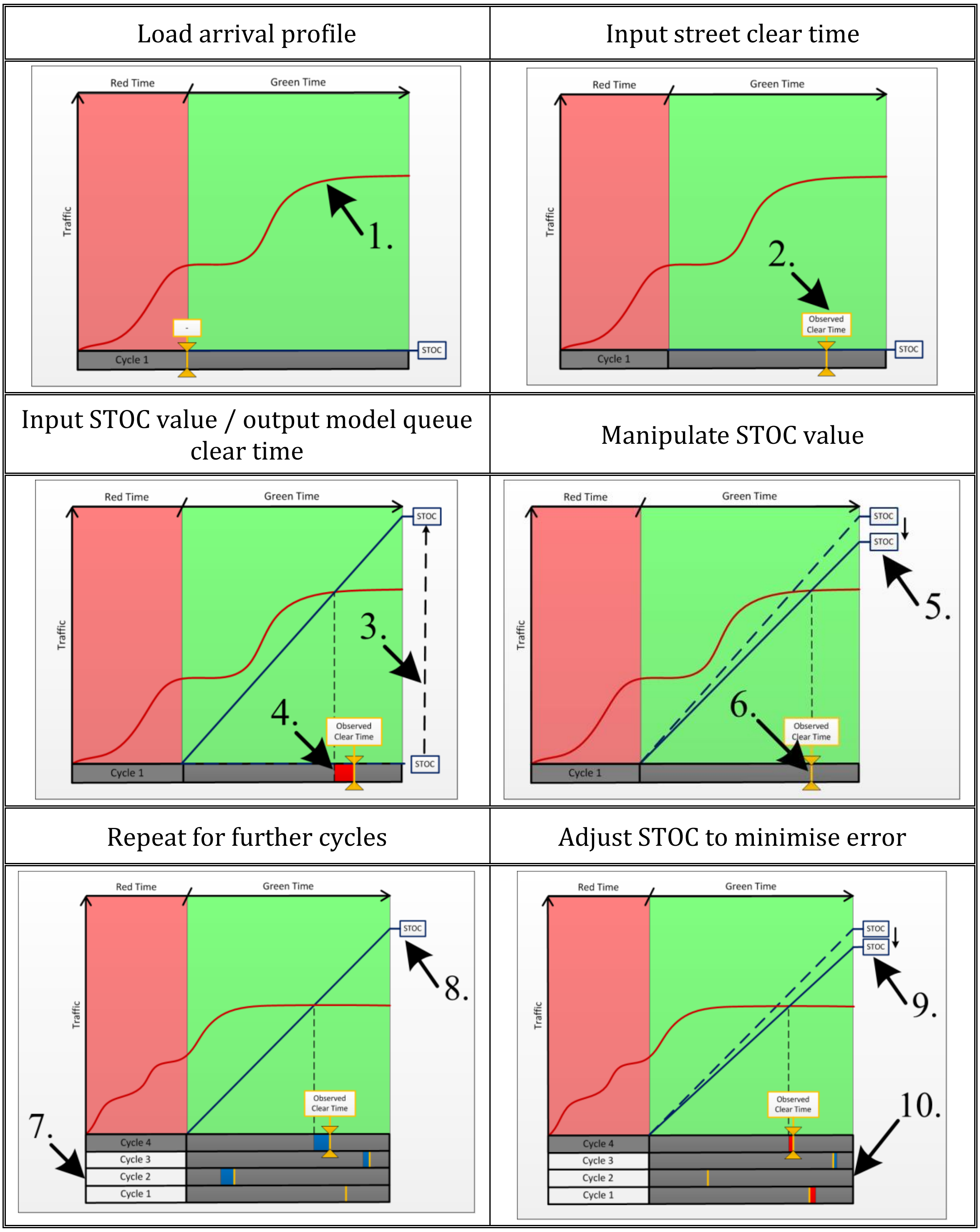


Figure 6-7: Ecological tool functions

Table 6-5: Design process summary

Representation	CWA Phase	Purpose	EID Use	Interface Outcome
Abstraction Hierarchy	WDA	Identify fundamental constraints by describing the system in terms of its environment, accounting for purpose, values, functions, processes, physical components and the links between elements	Identify what functions are performed, why they are required and how they are achieved Nodes inform information requirements Means-ends links inform interface organisation Enables development of an externalised mental model	Five primary validation tool functions were identified and examined Input measured parameter Input STOC value Output modelled parameters Provide clear time comparison Enable data validity assessment
Contextual Activity Template	ConTA and SOCA	Consider temporal and spatial constraints on functionality and the resulting impacts on agent's role	Identify where activities take place and the effects of situational context on how functions are undertaken and interface organisation Temporally grouping functions informs interface organisation Identify functional requirements for specific agents	Validation tool required to operate roadside and from an office environment Two functional groups concern validators Data collection and input Projection of node performance
Decision Ladder	ConTA and SOCA	Consider what decisions must be made, by who and with what information to achieve system goals as well as the impacts of experience on the decision-making process	Identify the decisional constraints for each system function Identify how decision support can be provided for users of varying degrees of experience	Identified priorities for design Support appropriate adjustment of STOC values based on differences between observed and modelled queue clear times Support judgement of cycle data validity

Representation	CWA Phase	Purpose	EID Use	Interface Outcome
Skills, Rules and Knowledge Inventory	WCA	Consider how agent skill is represented within the domain and impacts how functions are undertaken	Identify the skill, rule and knowledge based behaviour associated with each function Informs how to present information to support each behaviour type	Described the behaviours utilised in the most complex validation tool functions Clear time comparison Data validity assessment Informed design of the ecological concept
Strategy Flowcharts	StrA and SOCA	Consider how system activities are or potentially could be conducted	Detail how existing interfaces are used to achieve system goals Identify gaps in functionality Model changes to the task process using potential alternative interfaces	Weaknesses with current LVAL interface identified in conjunction with the SRK inventory Proposed EID interface developed using all outputs and modelled to show changes

Table 6-6: LVAL and Ecological display behavioural support

	LVAL	Ecological
Skill-based behaviour	No specific interface support, skilled behaviour entirely reliant on validators' tacit knowledge	Direct manipulation of STOC value with real-time update of model error for all observed cycles, enabling immediate testing of multiple STOC values improving efficiency and accuracy (3,5,8,9 in Figure 6-7)
Rule-based behaviour	Model clear time displayed next to user input observed clear time with model error required to be calculated manually, a STOC estimate based on previous cycles' data is also provided (8,9,10 in Figure 6-5)	Model error represented graphically as compared to observed clear times and linked graphically to the STOC value being used (4,6,7,10 in Figure 6-7)
Knowledge-based behaviour	Modelled queue time for a single input STOC value provided with validators expected to understand how this value is calculated and to identify the error compared to the observed clear time manually (8,9 in Figure 6-5)	Domain externalised through graphical representation of traffic light status, arrival profile, observed clear time and model error (1-5 in Figure 6-7)

6.9 Conclusions

CWA is intimately linked to EID however designs are rarely informed by full analyses, work domain and worker competencies analyses receiving most attention. While consistent with EID's original description all five CWA phases have been argued to have a role in the design process.

Table 6-5 details the representations produced, their role within CWA and EID as well as the resulting outcomes and influences on the final interface's design while Table 6-6 details how each cognitive behaviour is accounted for within both LVAL and Ecological displays. Primary interface functions were identified through interrogation of the WDA's AH, while spatial, temporal and decisional constraints for each system agent were considered using ConTA and SOCA. WCA described the modes of cognitive control exhibited by validators for the most complex functions of comparing clear times and judging data validity. Finally StrA was used to model the task process using the current tool and give consideration to the support provided.

The existing interface was found to rely on validator's tacit knowledge regarding the task process and domain mechanics; hence a concept ecological interface was proposed which utilised graphical depiction of the source data and domain constraints as well as enabled direct manipulation of the STOC value consistent with the principles of EID. To evaluate the impacts of this ecological display its performance will be empirically tested against the traditional displays used for STOC validation in chapters 7 and 8.

Chapter 7: Evaluation of an Ecological Interface for STOC Validation

7.1 Introduction

SaTuration OCcupancy (STOC) validation is crucial for setting up adaptively controlled traffic light networks which use Split Cycle Offset Optimisation Technique (SCOOT; Hunt et al., 1981) in order to ensure that the controlling traffic model accurately reflects on-street conditions. The STOC parameter models the discharge rate of vehicles when the light is green thus enabling calculation of the time required for a queue to dissipate. Validation is conducted using an Urban Traffic Control system called PC SCOOT (Siemens, 2011, 2013), which in chapter 6 was shown to be both time consuming to use and reliant on validator's experience and tacit domain knowledge, which is problematic given the limited number of qualified validators in contrast to the amount of SCOOT systems worldwide and the difficulty in training novices to use its historically constrained textual interface. To overcome these difficulties Ecological Interface Design (EID; Rasmussen & Vicente, 1989; Vicente & Rasmussen, 1992) was used to develop an alternative display in chapter 6 but before implementation its performance must be evaluated against the existing displays.

EID is a theoretical framework for designing interfaces which support rapid detection and interpretation of information in complex systems (Burns & Hajdukiewicz, 2004) by accounting for the domain's fundamental constraints and specific agent behaviours. The design process is facilitated through application of Cognitive Work Analysis (CWA; Jenkins et al., 2009; Rasmussen et al., 1994; Vicente, 1999), in particular construction of an Abstraction Hierarchy (AH; Rasmussen, 1985) to formatively identify a domain's functional constraints and application of the Skills, Rules and Knowledge (SRK) taxonomy (Rasmussen, 1983; Vicente, 2002) to assess the levels of cognitive control exhibited during each function. Inputs from CWA's central phases Control Task, Strategies and Social Organisation and Cooperation Analyses can also be used to inform designs (e.g. Sanderson et al., 2000), however relatively few EID applications have used or required all phases to be completed (McIlroy & Stanton, 2015; Stanton et al., 2013).

An interface designed using EID aims to support users regardless of the level of cognitive control being utilised, recognising that all behaviours can occur during operation, and is achieved through application of the principles described by Vicente and Rasmussen (1992).

1. Skill-Based Behaviour (SBB) – automatic actions supported through direct action on the interface while displaying information consistently with the part-whole structure of movements.
2. Rule-Based Behaviour (RBB) – associating perceived cues with stored rules requiring consistent one-to-one mapping between constraints and interface cues.
3. Knowledge-Based Behaviour (KBB) - analytical problem solving supported by providing an externalised mental model of the domain.

While traditional design techniques (e.g. mimic-based displays) and others such as User-Centred Design (UCD; e.g. Greenbaum & Kyng, 1991; Schuler & Namioka, 1993) can be effective when designing for anticipated or regularly occurring events, unanticipated scenarios are both potentially more damaging and by their nature difficult to design for (Perrow, 1984; Reason, 1990; Vicente & Rasmussen, 1992). EID aims to overcome this by enabling users to utilise a system's governing principles to solve problems analytically using KBB. In addition use of the lowest possible level of cognitive control is encouraged in order to improve consistency, reliability and predictability (Vicente & Rasmussen, 1992) and users' skill acquisition is supported (Rasmussen & Vicente, 1989).

Ecological interfaces have been applied and tested within many domains (McIlroy & Stanton, 2015; Vicente, 2002) including aerospace (e.g. Ellerbroek et al., 2013; Van Dam, Steens, Mulder, & Van Paasen, 2008), medicine (e.g. Effken, 2006), power generation (e.g. Burns et al., 2008; Hsieh, Chiu, & Hwang, 2014; Lau, Veland, et al., 2008), process control (e.g. Jamieson, 2007; Reising & Sanderson, 2004) and road transport (e.g. Lee, Hoffman, Stoner, Seppelt, & Brown, 2006; Seppelt & Lee, 2007). With the direct impacts on task performance as well as situational awareness (SA), workload and usability having been considered compared with traditional displays.

Tangible direct performance benefits have been exhibited in virtually all applications but are of course domain specific. Although other studies have been conducted within road transport these have focused on in-vehicle driver assistance systems (e.g. Lee et al., 2006; Seppelt & Lee, 2007) which is markedly different from STOC validation with non-transferable performance metrics. In terms of measuring performance the greatest similarities are with applications in the power generation and process control domains, in which the time taken to respond to scenarios as well as accuracy of responses are considered. In both cases improvements have been elicited by ecological displays when compared to traditional interfaces (e.g. Hsieh et al., 2014; Jamieson, 2002, 2007; Torenvliet, Jamieson, & Vicente, 2000).

A key aim of EID is to provide better support for dealing with unanticipated events which can be so damaging to a system's operation. To this end participants' SA (Endsley, 1995) has been shown to be improved, particularly during unforeseen scenarios (e.g. Burns et al., 2008; Ellerbroek et al., 2013; Hsieh et al., 2014; Van Dam et al., 2008), with tasks normally requiring projection transformed to simpler tasks of perception and observation (Ellerbroek et al., 2013). It should be noted that displays developed using EID must provide similarly comprehensive support for anticipated events in order to be effective and this may be less effective than some traditional designs (Burns et al., 2008).

There is conflicting evidence regarding ecological interfaces' effect on users' workload, the general consensus is that type of display has no bearing, determining factors being the volume and complexity of tasks (Lau, Jamieson, et al., 2008; Wickens & Hollands, 2000) and indeed several studies found no significant differences in workload between ecological and traditional displays (e.g. Effken, 2006; Garabet & Burns, 2004; Hsieh et al., 2014) however both workload increases (Lee et al., 2006) and decreases (Lau, Jamieson, et al., 2008) have also been reported.

Display usability has been considered in the aeronautical and medicine domains (see Effken, 2006; Ellerbroek et al., 2013) with ecological interfaces rated as superior by participants in both cases. Although these results are subjective it is encouraging that potential users of ecological displays appear to see the benefits of their use in addition to the multitude of objective benefits found, given that user acceptance of a new interface is likely to be a significant barrier to its implementation.

7.2 STOC Validation Interfaces

Three separate interfaces are of interest for this study, PC SCOOT's Link VALidation (LVAL) tool and expanded Multiple Concurrent Models (MCM) are currently used by validators while the ecological interface is a concept design and utilises a slightly different task process as detailed in Figure 7-1 and Figure 7-3. These show the activities which are undertaken by system agents via colour-coding as detailed in Table 7-1.

Table 7-1: SOCA agent colour codes

Colour	Agent
	Validator
	Traffic Model
	Validation Tool

7.2.1 Link Validation Tool

Figure 7-1 details the validation process using LVAL with corresponding interface components shown in Figure 7-2. On commencing validation a STOC value for the link is input by the validator by typing it in (1, in Figure 7-2). Over a cycle they observe the queue length (in number of vehicles) which builds while the light is red and measure the queue clear time (in seconds) using a stopwatch, both values are then input into the tool, again by typing (2, in Figure 7-2). Simultaneously the traffic model derives the arrival profile of cars from the traffic detector (usually an induction loop) and discharge rate as specified by the STOC value, using this information to calculate the queue length (in Link Profile Units (LPU; see Siemens, 2011) or converted into vehicles) and clear time (in seconds), these values are output by LVAL (3 and 4, in Figure 7-2) once the cycle is complete.

To judge data validity the validator considers the queue size during the cycle and whether the model queue size matches (5 and 6, in Figure 7-2) by comparing values. If the data is invalid the record is marked as such (7, in Figure 7-2) and the process is repeated for the next cycle until valid data is obtained. Consideration is then given to how well the model and street queue clear times match (8 and 9, in Figure 7-2) by comparing the values. If the model is deemed to have converged to accurately model the street conditions, by providing accurate clear times over a number of cycles, then validation is complete. If the model does not match then the validator is required to update their estimate of the STOC value, potentially using LVAL's STOC estimation feature (10, in Figure 7-2), and repeat the process with a new STOC value until the model converges.

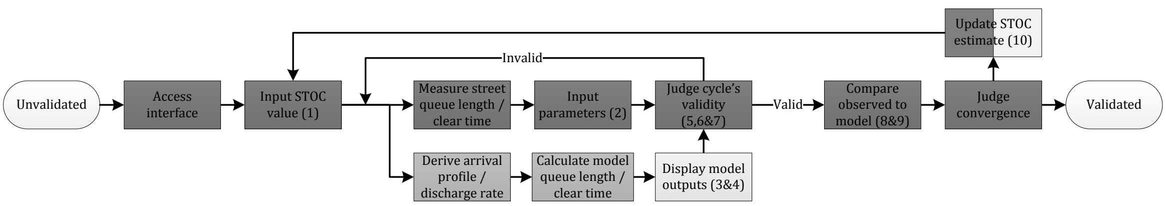


Figure 7-1: Traditional display validation task process

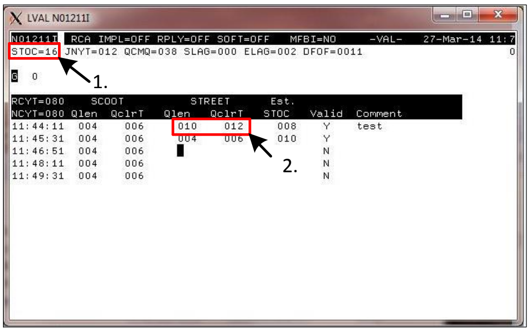
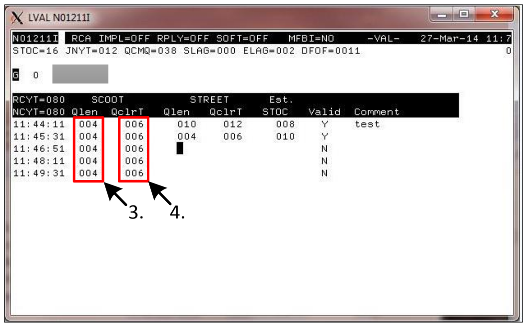
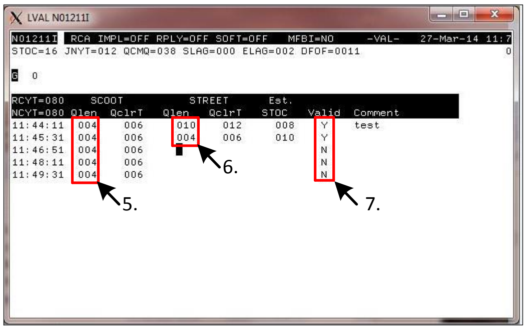
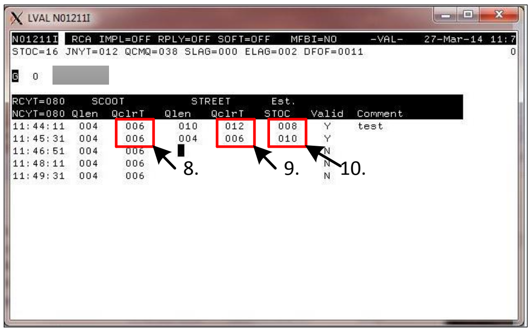
Input STOC value and street queue length / clear time (1&2)	Output model queue length / clear time (3&4)
	
Judge data validity (5,6&7)	Identify correct STOC value (8,9&10)
	

Figure 7-2: Validation functions using LVAL

7.2.2 Multiple Concurrent Models

Multiple Concurrent Models (MCM) is an expanded version of LVAL which effectively runs several versions of the traffic model such that queue clear times are computed and output for STOC values +/- 3 from what has been input by the validator. This should theoretically enable validators to identify an acceptable value quicker because additional traffic cycles are not required to identify consequences of small changes to the link's STOC value. Graphically the only difference from LVAL is that seven model clear times are displayed rather than one.

7.2.3 Ecological Tool

Figure 7-3 details the validation process using the ecological tool with corresponding interface components shown in Figure 7-4. On commencement of validation the interface would display the arrival profile of vehicles from the detector (1, in Figure 7-4) including the state of the traffic lights in near real-time, this output would be used by the validator to judge the cycle's validity through comparison with the observed conditions. After the cycle is complete the street clear time is input into the tool and marked on the graph's 'x axis' (2, in Figure 7-4) by typing in the value or dragging the slider. If the cycle is deemed invalid it must be discarded and further data must be collected otherwise a STOC value is input (3, in Figure 7-4) by typing or dragging the slider, plotting the discharge rate on the graph, with the resulting model queue clear time displayed on the graph's axes (4, in Figure 7-4).

If the model does not match, STOC is adjusted by dragging the discharge rate line as required (5, in Figure 7-4) resulting in a theoretically correct STOC value for that cycle (6, in Figure 7-4). The validator must then decide if the value is appropriate for the link, which requires the model to reasonably match observed values over several cycles. As further cycles of data are obtained model comparisons are displayed together (7, in Figure 7-4) with the STOC value persisting across cycles (8, in Figure 7-4), which may be adjusted as necessary throughout the process to minimise the model's error (9 and 10, in Figure 7-4), the effects on model clear times of changing the STOC value are immediately reflected within the interface for all cycles of data. Once a STOC value is identified which is perceived to minimise the error over sufficient cycles validation is complete.

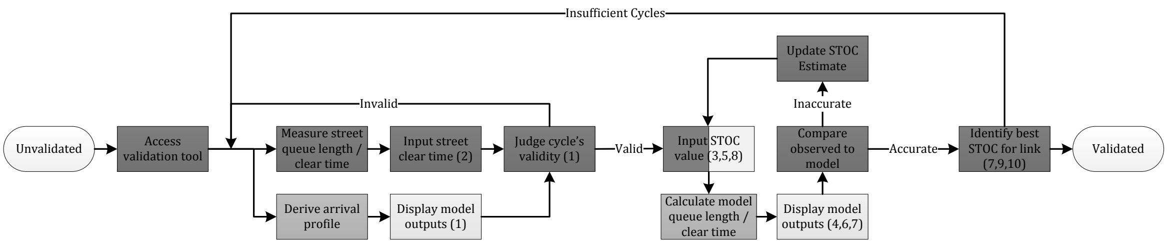


Figure 7-3: Ecological tool validation task process

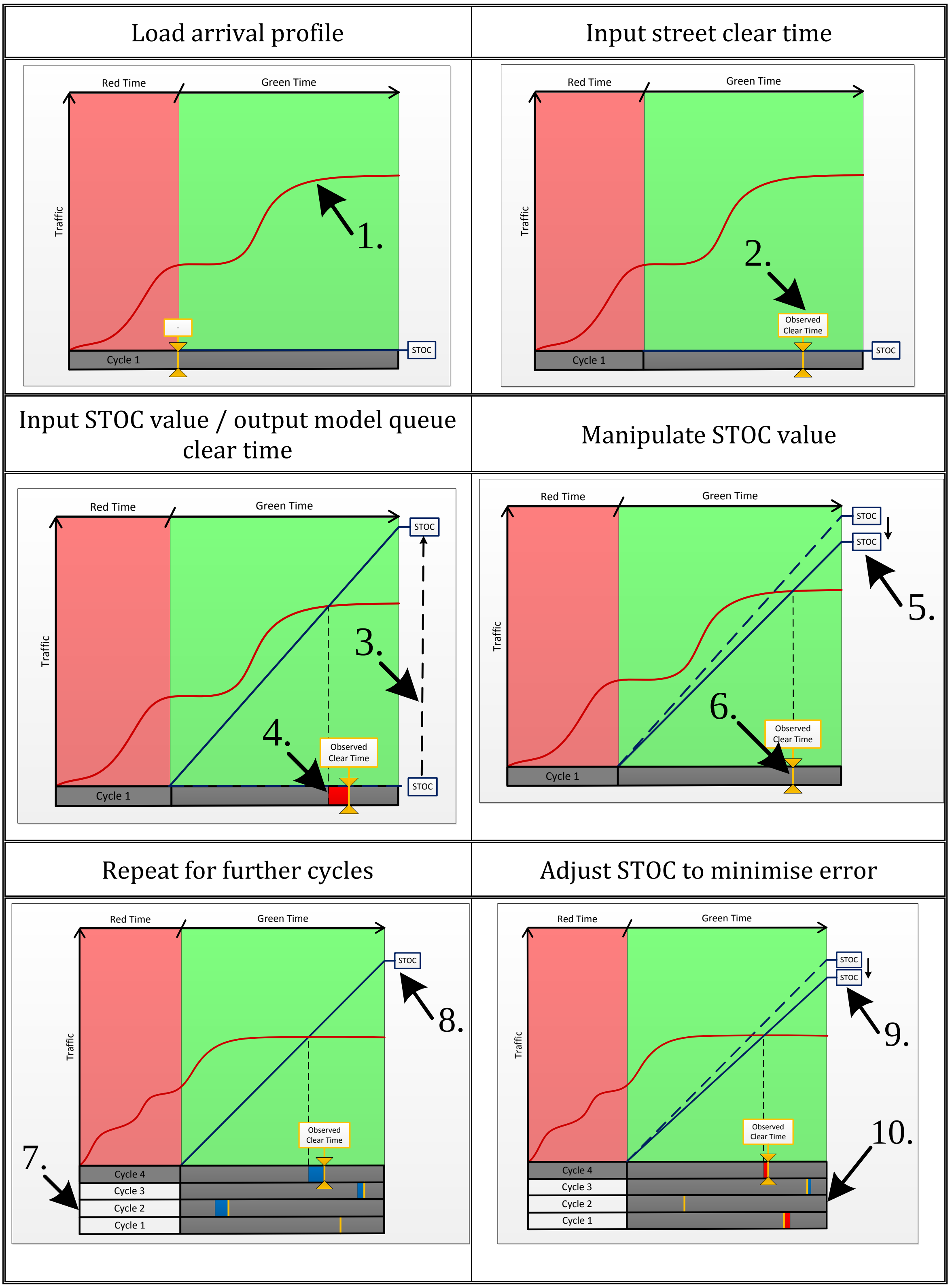


Figure 7-4: Ecological tool functions

7.3 Methodology

7.3.1 Participants

Participants were divided into three groups. Experts comprised of twelve experienced validators, ten male with a mean age of 45.1 years (σ = 11.9) and experience ranging from 3 to 30 years (μ = 13.5, σ = 10.9). Novices were divided into a group of twelve age and gender matched to the expert group as closely as possible (ten male, μ_{age} = 45.6, σ_{age} = 13.6), and an unmatched group of thirty (thirteen male) with a mean age of 34.4 (σ = 13.2), all having no experience of SCOOT validation.

7.3.2 Equipment

The experiment was undertaken on a laptop with a 15” display. Versions of each interface were produced in Microsoft Excel (version 2010, see Figure 7-5) with the validation processes as described in section 7.2; a line graph with adjustable STOC and street clear time parameters was used to replicate the ecological display. All displays were checked with an experienced SCOOT validator prior to commencing the experiment to ensure fitness for purpose. Navigation and interaction was carried out via keyboard and mouse.

7.3.3 Experimental Design

The experiment was designed as a between- and within-subjects repeated-measures where the factors *display* and *experience* were varied. The within-subjects factor *display* was divided into two existing displays (LVAL, MCM) and the proposed ecological display, all depicted in Figure 7-5. The between-subjects factor *experience* was divided into participants with validation experience (experts) and without (novices) who were subdivided into those age and gender matched to the expert group with the remaining placed in an unmatched group, this resulted in 9 conditions (3x3).

Dependent measures for this experiment consisted of both objective and subjective measures. *Performance* was measured in terms of the final validation error, mean cycle validation error, mean time spent per cycle and number of cycles used, validation error was categorised as the deviation from the expert’s median STOC value for each link. *System use* was measured in terms of the number of STOC adjustments made (ecological only), mean error from estimated STOC value (LVAL and MCM only) and the mean STOC adjustment. *Workload* was measured using the NASA-TLX assessment of overall workload with subscales for mental demand, physical demand, temporal demand, performance, effort and frustration. *System usability* was measured using the

SUS questionnaire with participants stating whether they "strongly agreed", "agreed", "neither agreed nor disagreed", "disagreed" or "strongly disagreed" with each statement shown in Table 7-2.

This experiment investigates the following hypotheses with each formulated based on theory and prior empirical studies of ecological interface's performance.

1. *H1:* Expert's tacit domain knowledge and experience using LVAL and MCM will enable faster and more accurate STOC identification over novices when using traditional displays, i.e. expert's training and experience will provide an advantage.
2. *H2:* Novice's performance will be closer to experts when using the ecological interface, owing to its novelty for all participants and the perceived high learning curve of the traditional displays (Siemens, 2011). Ecological interfaces are not intended to be used by untrained operators (Vicente, 1999) hence experts are still expected to perform best.
3. *H3:* STOC identification will be faster using the ecological display, the ecological task process not being limited to trailing a single STOC value per cycle and evidence from other applications showing that reduced response times can be elicited by ecological interfaces (e.g. Hsieh et al., 2014; Jamieson, 2002, 2007; Torenvliet et al., 2000).
4. *H4:* Participant's workload will be unaffected by the display used, precedence for this having been shown in a number of studies (e.g. Effken, 2006; Garabet & Burns, 2004; Hsieh et al., 2014).
5. *H5:* Subjective usability for the ecological display will be higher than LVAL or MCM, there are only a few examples of usability testing within the context of EID however the results have indicated preferences for ecological interfaces (Effken, 2006; Ellerbroek et al., 2013) over traditional designs.

7.3.4 Procedure

Subjects were briefed on the purpose of the experiment and were allocated to a group. Conditions were undertaken in a predetermined counterbalanced order to account for learning effects. Each condition commenced with a practice session to familiarise the subject with the validation task using the interface. Subjects were required to manipulate the STOC value such that the model provided accurate queue clear times in relation to observed values, it was explained that there was no correct answer and to cease validation once they were satisfied with a particular value. Three real links were then validated using the interface, the order of which was counterbalanced using a Latin Square.

Model inputs for each link included traffic arrival profiles obtained from nine links in Reading using PC SCOOT's M14 messages (see Siemens, 2011) and street queue clear times which were determined to be the model's queue clear time at the real STOC value with a normally distributed (μ=0, σ=1) error applied, accounting for variability in clear time measurement. Thirty valid cycles (where a queue formed and was discharged within a green period) of data were acquired for each link.

After completing each condition a NASA-TLX assessment (Hart & Staveland, 1988) and System Usability Scale (SUS; Brooke, 1996) questionnaire were completed. The process was repeated until all three conditions were completed; typically taking between 30mins and 1hr. Ethical approval was obtained from the University of Southampton's ethics committee prior to commencement of data collection (ethics number 11917).

7.3.5 Data Analysis

All data analysis will be conducted using SPSS (version 19) with significance set at 5%. Each dependent measures' normality will be assessed using a Shapiro-Wilk test. Where normality can be assumed parametric tests will be used; ANalysis Of Variance (ANOVA) for repeated-measures data and either independent or paired samples T-Tests to compare between-subjects effects as appropriate. Conversely where normality cannot be assumed non-parametric tests will be used; Friedman tests for repeated-measures data comparing within-subjects effects and either Wilcoxon-Mann Whitney or Wilcoxon Signed Ranks tests to compare between-subjects effects. Should the normality assumption vary within a dependent measure parametric tests will be used due to both ANOVA and T-Tests' reasonable robustness to the normality assumption (Kirk, 1995). Categorical data collected by the SUS will be evaluated using a Chi-Square test. Effect sizes for all measures excluding categorical data will be evaluated using Cohen's d (Cohen, 1988).

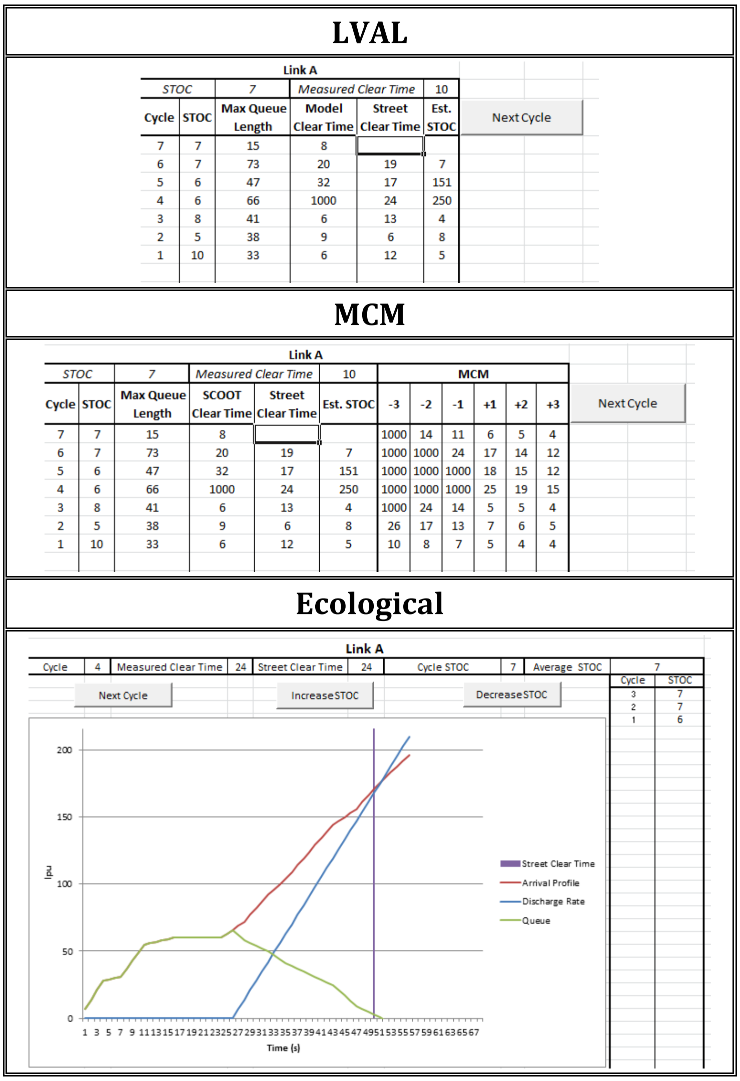


Figure 7-5: Experimental displays

Table 7-2: SUS questions

No.	Question
1	I think that I would like to use this system frequently
2	I found the system unnecessarily complex
3	I thought the system was easy to use
4	I think that I would need the support of a technical person in order to be able to use this system
5	I found the various functions in this system were well integrated
6	I thought there was too much inconsistency in this system
7	I would imagine that most people would learn to use this system very quickly
8	I found the system very cumbersome to use
9	I felt very confident using the system
10	I needed to learn a lot of things before I could get going with this system

7.4 Results and Discussion

Shapiro-Wilk tests on each dependent measure revealed mixed normality assumptions (Table 7-3), therefore a variety of parametric and non-parametric tests were utilised for data analysis as specified in section 7.2.5.

Table 7-3: Shapiro-Wilk normality test p values for performance, system use, workload and system usability measures

		Group								
		Expert			Matched Novice			Novice		
Factor	**Measure**	**LVAL**	**MCM**	**Eco**	**LVAL**	**MCM**	**Eco**	**LVAL**	**MCM**	**Eco**
Performance	Final validation error	**.008**	**.005**	**.001**	**.000**	.212	**.002**	**.000**	**.000**	**.000**
	Mean cycle validation error	.707	**.002**	.108	.621	.891	.464	**.011**	**.004**	**.018**
	Mean time spent per cycle	**.044**	**.043**	**.045**	**.000**	**.001**	**.044**	**.000**	.331	**.001**
	Cycles required	.352	.074	.716	.648	.403	.108	**.002**	**.000**	**.000**
System use	Total ecological adjustments per cycle	N/A	N/A	.318	N/A	N/A	.963	N/A	N/A	**.003**
	Estimated STOC error	**.036**	.081	N/A	.117	**.032**	N/A	**.002**	**.019**	N/A
	Mean STOC adjustment	**.007**	.053	.167	.069	**.001**	.210	**.001**	**.003**	**.023**
Workload	Overall Workload	.197	.116	.020	.498	.972	.198	.572	.367	.063
	Mental Demand	**.023**	.355	.435	.235	.193	.561	**.042**	.244	**.011**
	Physical Demand	**.001**	**.007**	**.004**	**.001**	**.028**	**.005**	**.000**	**.000**	**.000**
	Temporal Demand	.592	.553	.212	**.003**	**.020**	**.005**	**.002**	**.007**	**.002**
	Performance	.157	**.029**	.070	.094	.231	.053	.134	.058	**.009**
	Effort	**.008**	.540	.456	.586	.137	.182	.052	.527	.026
	Frustration	**.001**	**.003**	**.032**	**.011**	.107	.056	.140	.164	**.000**
System usability	System usability	.464	.234	.110	**.043**	.158	.062	.358	.877	.457

7.4.1 Experience Effects on Traditional Display Performance

H1 stated that higher performance would be elicited by experts, in terms of speed and accuracy of validation, over novice groups when using LVAL and MCM owing to their experience using these systems. No effect on final accuracy was observed with all participant groups identifying identical median STOC values for each link (Table 7-4) and with no significant differences for validation error (see Table 7-5, for the summary of performance measures, and Figure 7-6); however experts recorded lower mean cycle validation errors suggesting that at any point they were likely to be closer to the "correct" STOC value than novices (Figure 7-7). Experience did affect the speed with which validation was completed, experts requiring fewer cycles than novice groups to identify STOC (Figure 7-8) with both traditional displays, although the difference was only significant compared to the unmatched group. The actual time spent validating per cycle did not differ significantly between groups for either LVAL or MCM although experts were slightly faster (Figure 7-9).

System use measures (Table 7-6) reveal that experts made smaller incremental adjustments to STOC cycle to cycle while novice groups made larger changes. It seems that by following a systematic procedure and avoiding drastic changes, experts were less likely to oscillate either side of an accurate STOC value, a behaviour observed in both novice groups resulting in wasted cycles. This appears to be a rule obtained by experts through experience and potentially used to invoke RBB (Rasmussen, 1983) to obtain a tangible benefit over those lacking this domain knowledge.

EID aims to support users' acquisition of the necessary skills to utilise lower levels of cognitive control (Rasmussen & Vicente, 1989) however support within the traditional displays is limited to a simple STOC estimation tool. There is no evidence that this tool provides any significant benefit with experts and novices using the tool similarly despite performance variations, suggesting that following the estimated value will not emulate expert performance. It is also interesting to note that the inclusion of extra information in the MCM condition did not affect how either experts or matched novices reacted to the estimated value or provide any significant benefits raising questions as to its effectiveness.

7.4.2 Experience Effects on Ecological Display Performance

Similarly to both traditional displays all participant groups were able to correctly identify each link's STOC value with no significant difference in terms of the final validation error (Table 7-4, Table 7-5 and Figure 7-6). Novices' cycle validation error (Figure 7-7) was however similar to experts', as was speed of validation both in terms of cycles used (Figure 7-8) and time spent per cycle (Figure 7-9). It was expected that the ecological display would normalise the performance variation between experts and novices (*H2*) although some variation was still expected, ecological displays not being intended or able to overcome the need for training (Vicente, 1999). In this case however the ecological display enabled novices to achieve a comparable level of performance to experts, eliminating all significant points of difference found when using the traditional displays, although it is worth noting that experts still achieved the lowest cycle validation error and required the fewest cycles.

In terms of system use (Table 7-6) experts made significantly fewer adjustments to STOC throughout each link's validation than novices, suggesting less reliance on the display; however adjustments made cycle to cycle were similar for all participants. The reason for this is that by enabling direct manipulation of the STOC parameter and showing changes' impacts in real-time users only have to select their perceived best option rather than predicting what the outcomes will be. Synergies can be seen here with studies investigating ecological displays' effects on users' SA, which have shown that tasks normally requiring projection can be transformed into simpler tasks of perception and observation (e.g. Ellerbroek et al., 2013). As a result performance appears to be more consistent regardless of experience.

7.4.3 Display Effects on Validation Speed

Validation speed can be considered in terms of the time spent using the interface and the number of cycles required to validate a link, with the ecological display predicted to be the fastest to use based on prior empirical evaluations of response times and removal of the single STOC value per cycle constraint (*H3*).

With regards to the first measure of validation speed all participant groups were shown to spend longer using the ecological display compared to both traditional displays (Table 7-5 and Figure 7-9), for example experts spent a mean of 26 seconds to adjust STOC using the ecological display compared to means of 10 and 13 seconds using LVAL and MCM respectively. While response times have typically be shown to be reduced by ecological displays (e.g. Hsieh et al., 2014; Jamieson, 2002, 2007; Torenvliet et al., 2000) there is also evidence to suggest that the amount of information presented within an ecological display increases its complexity potentially hindering performance (Lee et al., 2006). The ecological display through graphical representation of the source data and the need to physically act upon the display is more complex than the traditional displays' textual representation with the resulting impact on performance being that the ecological display takes longer to use.

In contrast the second measure of validation speed, the number of cycles used, was found to be significantly reduced using the ecological display compared to both traditional displays (Figure 7-8) for all participant groups, particularly in comparison to LVAL. The reason for this is that by enabling participants to find the most accurate STOC value for each cycle through direct manipulation each cycle can be used effectively, whereas if an inaccurate STOC value is chosen using either traditional display further cycles are required to correct the error.

The results regarding H3 are therefore contradictory; however it is important to consider that total validation time is predominantly dependent on the number of cycles used rather than the time spent using the interface within a single cycle. This is because a cycle typically lasts between two and four minutes (Siemens, 2011); therefore so long as an increase in time spent using the display does not cause validators to miss the subsequent traffic cycle then the reduction in cycles used will translate to an overall reduction in response time for the task. Given that the ecological display requires on average only a few more seconds to use than either traditional display an overall improvement in response time for the task is elicited by the ecological display, consistent with prevailing findings in the literature and in support of H3.

It is encouraging that performance benefits were elicited by the ecological display for all participant groups, even when experts could have been restricted by limited training. Although ecological interfaces do not negate the need for training (Vicente, 1999) it does suggest that the training provided is robust to changes in information presentation but could be better supported with an ecological display echoing Jamieson's (2007) findings in the process control domain.

Table 7-4: Median validated link STOC values by group

Group	Link A	B	C	D	E	F	G	H	I
Experts	7	12	18	7	14	11	9	10	14
Matched Novices	7	12	18	7	14	11	9	10	14
Novices	7	12	18	7	14	11	9	10	14

Table 7-5: Means (standard deviations between parentheses) for performance measures

	Group									**Significance**					
	Expert (EX)			**Matched Novice (MN)**			**Novice (N)**			**Within-subjects**			**Between-subjects**		
Measure	**1. LVAL (L)**	**2. MCM (M)**	**3. Eco. (E)**	**4. LVAL (L)**	**5. MCM (M)**	**6. Eco. (E)**	**7. LVAL (L)**	**8. MCM (M)**	**9. Eco. (E)**	**p value**	**sig. pairs**	**effect Size (d)**	**p value**	**sig. pairs**	**effect Size (d)**
Final validation error	0.39 (0.73)	0.25 (0.5)	0.22 (0.59)	0.58 (1.32)	0.28 (0.78)	0.28 (0.61)	0.38 (1.74)	0.49 (1.23)	0.22 (0.54)	>0.05 (EX/ MN/N)	N/A	N/A	>0.05 (L/M/E)	N/A	N/A
Mean cycle validation error	1.38 (1.13)	1.6 (1.28)	0.38 (0.49)	2.06 (1.39)	2.22 (2.13)	0.50 (0.59)	2.01 (1.58)	2.20 (1.54)	0.57 (0.78)	<0.005 (EX) <0.005 (MN) <0.0005 (N)	13 23 46 56 79 89	0.27 0.29 0.34 0.24 0.17 0.20	<0.05 (L/M) > 0.05 (E)	14, 28	0.18 0.14
Cycles required	9.7 (5.8)	8.3 (6.4)	5.6 (3.2)	10.5 (5.2)	10.2 (4.9)	6.9 (3.4)	13.2 (7.8)	12.0 (6.4)	7.8 (6.5)	<0.05 (EX/ MN) <0.0005 (N)	13, 46, 79, 89	0.21 0.21 0.13 0.12	<0.05 (L/M) > 0.05 (E)	17, 28	0.17 0.17
Mean time spent per cycle (sec)	10 (4)	13 (6)	26 (14)	15 (13)	19 (11)	24 (15)	11 (7)	14 (6)	21 (9)	<0.0005 (EX/ MN/N)	12, 13, 23, 46, 56, 79, 89	0.22 0.97 0.58 0.20 0.13 0.26 0.21	>0.05 (L/M/E)	N/A	N/A

Table 7-6: Means (standard deviations between parentheses) for system use measures

	Group									Significance					
	Expert (EX)			Matched Novice (MN)			Novice (N)			Within-subjects			Between-subjects		
Measure	**1. LVAL (L)**	**2. MCM (M)**	**3. Eco. (E)**	**4. LVAL (L)**	**5. MCM (M)**	**6. Eco. (E)**	**7. LVAL (L)**	**8. MCM (M)**	**9. Eco. (E)**	**p value**	**sig. pairs**	**effect Size (d)**	**p value**	**sig. pairs**	**effect Size (d)**
Total ecological STOC adjustments per link	N/A	N/A	23.7 (18.3)	N/A	N/A	30.5 (18.6)	N/A	N/A	41.8 (32.7)	N/A	N/A	N/A	<0.05 (E)	36, 39	0.11 0.27
LVAL Estimated STOC error	1.75 (1.42)	1.86 (1.40)	N/A	1.81 (1.32)	1.85 (1.64)	N/A	1.45 (1.49)	2.20 (1.86)	N/A	>0.05 (EX/MN) <0.05 (N)	78	0.09	>0.05 (L/M/E)	N/A	N/A
Mean STOC adjustment	1.05 (1.21)	1.18 (1.11)	0.59 (0.71)	2.08 (2.48)	2.64 (4.86)	0.63 (0.85)	2.48 (2.84)	1.82 (1.51)	0.84 (1.1)	>0.05 (EX/MN) <0.005 (N)	79, 89	0.11 0.12	<0.05 (L/M) >0.05 (E)	14, 17, 28	0.24 0.31 0.16

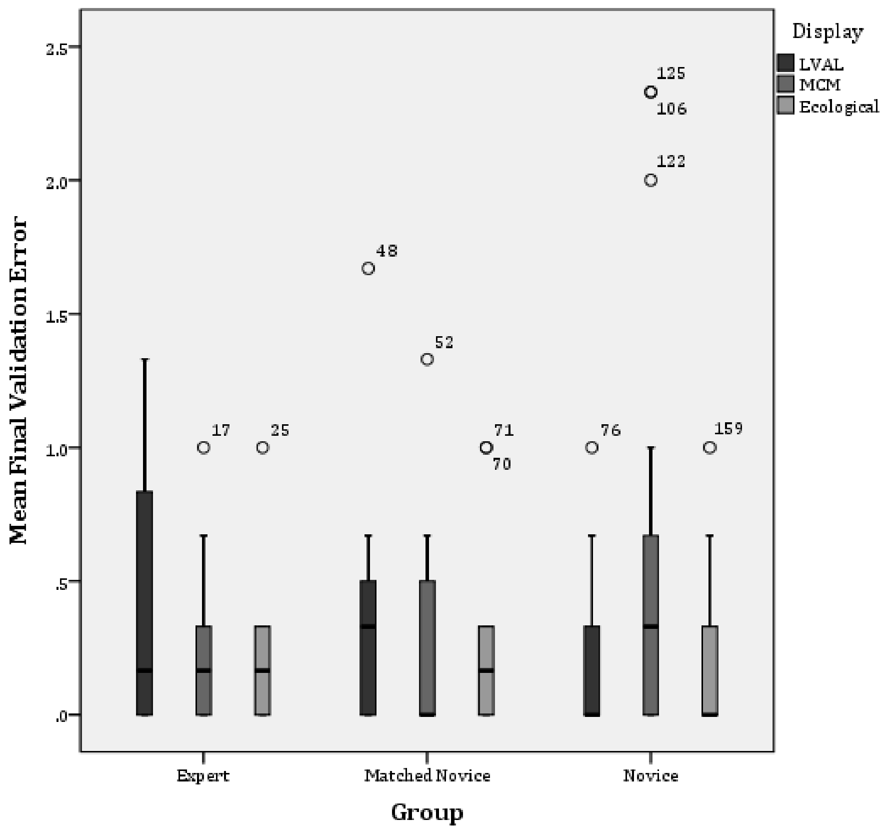


Figure 7-6: Mean final validation error for each group subdivided by display

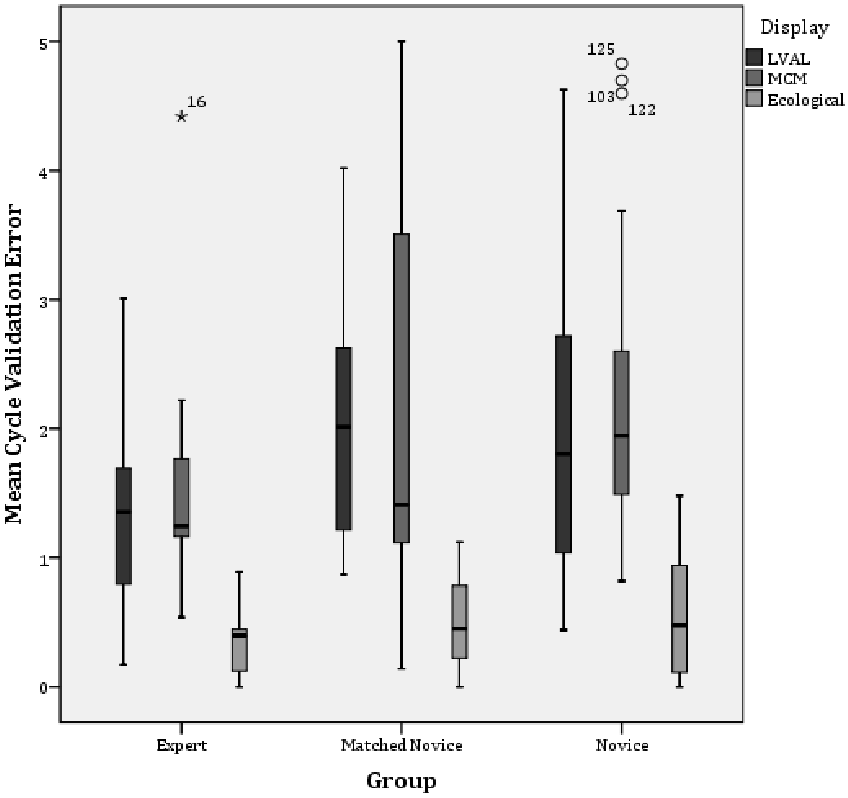


Figure 7-7: Mean cycle validation error for each group subdivided by display

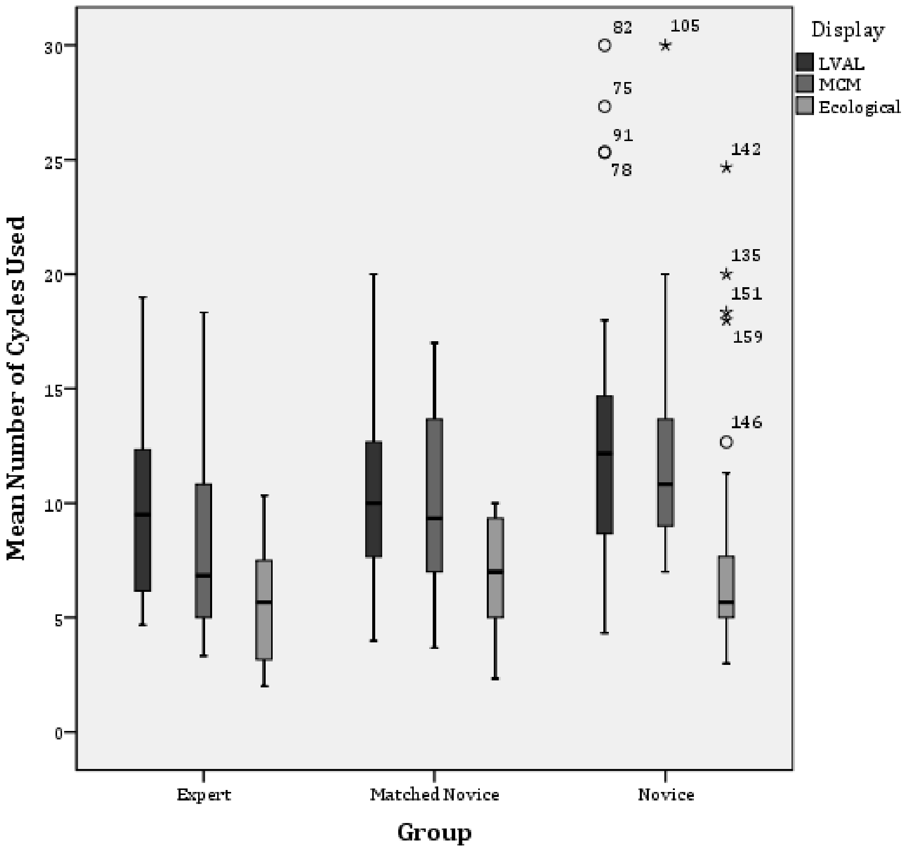


Figure 7-8: Mean number of cycles use to validate each link for each group subdivided by display

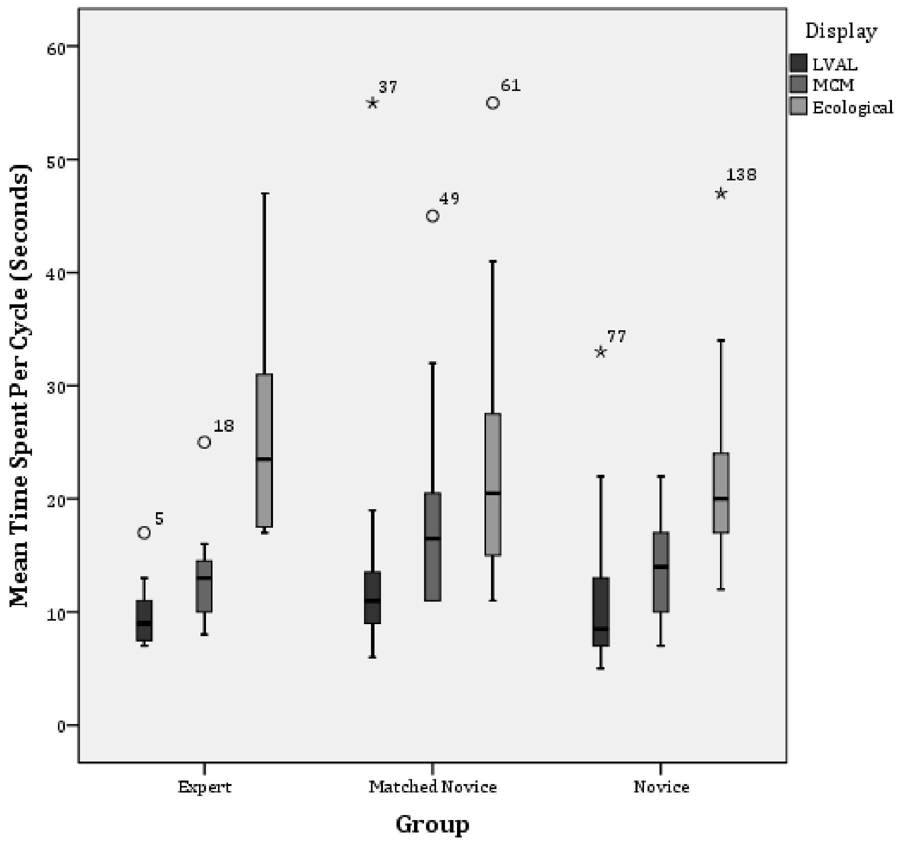


Figure 7-9: Mean time spent per cycle for each group subdivided by display

7.4.4 Effects on Workload

The display used was not predicted to directly affect workload (*H4*) and experts' responses to the NASA-TLX questionnaire (see Table 7-7) support this with no significant effect caused by the display on either overall workload (Figure 7-10) or any subscale, however reductions were elicited by both novice groups when using the ecological display, in particular a reduction in mental demand, effort and frustration as well as an increase in perceived performance resulting in significantly lower overall workload compared to the traditional displays.

Although most previous studies have shown that use of an ecological interface should not affect workload (e.g. Effken, 2006; Garabet & Burns, 2004; Hsieh et al., 2014) where the volume or complexity of tasks conducted is not comparable variations may occur (Lau, Jamieson, et al., 2008; Wickens & Hollands, 2000). From the validation task process diagrams (Figure 7-1 and Figure 7-3) it can be seen that the key difference between the traditional and ecological displays is that direct manipulation of the STOC value effectively creates a real-time feedback loop through which the impacts of any changes on the traffic model are provided. Using traditional displays users must predict these impacts based on their domain knowledge. The workload results could indicate that novices find this projection process cognitively demanding, with limited experience or knowledge to draw on. Conversely experts have no difficulty, potentially utilising less demanding Rule- or Skill-Based Behaviour (Rasmussen, 1983) to make decisions. Crucially experts did not appear to be impeded by the change in information presentation which adds to the evidence concluding that techniques such as EID don't result in higher workload (e.g. Garabet & Burns, 2004; Lau, Jamieson, et al., 2008).

7.4.5 Effects on Perceived System Usability

There is some evidence suggesting that ecological interfaces are perceived to be more usable than traditional designs ((*H5*); e.g. Effken, 2006; Ellerbroek et al., 2013), in this case the SUS responses (Table 7-8) show that there is a difference of opinion between experts and novices. Novices rated the ecological display as significantly more usable than either LVAL or MCM (Figure 7-11), being more likely to want to use the ecological system, find it easy to use, be well integrated and feel confident using it, while being less likely to find it unnecessarily complex, inconsistent or cumbersome to use. Experts on the other hand reported no significant differences between any of the displays.

Bangor, Kortum, and Miller (2008) in their evaluation of the SUS scale state that while acceptable scores will vary between domains a value of at least seventy is desired. All three participant groups rated the traditional displays below the acceptable level which could indicate a serious usability failure with the textual interfaces, MCM being of particular concern by consistently being rated the least usable display. Only the ecological display elicited a "passable" score however this was not unanimous, experts rating its usability significantly lower than novices but comparable to the traditional displays. These results resemble those observed for workload, the ecological display not appearing to be any less usable than traditional displays but the discrepancy between experts and novices being a cause for concern.

Potentially the cause could be the relative level of training, experts being skewed towards the traditional displays while novices were comparable between all interfaces. If this is the case then the perceived benefits shown by novices could translate to experts provided they are given the training necessary to use the ecological display (see Vicente, 1999). Similarly training appears to overcome the traditional displays' initial perceived difficulty, however given the objective performance improvements previously discussed adoption of an ecological display would still be recommended.

7.4.6 Limitations

Several experimental limitations should be considered. Firstly the validation process was simplified compared to reality by providing participants with street clear times designed to lead to a particular STOC value. This was necessary to standardise the experimental procedure and keep the time demands on participants manageable. As a consequence experts' performance could be underestimated in comparison to novices, for example the number of cycles required could be inflated due to the forcing of an initial random guess instead of a reasonable initial estimate based on the road layout. Secondly each display was to some extent limited by Microsoft Excel's constraints; most significantly it was not possible to implement true direct manipulation in the time frame of the experiment. It is encouraging that significant performance improvements were elicited by the ecological display however future work should address these limitations to test translation to the real-world.

Table 7-7: Means (standard deviations between parentheses) for workload measures

	Group									Significance					
	Expert (EX)			Matched Novice (MN)			Novice (N)			Within-subjects			Between-subjects		
Measure	1. LVAL (L)	2. MCM (M)	3. Eco. (E)	4. LVAL (L)	5. MCM (M)	6. Eco. (E)	7. LVAL (L)	8. MCM (M)	9. Eco. (E)	p value	sig. pairs	effect Size (d)	p value	sig. pairs	effect Size (d)
Overall workload	25.3 (13.2)	28.0 (15.0)	29.0 (14.9)	32.8 (16.6)	39.0 (14.5)	25.0 (12.2)	36.0 (13.9)	41.8 (13.5)	24.0 (12.0)	>0.05 (EX) <0.05 (MN) <0.0005 (N)	56, 78 79, 89	0.29 0.08 0.16 0.24	<0.05 (L/M) >0.05 (E)	17, 25, 28	0.24 0.22 0.27
Mental demand	33.0 (19.1)	35.4 (22.6)	38.3 (21.4)	40.0 (29.3)	53.8 (22.7)	29.2 (19.3)	44.0 (23.5)	57.5 (20.4)	29.7 (21.5)	>0.05 (EX) <0.05 (MN) <0.0005 (N)	56, 78, 79, 89	0.32 0.11 0.11 0.25	>0.05 (L/E) <0.05 (M)	25, 28	0.24 0.29
Physical demand	14.2 (14.8)	15.8 (14.3)	16.3 (15.7)	9.2 (6.0)	10.8 (6.7)	11.3 (8.0)	12.7 (9.0)	10.8 (8.3)	11.8 (7.6)	0.85 (EX) 0.31 (MN) 0.14(N)	N/A	N/A	>0.05 (L/M /E)	N/A	N/A

Measure	Group									Significance					
	Expert (EX)			Matched Novice (MN)			Novice (N)			Within-subjects			Between-subjects		
	1. LVAL (L)	2. MCM (M)	3. Eco. (E)	4. LVAL (L)	5. MCM (M)	6. Eco. (E)	7. LVAL (L)	8. MCM (M)	9. Eco. (E)	p value	sig. pairs	effect Size (d)	p value	sig. pairs	effect Size (d)
Temporal demand	28.3 (16.6)	30.0 (19.2)	28.8 (16.3)	25.0 (23.6)	23.3 (20.5)	23.8 (24.1)	27.7 (18.5)	29.5 (21.4)	17.8 (12.0)	>0.05 (EX/ MN) <0.05 (N)	79, 89	0.10 0.10	>0.05 (L/M) <0.05 (E)	39	0.20
Performance	25.8 (12.8)	25.8 (16.9)	26.7 (12.7)	43.8 (20.7)	51.3 (21.6)	34.6 (21.6)	47.2 (20.6)	49.5 (19.8)	30.7 (15.6)	>0.05 (EX/ MN) <0.0005 (N)	79, 89	0.15 0.18	<0.05 (L/M) >0.05 (E)	14, 17, 25, 28	0.40 0.47 0.44 0.40
Effort	25.8 (13.3)	32.5 (14.5)	34.2 (16.6)	41.3 (26.6)	54.6 (24.4)	25.8 (17.4)	42.8 (23.4)	56.0 (20.9)	32.7 (21.3)	>0.05 (EX) <0.005 (MN) <0.0005 (N)	56, 78 89	0.35 0.10 0.21	<0.05 (L/M) >0.05 (E)	14, 17, 25, 28	0.32 0.35 0.43 0.46
Frustration	24.6 (23.6)	28.3 (23.4)	29.6 (24.4)	37.9 (30.8)	40.0 (28.5)	25.4 (17.9)	41.8 (23.1)	47.7 (23.8)	21.2 (16.8)	>0.05 (EX/ MN) <0.0005 (N)	79, 89	0.16 0.21	<0.05 (L/M) >0.05 (E)	17, 28	0.21 0.24

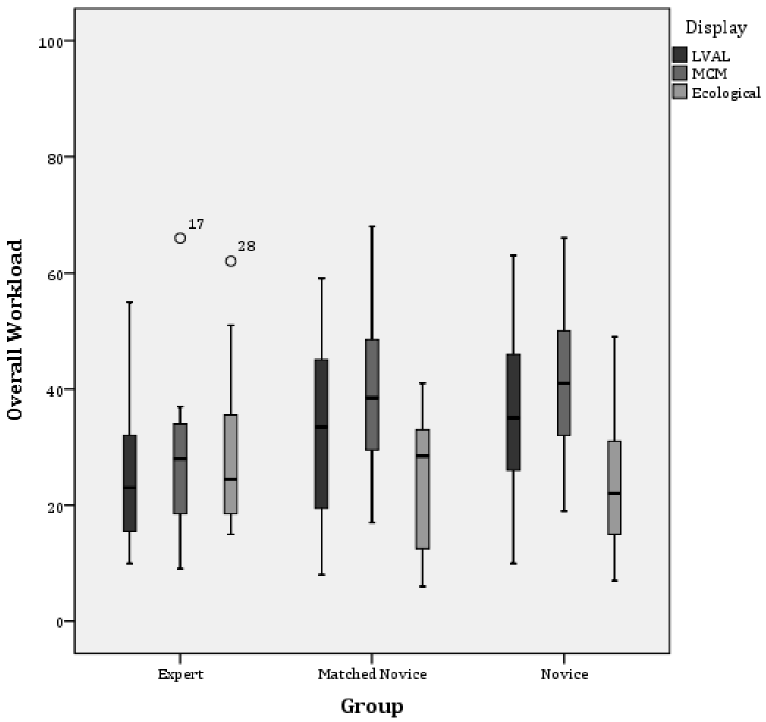


Figure 7-10: Overall workload calculated using TLX subscale responses for each group subdivided by display

Table 7-8: Mean (standard deviations between parenthesis) system usability and responses to SUS questions (Strongly Agree/Agree/Neither Agree or Disagree/Disagree/Strongly Disagree)

	Group									Significance					
	Expert (EX)			Matched Novice (MN)			Novice (N)			Within-subjects			Between-subjects		
Measure	1. LVAL (L)	2. MCM (M)	3. Eco. (E)	4. LVAL (L)	5. MCM (M)	6. Eco. (E)	7. LVAL (L)	8. MCM (M)	9. Eco. (E)	p value	sig. pairs	effect Size (d)	p value	sig. pairs	effect Size (d)
System usability	68.8 (17.1)	62.5 (18.3)	66.5 (19.7)	59.2 (21.0)	51.5 (23.6)	77.1 (17.3)	61.2 (17.1)	53.5 (19.1)	77.8 (13.7)	>0.05 (EX/ MN) <0.0005 (N)	78, 79, 89	0.08 0.18 0.24	>0.05 (L/M) <0.05 (E)	39	0.17
Question 1	0/2/3/6/1	0/2/4/5/1	1/1/4/4/2	4/1/4/3/0	4/2/2/4/0	0/2/5/4/1	3/9/11/7/0	3/11/8/8/0	1/1/6/12/10	>0.05 (EX/ MN) <0.0005 (N)	79, 89	N/A	>0.05 (L/M/ E)	N/A	N/A
Question 2	3/6/3/0/0	0/7/2/3/0	0/8/1/2/1	1/7/3/0/0	0/7/2/3/0	0/8/1/2/1	3/17/5/5/0	3/7/9/9/2	9/16/4/1/0	>0.05 (EX/ MN) <0.005 (N)	89	N/A	>0.05 (L/M/ E)	N/A	N/A
Question 3	0/0/2/6/4	0/1/4/6/1	0/3/2/4/3	0/2/4/5/1	1/4/4/3/0	0/1/3/3/5	1/5/4/17/3	1/9/7/9/4	0/0/4/11/15	>0.05 (EX/ MN) <0.005 (N)	79, 89	N/A	>0.05 (L/M/ E)	N/A	N/A
Question 4	4/5/3/0/0	3/6/2/1/0	4/6/1/1/0	4/4/3/1/0	3/5/0/4/0	7/3/1/1/0	4/11/6/8/1	5/10/6/7/2	13/8/7/1/1	>0.05 (EX/ MN/N)	N/A	N/A	>0.05 (L/M/ E)	N/A	N/A
Question 5	0/2/3/7/0	0/2/5/4/1	0/3/5/4/0	0/1/7/4/0	0/1/6/4/1	0/2/4/3/3	0/4/13/10/3	1/5/16/6/2	0/0/7/17/6	>0.05 (EX/ MN) <0.05 (N)	79, 89	N/A	<0.05	39	N/A
Question 6	0/7/5/0/0	1/5/4/2/0	2/7/3/0/0	3/2/5/2/0	3/4/4/1/0	6/6/0/0/0	7/9/11/3/0	3/10/11/6/0	9/16/5/0/0	>0.05 (EX/ MN) <0.05 (N)	89	N/A	>0.05 (L/M/ E)	N/A	N/A
Question 7	1/2/2/4/3	1/2/2/3/4	1/1/1/6/3	0/2/1/5/4	0/4/2/4/2	0/0/2/3/7	1/3/2/18/6	1/5/5/11/8/	0/1/0/16/13	>0.05 (EX/ MN/N)	N/A	N/A	>0.05 (L/M/ E)	N/A	N/A
Question 8	0/7/4/1/0	0/4/6/2/0	1/7/2/1/1	3/6/1/2/0	4/2/2/3/1	6/5/1/0/0	3/16/5/6/0	5/7/9/9/0	10/17/1/2/0	>0.05 (EX/ MN) <0.005 (N)	79, 89	N/A	>0.05 (L/M/ E)	N/A	N/A
Question 9	0/1/2/4/5	0/1/4/5/2	0/0/3/8/1	1/2/4/4/1	2/2/4/4/0	0/3/2/4/3	1/4/11/12/2	2/13/9/5/1	0/1/4/15/10	>0.05 (EX/ MN) <0.0005 (N)	79, 89	N/A	>0.05 (L/M/ E)	N/A	N/A
Question 10	2/6/3/0/1	3/3/5/0/1	5/3/4/0/0	3/5/3/1/0	4/4/2/1/1	6/2/4/0/0	6/14/3/4/3	2/13/5/8/2	9/12/6/3/0	>0.05 (EX/ MN/N)	N/A	N/A	>0.05 (L/M/ E)	N/A	N/A

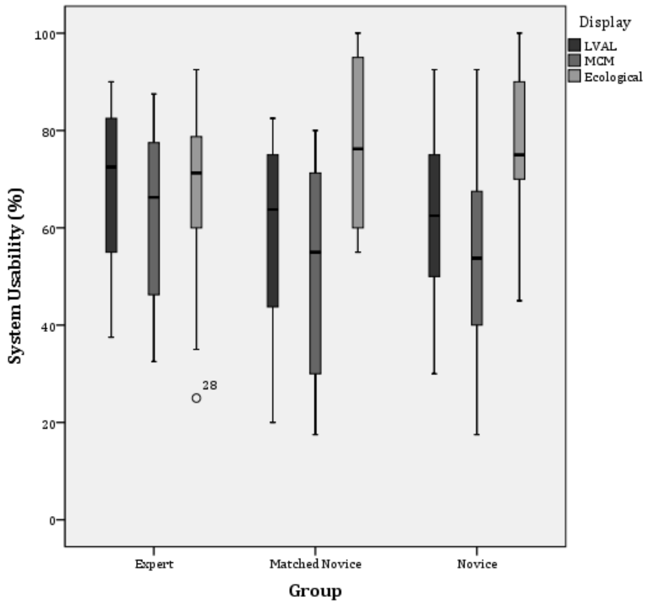


Figure 7-11: System usability (%) calculated using SUS responses for each group subdivided by display

7.5 Conclusions

An experiment was conducted to compare a concept ecological display against two traditional interfaces used to validate STOC values for SCOOT controlled traffic lights and to consider the role of experience on performance. The validation task was completed accurately by both experts and novices using all three displays however the ecological interface provided a number of performance benefits. Difficulties experienced by novices using traditional interfaces were overcome, with performance normalised in the ecological condition. Validation was also faster using the ecological interface with significant reductions in the number of cycles required elicited by all groups. Subjective assessments of workload and usability showed that the ecological design had a positive impact on novices but did not affect experts, suggesting that the traditional displays are initially hard to use but this can be overcome with training. Overall the experimental results support the continued development of an ecological interface for this domain; however further investigation is required to address several experimental limitations occurring within this study and confirm performance improvements, this is conducted in chapter 8.

Chapter 8: Further Evaluation of an Ecological Interface for STOC Validation

8.1 Introduction

An ecological SaTuration OCcupacy (STOC) tool could potentially overcome the limitations with the current Link VALidation (LVAL) tool used within PC SCOOT (see Siemens, 2013), which is perceived to be time consuming to use and with performance highly reliant on validators having extensive tacit knowledge regarding the domain. The experiment conducted in chapter 7 largely confirmed these concerns and demonstrated that validation using a concept ecological display (designed based on the principles of Ecological Interface Design (EID) in chapter 6) was not only comparably accurate to LVAL, but required fewer cycles to effectively validate, was less demanding of novice validators and improved their performance such that it was normalised with experts. Although these findings are compelling the experiment suffered from a number of limitations which must be addressed through further empirical testing before meaningful recommendations regarding STOC validation interface design can be provided.

The first concern is that the experimental validation process was simplified by providing participants with observed clear times designed to lead to a particular STOC value rather than recording real times from the link in question. This was necessary to standardise the experiment's procedure while meeting experimental deadlines. As a consequence performance may not be reflective of what could be expected in the real-world, in particular experts' performance may have been underestimated in comparison to novices because they were not able to begin with a reasonable estimate based on the road layout. To address this in chapter 8 source data will be acquired by measuring real observed clear times in order to make the experiment more realistic.

The second major concern related to the experimental ecological display which was constructed in Microsoft Excel and suffered from several limiting constraints. Firstly, it was not possible to implement true direct manipulation, STOC values were instead adjusted by clicking 'increase' and 'decrease' buttons (1 in Figure 8-1). Secondly, modelled clear times were shown as the 'x axis' intercept of a queue length line, comparison to observed clear times hence had to be calculated by participants manually (2 in Figure 8-1). Thirdly, STOC values selected for previous cycles were simply recorded as the value selected, participants had to decide on the best STOC for the link by comparing these static values (3 in Figure 8-1) instead of being able to compare the impacts of changing STOC values on all completed cycles. To address this limitation a more advanced, and truly ecological concept display will be developed which can be tested empirically against the traditional display.

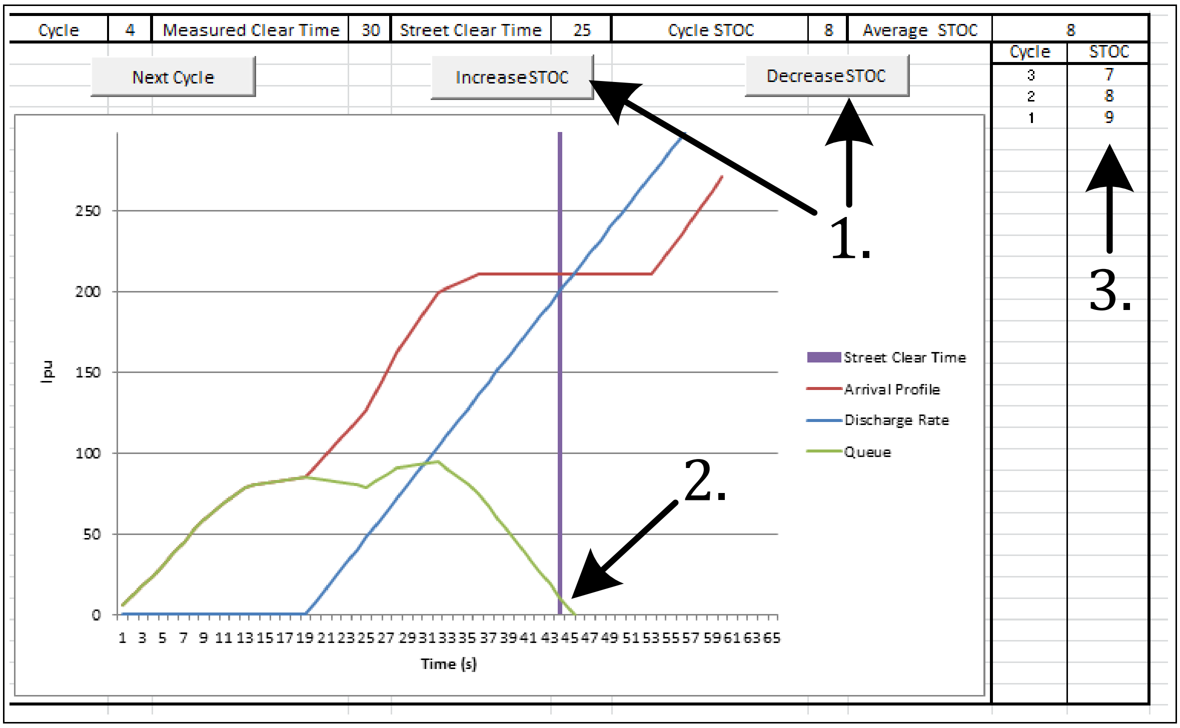


Figure 8-1: Chapter 7's ecological experimental limitations

8.2 Ecological STOC validation display development

The ecological validation process is detailed in Figure 8-2 with corresponding interface components for the developed ecological display, as compared to the concept designs produced in chapter 6, shown in Figure 8-3.

On commencement of validation an arrival profile from the link's induction loop detector is displayed in real time on a graph detailing the current state of the traffic lights in near real-time (1, in Figure 8-3). After the cycle is complete the observed clear time is input into the tool by dragging the slider along the graph's 'x axis' or by typing the value in (2, in Figure 8-3). STOC values are similarly input by dragging the slider along the graph's perimeter, plotting the modelled discharge rate (3, in Figure 8-3) with the resulting difference between modelled and observed clear times displayed below the graph (4, in Figure 8-3).

Further STOC adjustments can be made by dragging the slider to a new location (5, in Figure 8-3) with an aim of minimising the error between modelled and observed clear times to identify a theoretically correct STOC value for the current cycle (6, in Figure 8-3). As further cycles of data are obtained model comparisons are displayed together (7, in Figure 8-3) with the STOC value used persisting across cycles (8, in Figure 8-3), which may be adjusted as necessary throughout validation to minimise the model's average error (9 and 10, in Figure 8-3), the effects on model clear times of changing the STOC value are immediately reflected within the interface for all cycles of data. Once a STOC value is identified which is perceived to minimise the error over sufficient cycles validation is complete.

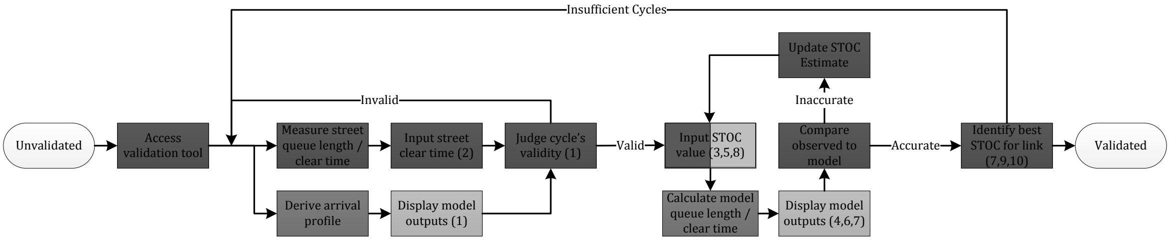
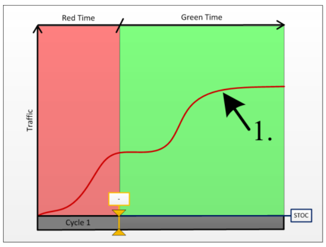
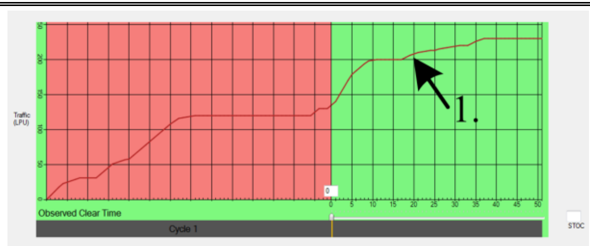
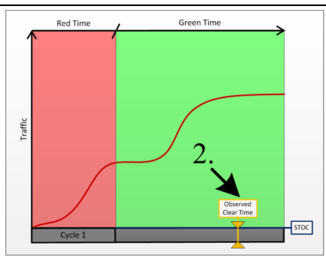
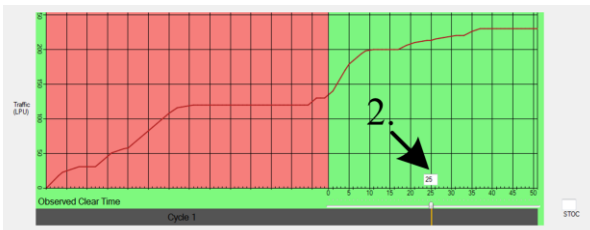
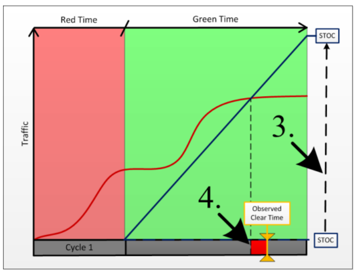
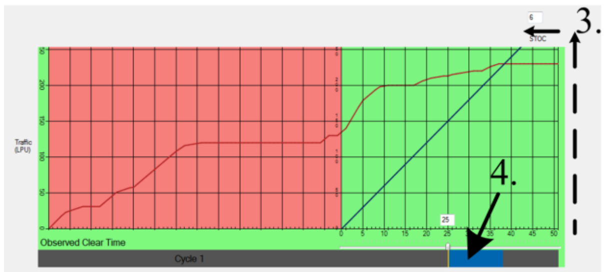


Figure 8-2: Ecological tool validation task process

Function	Concept	Experimental Display
Load arrival profile (1)		
Input street clear time (2)		
Input STOC value / output model queue clear time (3&4)		

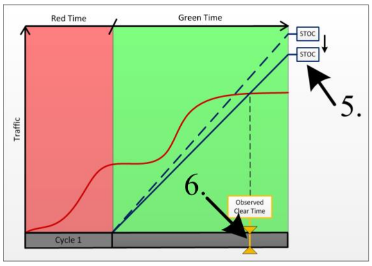
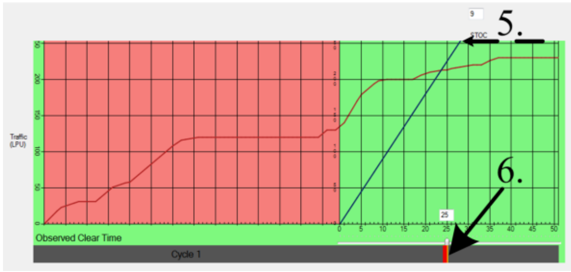
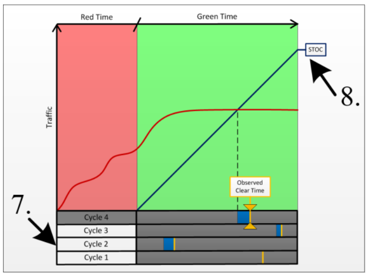
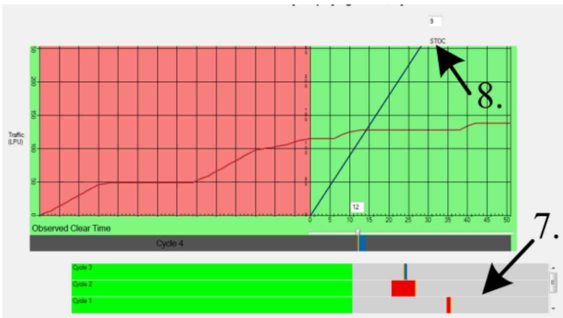
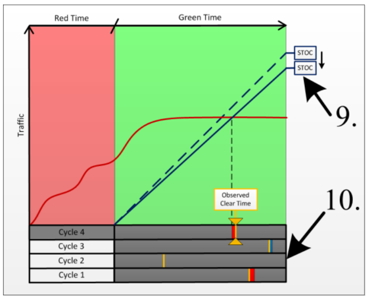
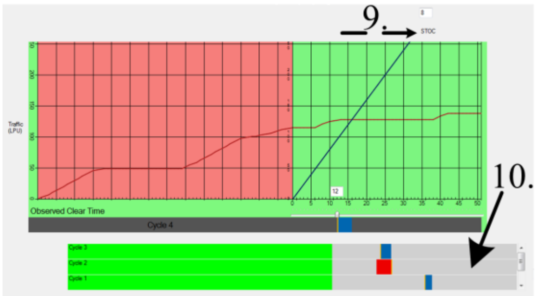
Function	Concept	Experimental Display
Manipulate STOC value (5&6)		
Repeat for further cycles (7&8)		
Adjust STOC to minimise error (9&10)		

Figure 8-3: Ecological display development

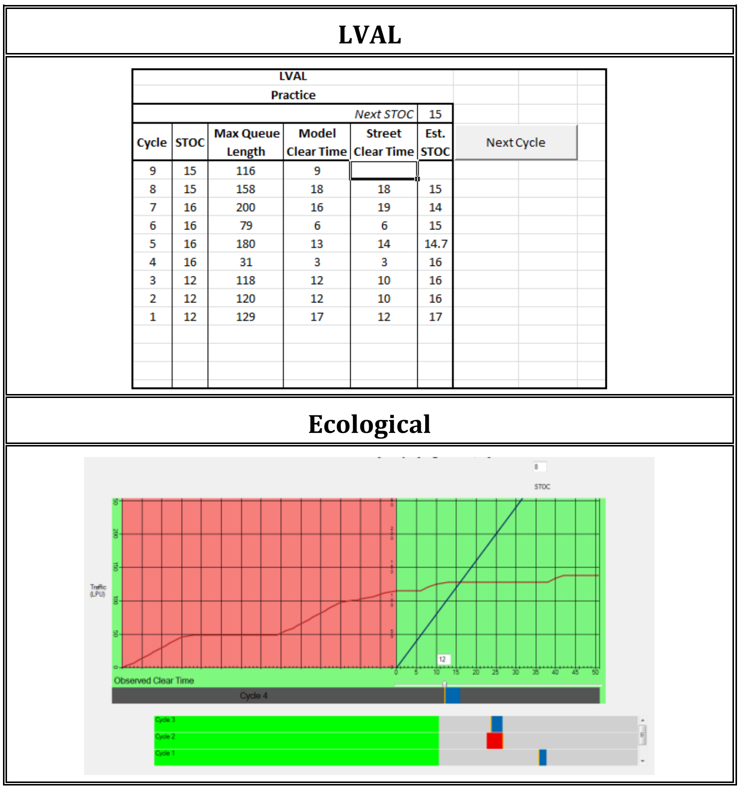
8.3 Methodology

8.3.1 Participants

Participants were divided into three groups. Experts comprised of six experienced validators, four male with a mean age of 44.0 years (σ = 12.3) and experience ranging from 6 to 30 years (μ = 15.0, σ = 10.5). Novices were divided into a group of six age and gender matched to the expert group as closely as possible (four male, μ_{age} = 44.5, σ_{age} = 12.1), and an unmatched group of thirty (sixteen male) with a mean age of 35.6 (σ = 12.9), all having no experience of SCOOT validation.

8.3.2 Equipment

The experiment was undertaken on a laptop with a 15” display. The LVAL interface was produced in Microsoft Excel (version 2010, see Figure 8-4), and is comparable to the condition in chapter 7. A stand-alone application was produced for the ecological display using the Microsoft .Net Framework. All displays were checked with an experienced SCOOT validator prior to commencing the experiment to ensure fitness for purpose. Navigation and interaction was carried out via keyboard and mouse.



Cycle	STOC	Max Queue Length	Model Clear Time	Street Clear Time	Est. STOC
9	15	116	9		
8	15	158	18	18	15
7	16	200	16	19	14
6	16	79	6	6	15
5	16	180	13	14	14.7
4	16	31	3	3	16
3	12	118	12	10	16
2	12	120	12	10	16
1	12	129	17	12	17

Figure 8-4: Experimental displays

8.3.3 Experimental Design

The experiment was designed as a between- and within-subjects repeated-measures where the factors *display* and *experience* were varied. The within-subjects *display* factor was divided into the existing LVAL display and the proposed ecological display. The between-subjects factor *experience* was divided into participants with validation experience (experts) and without (novices) who were subdivided into those age and gender matched to the expert group with the remaining placed in an unmatched group, this resulted in six conditions (2x3).

Dependent measures for this experiment consisted of both objective and subjective measures. *Performance* was measured in terms of the final validation error, mean cycle validation error, mean time spent per cycle and number of cycles used, validation error was categorised as the absolute deviation from the expert's median STOC value for each link. *System use* was measured in terms of the number of STOC adjustments made (ecological condition only), mean error from estimated STOC value (LVAL condition only) and the mean STOC adjustment cycle to cycle. *Workload* was measured using the NASA-TLX assessment of overall workload with subscales for mental demand, physical demand, temporal demand, performance, effort and frustration. *System usability* was measured using the SUS questionnaire with participants stating whether they "strongly agreed", "agreed", "neither agreed nor disagreed", "disagreed" or "strongly disagreed" with each statement shown in Table 8-1.

This experiment investigates the following hypotheses with each formulated based on the results from the first empirical study in chapter 7.

1. *H1:* Accuracy will be comparable regardless of *experience* but the ecological condition will elicit a reduction in the number of cycles required for all participants.
2. *H2:* Expert and novice performance will be normalised in the ecological condition and more variable when using LVAL.
3. *H3:* The ecological condition will take longer to use but this increase will not cause an increase in the number of cycles required to validate.
4. *H4:* Expert workload will be unaffected by *display* consistent with previous studies (e.g. Effken, 2006; Garabet & Burns, 2004; Hsieh et al., 2014), however novice workload will be reduced in the ecological condition.
5. *H5:* Novices will find the ecological condition more usable consistent with previous studies (e.g. Effken, 2006; Ellerbroek et al., 2013) however experts will be unaffected.

8.3.4 Procedure

Subjects were briefed on the purpose of the experiment and were allocated to a group. Conditions were undertaken in a predetermined counterbalanced order to account for learning effects. Each condition commenced with a practice session to familiarise the subject with the validation task using the display. Subjects were required to manipulate the STOC value such that the model provided accurate queue clear times in relation to observed values, it was explained that there was no correct answer and to cease validation once they were satisfied with a particular value. Three real links were then validated using the display, the order of which was counterbalanced using a Latin Square.

Source data for each link included traffic arrival profiles obtained from six links in Bristol (see Figure 8-5) using PC SCOOT's M14 messages (see Siemens, 2011) and observed clear times measured directly by monitoring the recorded link using Bristol Traffic Management Centre's CCTV system (see Figure 8-6 and Table 8-2). Twenty-five valid cycles (where a queue formed and was discharged in less than the Queue Clear Maximum Queue (QCMQ; Siemens, 2011) time) were obtained for each link.

After completing each condition a NASA-TLX assessment (Hart & Staveland, 1988) and System Usability Scale (SUS; Brooke, 1996) questionnaire were completed. The process was repeated for the second condition and typically took between 30mins and 1hr. Ethical approval was obtained from the University of Southampton's ethics committee prior to commencement of data collection (ethics number 14367).

8.3.5 Data Analysis

All data analysis will be conducted using SPSS (version 22) with significance set at 5%. Each dependent measures' normality will be assessed using a Shapiro-Wilk test. Where normality can be assumed either independent or paired samples T-Tests will be used to compare within- and between-subjects effects as appropriate. Conversely where normality cannot be assumed either Wilcoxon-Mann Whitney or Wilcoxon Signed Ranks tests will be used to compare both within- and between-subjects effects. Should the normality assumption vary within a dependent measure parametric tests will be used due to T-Tests' reasonable robustness to the normality assumption (Kirk, 1995). Categorical data collected by the SUS will be evaluated using a Chi-Square test. Effect sizes for all measures excluding categorical data will be evaluated using Cohen's d (Cohen, 1988).

Table 8-1: SUS questions

No.	Question
1	I think that I would like to use this system frequently
2	I found the system unnecessarily complex
3	I thought the system was easy to use
4	I think that I would need the support of a technical person in order to be able to use this system
5	I found the various functions in this system were well integrated
6	I thought there was too much inconsistency in this system
7	I would imagine that most people would learn to use this system very quickly
8	I found the system very cumbersome to use
9	I felt very confident using the system
10	I needed to learn a lot of things before I could get going with this system

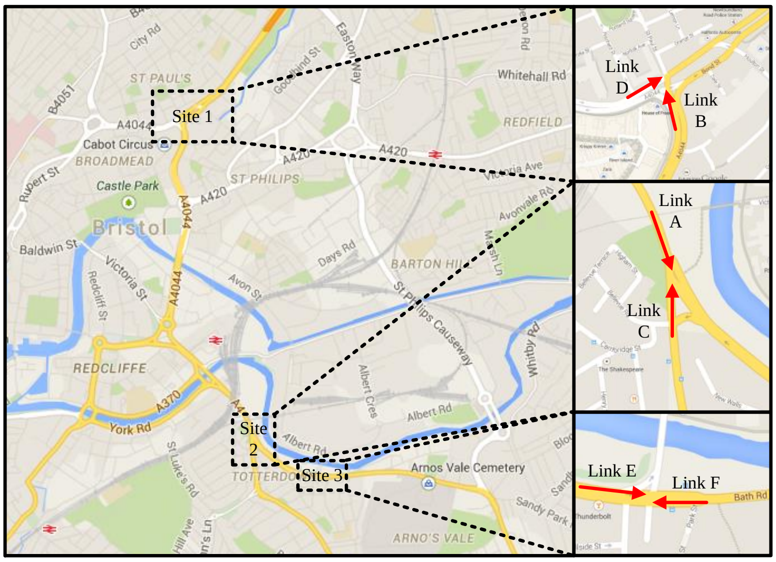


Figure 8-5: Link location plan

Link A	Link B
	
Link C	**Link D**
	
Link E	**Link F**
	

Figure 8-6: Link CCTV feeds

Table 8-2: Observed clear time (seconds) for all links

	Link					
Cycle	A	B	C	D	E	F
1	34	18	10	11	18	4
2	15	21	31	12	20	25
3	18	9	12	5	18	22
4	20	24	20	14	27	14
5	24	33	33	8	19	20
6	13	14	34	12	8	9
7	14	20	26	8	8	25
8	10	7	23	6	10	12
9	24	27	18	6	20	9
10	17	20	30	11	8	12
11	16	15	31	7	11	7
12	24	17	27	6	12	19
13	29	21	21	9	13	22
14	5	32	23	8	4	17
15	8	23	25	12	20	18
16	20	18	22	11	22	18
17	7	8	34	9	12	7
18	22	18	45	10	25	5
19	13	20	19	6	12	23
20	23	14	47	10	13	36
21	31	15	34	7	6	13
22	16	14	13	11	11	7
23	9	30	36	14	17	21
24	18	21	37	12	27	14
25	8	20	35	17	10	16

8.4 Results and Discussion

Shapiro-Wilk tests on each dependent measure revealed mixed normality assumptions (Table 8-3), therefore a variety of parametric and non-parametric tests were utilised for data analysis as specified in section 8.2.5

Table 8-3: Shapiro-Wilk normality test p values for performance, system use, workload and system usability measures

		Group					
		Expert		Matched Novice		Novice	
Factor	**Measure**	**LVAL**	**Eco**	**LVAL**	**Eco**	**LVAL**	**Eco**
Performance	Final validation error	.623	.124	.931	.396	.749	.212
	Mean cycle validation error	.425	.498	.319	.119	.679	.208
	Mean time spent per cycle	.643	.668	**.007**	.954	.129	**.004**
	Cycles required	.279	.329	**.041**	.092	.693	.120
System use	Eco. STOC Adjustments	N/A	.067	N/A	.905	N/A	.875
	Eco. Observed Clear Time Adjustments	N/A	**.010**	N/A	.523	N/A	**.036**
	Estimated STOC error	.372	N/A	.492	N/A	.808	N/A
	Mean STOC adjustment	.205	**.019**	.257	.413	.402	.717
Workload	Overall Workload	.073	.854	.131	.191	.244	.417
	Mental Demand	.387	.985	.134	.875	.083	.266
	Physical Demand	.234	.230	.078	.389	.110	**.000**
	Temporal Demand	.089	.315	**.002**	.415	.817	.212
	Performance	.320	.417	.596	**.039**	.673	.415
	Effort	.800	.781	.256	.737	.158	.331
	Frustration	.058	.674	.614	**.010**	.353	.117
System usability	System usability	.324	.307	.356	.107	.074	.460

8.4.1 Experience Effects on LVAL Display Performance

Minor differences were found when comparing novice groups' median validated STOC values to experts (Table 8-4) however each of these discrepancies was within one STOC value which based on discussions with Siemens' validators is an acceptable tolerance for link validation. No significant between-subjects effects were found for any performance measure suggesting that LVAL performance is not reliant on experience (see Table 8-5 for performance measure summary, Figure 8-7 and Figure 8-8) at least in controlled experimental conditions in support of *H1*. Novices were able to validate effectively using LVAL however while they did require more cycles than experts this increase was not as pronounced as previously observed. Overall novice performance using LVAL was found to be far more normalised with experts than the results from chapter 7, however they were more variable particularly in terms of final validation error and number of cycles used. This suggests that while novices are capable of using the LVAL display they are less predictable and therefore not as reliable as experts, this is in support of *H2*.

System use measures (Table 8-6) reveal that experts tended to make smaller incremental adjustments to STOC cycle to cycle. It was suggested that this may represent a rule-based behaviour (Rasmussen, 1983) employed to prevent wasteful oscillation either side of a correct STOC value, although limited benefit was obtained in this experiment, potentially due to the nature of the specific links validated, this strategy did not impede performance and should generally speaking lead to benefits. It was also found that the LVAL Estimate tool was typically ignored by both expert and novice groups, presumably because participants believed their own judgement regarding STOC adjustments to be superior. This lack of trust effectively negates any potential benefit provided by the tool and correlates with chapter 7's findings.

8.4.2 Experience Effects on Ecological Display Performance

Similarly to LVAL all participant groups were able to correctly identify link's STOC values with no significant between-subjects effects for any performance measure (Table 8-4, Table 8-5 and Figure 8-7 to Figure 8-10). As observed in the LVAL condition experience did not appear to impact performance with all participants being able to effectively use the display (in support of *H1*). This finding is particular encouraging because it suggests that all validators are able to achieve comparable performance to LVAL despite the limited training provided in the display's use. The ecological display also elicited a substantial reduction in novices' variability (in support of *H2*) and hence they could be perceived to be more reliable, giving the ecological display an important advantage over LVAL, although it should be reiterated that use of the ecological interface does not negate the need for effective training (Vicente, 1999).

System use measures (Table 8-6) did not reveal any significant between-subjects differences suggesting that experts and novice groups tended to use the ecological display similarly; this was a slight difference to that observed in chapter 7 where experts tended to make fewer adjustments to STOC, but could be due to differences both in the display and source data used.

8.4.3 Display Effects on Validation Speed

The number of cycles used to validate a link is the primary measure of validation speed, with time spent using the display also considered. The ecological display elicited a significant reduction in the number of cycles used to validate by all participant groups (Table 8-5 and Figure 8-9). Reductions were in the order of 50% over the LVAL condition which represents a significant potential time saving given cycles typically last between two and four minutes (Siemens, 2011). This reduction is approximately comparable to that observed in chapter 7 and lends support both to *H1* and the evidence suggesting response times can be improved when using ecological displays (e.g. Hsieh et al., 2014; Jamieson, 2002, 2007; Torenvliet et al., 2000).

This benefit was however obtained at the cost of participants spending significantly longer using the ecological display compared to LVAL within a cycle (Table 8-5 and Figure 8-10). As discussed in chapter 7 this increase is only relevant if it causes a subsequent traffic cycle to be missed which would not be the case given the magnitude of the increase (approximately twenty seconds on average). This confirms *H3* and correlates with the findings in chapter 7 where it was found that adjusting STOC values graphically is more time consuming than simply comparing the textual clear times provided by LVAL.

Ultimately this trade-off is inconsequential with the potential reduction in cycles required to validate elicited by the ecological display important for several reasons. Firstly, validation typically occurs in close proximity to a road and therefore validators are exposed to the potential risks of this working environment, by reducing the amount of time validators are exposed to these risks an important safety benefit can be achieved (see Department for Transport, 2013; Knight & Emmerson, 2008). Secondly, SCOOT validation is very time consuming typically accounting for approximately 30% of the time spent commissioning a SCOOT system (Siemens, 2011), and hence a significant portion of the implementation cost, by reducing the time required to validate links the SCOOT system as a whole should be validated more efficiently, which could result in cost savings being achieved, although further real-world investigation would be required to confirm this benefit.

Table 8-4: Median validated link STOC values by group

	Link					
Group	A	B	C	D	E	F
Experts	7	18	9	22	13	9
Matched Novices	6	19	9	21	13	9
Novices	7	19	9	22	13	9

Table 8-5: Means (standard deviations between parentheses) for performance measures

	Group						Significance					
	Expert (EX)		Matched Novice (MN)		Novice (N)		Within-subjects			Between-subjects		
Measure	1. LVAL (L)	2. Eco (E)	3. LVAL (L)	4. Eco (E)	5. LVAL (L)	6. Eco (E)	p value	sig. pairs	effect Size (d)	p value	sig. pairs	effect Size (d)
Final validation error	0.45 (0.61)	0.49 (0.51)	0.40 (0.45)	0.60 (0.67)	0.64 (0.69)	0.46 (0.51)	>0.05 (EX/ MN/N)	N/A	N/A	>0.05 (L/E)	N/A	N/A
Mean cycle validation error	1.37 (1.17)	0.94 (0.82)	1.16 (0.89)	0.86 (0.52)	1.18 (0.76)	0.79 (0.44)	>0.05 (EX/ MN) <0.005 (N)	56	0.17	>0.05 (L/E)	N/A	N/A
Cycles required	11.72 (6.33)	6.06 (1.35)	9.72 (4.99)	5.39 (1.58)	13.54 (5.76)	6.40 (2.71)	<0.05 (EX) <0.005 (MN/ N)	12 34 56	0.40 0.33 0.33	>0.05 (L/E)	N/A	N/A
Mean time between cycles (sec)	10 (4)	35 (8)	9 (4)	30 (4)	10 (4)	31 (8)	<0.005 (EX/MN /N)	12 34 56	2.36 2.77 1.98	>0.05 (L/E)	N/A	N/A

Table 8-6: Means (standard deviations between parentheses) for system use measures

	Group						**Significance**					
	Expert (EX)		**Matched Novice (MN)**		**Novice (N)**		**Within-subjects**			**Between-subjects**		
Measure	**1. LVAL (L)**	**2. Eco (E)**	**3. LVAL (L)**	**4. Eco (E)**	**5. LVAL (L)**	**6. Eco (E)**	**p value**	**sig. pairs**	**effect size (d)**	**p value**	**sig. pairs**	**effect size (d)**
Mean Ecological OCT adjustments per cycle	N/A	1.84 (0.73)	N/A	2.05 (0.59)	N/A	3.10 (4.29)	N/A	N/A	N/A	>0.05 (E)	N/A	N/A
Mean Ecological STOC adjustments per cycle	N/A	10.37 (7.13)	N/A	10.72 (5.08)	N/A	10.08 (5.75)	N/A	N/A	N/A	>0.05 (E)	N/A	N/A
LVAL Estimated STOC error	2.42 (1.40)	N/A	1.66 (1.15)	N/A	1.68 (1.06)	N/A	N/A	N/A	N/A	>0.05 (L)	N/A	N/A
Mean STOC adjustment	0.42 (0.39)	1.05 (1.37)	0.86 (0.86)	0.82 (0.69)	0.90 (0.70)	0.72 (0.62)	>0.05 (EX/MN/N)	N/A	N/A	<0.05 (L) >0.05 (E)	15	0.11

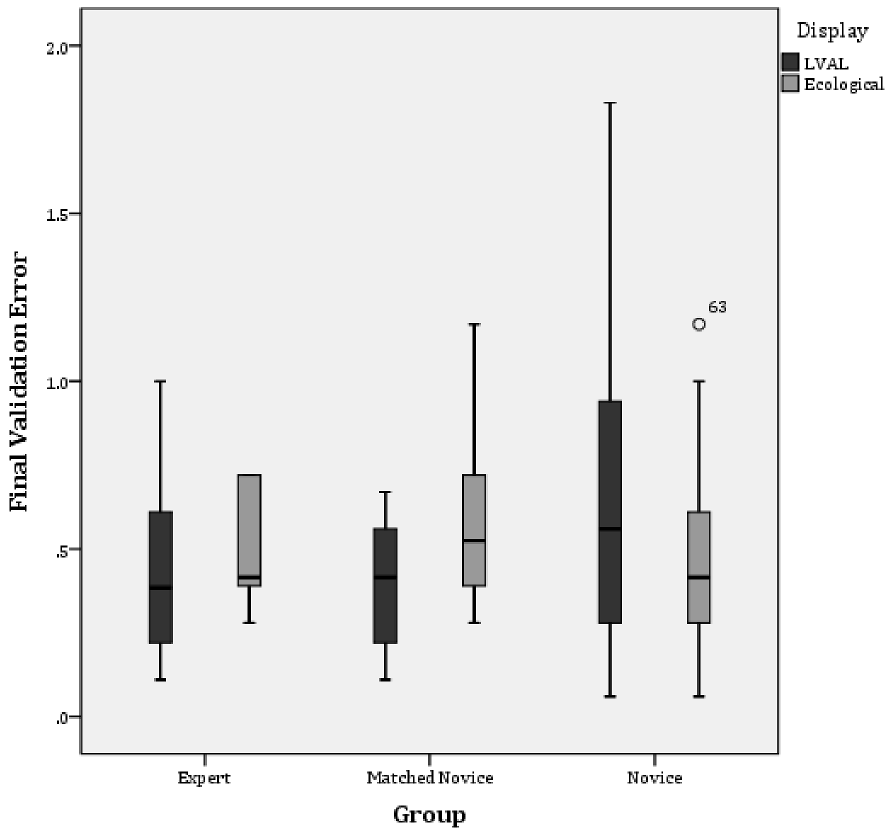


Figure 8-7: Final validation error for each group subdivided by display

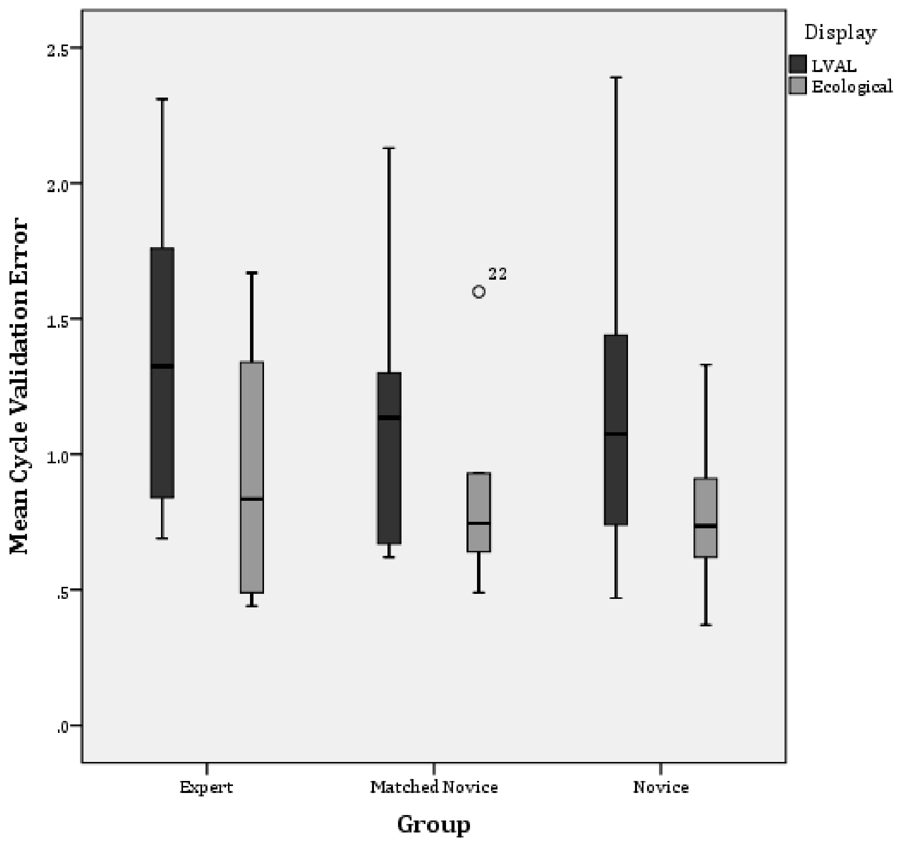


Figure 8-8: Mean cycle validation error for each group subdivided by display

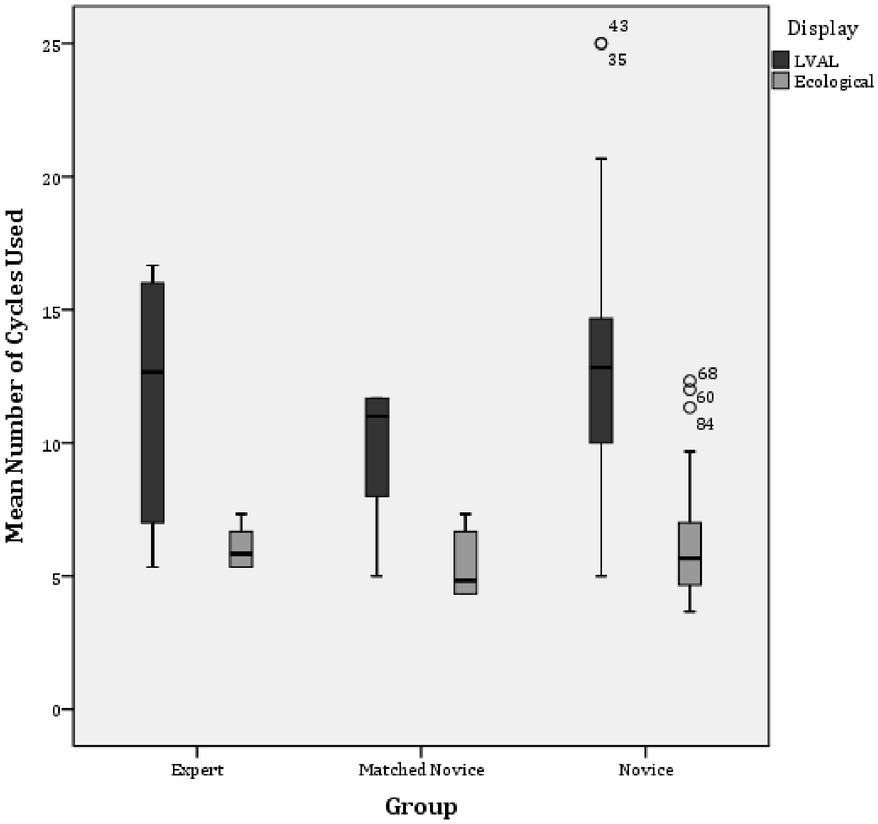


Figure 8-9: Mean number of cycles used to validate each link for each group subdivided by display

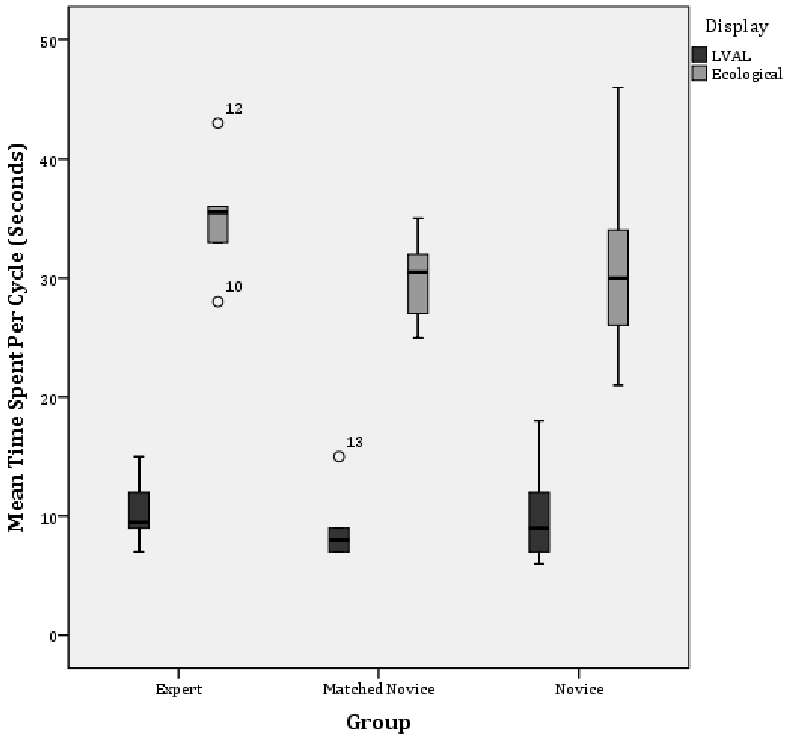


Figure 8-10: Mean time spent per cycle for each group subdivided by display

8.4.4 Effects on Workload

Responses to the NASA-TLX questionnaire (Table 8-7 and Figure 8-11) reveal no significant within-subjects effects observed for the expert group in terms of each subscale and overall workload, hence they did not report the ecological display to be significantly harder to use than LVAL despite only having limited exposure with it. Significant within-subjects effects were reported in the novice groups, where the ecological display was found to elicit reductions in overall workload and most component subscales, particularly mental demand and perceived performance, effort and frustration. This evidence is directly in support of *H4* and correlates with the findings from chapter 7.

Previous studies have suggested that changing displays should not impact workload if the tasks performed are comparable (e.g. Effken, 2006; Garabet & Burns, 2004; Hsieh et al., 2014), however if the volume or complexity of tasks is altered variations may occur (e.g. Lau, Jamieson, et al., 2008; Wickens & Hollands, 2000). This could suggest that the task process used by the ecological display is consistent with experts' mental model using LVAL, hence workload was not affected by the change of display. Conversely novices have to develop this model when using LVAL representing an increase in complexity thereby increasing workload and enabling the ecological display to provide a benefit by enabling access to this expert behaviour.

In addition several significant between-subjects effects were observed. In relation to LVAL novices found the display more frustrating to use and perceived their performance to be worse than experts despite being comparatively accurate. This is interesting because it suggests that LVAL's feedback is difficult to interpret without experience. It may be that the feedback provided by LVAL is inappropriate (Norman, 1990) for the validation task and instead of aiding inexperienced validators it instead represents a major barrier to the display's accessibility.

In the ecological condition experts reported significantly higher mental and temporal demand as well as frustration than novices; bringing these values in line with those they reported using LVAL, but as discussed not significantly exceeding them. This experiment therefore provides further evidence that use of an ecological display does not increase workload (Garabet & Burns, 2004; Lau, Jamieson, et al., 2008). Given the findings for novice groups it is possible that were experts to have a comparable degree of experience using the ecological display workload reductions could be elicited, however further investigations would be required to confirm this.

Table 8-7: Means (standard deviations between parentheses) for workload measures

	Group						**Significance**					
	Expert (EX)		**Matched Novice (MN)**		**Novice (N)**		**Within-subjects**			**Between-subjects**		
Measure	**1. LVAL (L)**	**2. Eco (E)**	**3. LVAL (L)**	**4. Eco (E)**	**5. LVAL (L)**	**6. Eco (E)**	**p value**	**sig. pairs**	**effect size (d)**	**p value**	**sig. pairs**	**effect size (d)**
Overall workload	30.8 (8.7)	35.4 (12.9)	36.9 (13.1)	17.9 (8.5)	37.7 (12.0)	24.5 (12.3)	>0.05 (EX) <0.05 (MN) <0.005 (N)	34 56	0.05 0.67	>0.05 (L/E)	N/A	N/A
Mental demand	43.0 (17.8)	48.3 (13.7)	53.0 (20.7)	24.2 (10.7)	51.0 (21.2)	33.0 (18.6)	>0.05 (EX) <0.05 (MN) <0.005 (N)	34 56	0.10 0.59	>0.05 (L) <0.05 (E)	24	0.76
Physical demand	23.3 (19.4)	21.7 (18.1)	15.0 (5.5)	12.5 (7.6)	13.8 (11.8)	13.7 (12.7)	>0.05 (EX/ MN/N)	N/A	N/A	>0.05 (L/E)	N/A	N/A
Temporal demand	40.8 (11.1)	35.8 (15.9)	25.8 (20.1)	13.3 (6.1)	28.2 (15.2)	18.5 (11.8)	>0.05 (EX/ MN) <0.05 (N)	56	0.36	>0.05 (L) <0.05 (E)	24 26	0.63 0.47
Performance	20.0 (10.5)	29.2 (22.7)	39.2 (18.6)	29.2 (24.0)	49.8 (19.4)	30.3 (16.3)	>0.05 (EX/MN) <0.0005 (N)	56	0.22	<0.005 (L) >0.05 (E)	15	1.10
Effort	40.0 (16.4)	38.3 (23.2)	53.3 (21.1)	18.3 (9.3)	44.3 (18.7)	30.8 (18.7)	>0.05 (EX) <0.05 (MN) <0.005 (N)	56	0.80	>0.05 (L/E)	N/A	N/A
Frustration	17.5 (10.4)	39.2 (22.7)	35.0 (24.3)	10.0 (7.8)	39.2 (23.7)	20.5 (18.9)	>0.05 (EX/MN) <0.005 (N)	56	0.46	<0.05 (L/E)	15 24 26	0.76 0.57 0.36

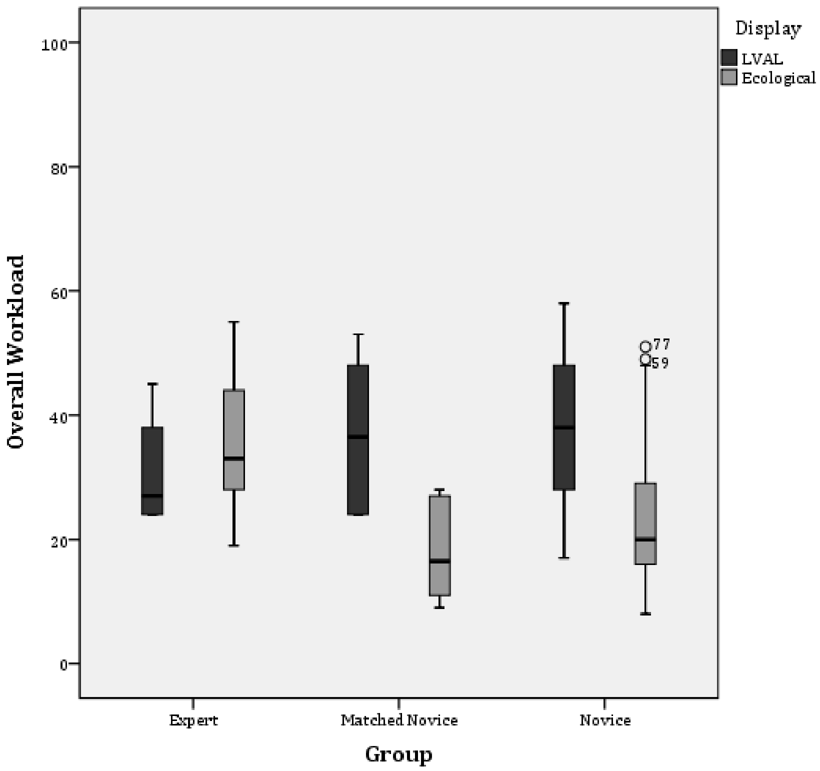


Figure 8-11: Overall workload calculated using TLX subscale responses for each group subdivided by display

8.4.5 Effects on Perceived System Usability

Responses to the SUS questionnaire (Table 8-8 and Figure 8-12) reveal significant within-subjects effects were only obtained for the novice group. Although experts on average reported the ecological display to be less usable than the LVAL display this was not significant, with novice groups conversely reporting the opposite. This is directly in support of *H5* and the findings in chapter 7. Novices were more likely to want to use the ecological system, find it easy to use, be well integrated and feel confident using it, while being less likely to find it unnecessarily complex, inconsistent or cumbersome to use.

These findings are consistent with evidence from other studies which have demonstrated that ecological displays are perceived to be more usable than traditional designs (e.g. Effken, 2006; Ellerbroek et al., 2013), however between-subjects effects reveal significant differences between expert and novice groups in respect to this.

Experts found LVAL to be significantly more usable than novices which was unsurprising given that they had considerably more experience using the display. Conversely novice groups found the ecological display significantly more usable than experts. Novice's had comparable degrees of experience with both displays; it is therefore important to establish if these benefits are limited to novices or whether they can be elicited whenever experience is comparable across displays. As was the case in chapter 7 and has been noted in other studies (e.g. Ellerbroek et al., 2013; Lau, Jamieson, et al., 2008) it is rarely possible to provide sufficient training in a concept system to fairly compare it to a traditional system, which is a significant limitation given that ecological displays are not intended to eliminate the need for this training (Vicente, 1999). If sufficient training could be provided then it is possible that the benefit observed by novices could also transfer to experts, however further investigations would be required to confirm this.

Table 8-8: Mean (standard deviations between parenthesis) system usability and responses to SUS questions (Strongly Agree/Agree/Neither Agree or Disagree/Disagree/Strongly Disagree)

	Group						**Significance**					
	Expert (EX)		**Matched Novice (MN)**		**Novice (N)**		**Within-subjects**			**Between-subjects**		
Measure	**1. LVAL (L)**	**2. Eco (E)**	**3. LVAL (L)**	**4. Eco (E)**	**5. LVAL (L)**	**6. Eco (E)**	**p value**	**sig. pairs**	**effect size (d)**	**p value**	**sig. pairs**	**effect size (d)**
System usability	74.6 (6.0)	57.9 (16.1)	56.7 (25.0)	85.0 (14.9)	54.3 (17.6)	77.6 (15.8)	>0.05 (EX/MN) <0.0000 5 (N)	56	0.69	<0.05 (L/E)	15 24 26	1.11 0.72 0.52
Question 1	0/0/1/ 4/1	0/2/1/ 3/0	1/2/2/ 1/0	0/1/2/ 1/2	2/17/4 /7/0	1/6/3/ 15/5	>0.05 (EX/MN) <0.005 (N)	56	N/A	<0.05 (L) >0.05 (E)	15	N/A
Question 2	2/3/0/ 1/0	0/2/2/ 2/0	0/4/0/ 2/0	3/3/0/ 0/0	4/9/10 /7/0	11/13/ 2/4/0	>0.05 (EX/MN) <0.05 (N)	56	N/A	>0.05 (L/E)	N/A	N/A
Question 3	0/0/0/ 6/0	1/2/0/ 3/0	1/1/2/ 1/1	0/0/0/ 3/3	1/11/5 /9/4	0/2/2/ 11/15	>0.05 (EX/MN) =0.005 (N)	56	N/A	<0.05 (L/E)	15 26	N/A
Question 4	3/3/0/ 0/0	2/2/1/ 1/0	2/3/0/ 0/1	5/1/0/ 0/0	5/9/10 /6/0	11/13/ 5/1/0	>0.05 (EX/MN) <0.05 (N)	56	N/A	<0.05 (L) >0.05 (E)	35	N/A
Question 5	0/2/3/ 1/0	0/2/2/ 2/0	0/2/1/ 2/1	0/0/1/ 2/3	0/7/15 /6/2	0/1/6/ 14/9	>0.05 (EX/MN) <0.005 (N)	56	N/A	>0.05 (L) =0.05 (E)	26	N/A
Question 6	1/3/1/ 1/0	1/2/2/ 0/1	2/1/2/ 1/0	3/3/0/ 0/0	3/8/10 /6/3	12/12/ 4/2/0	>0.05 (EX/MN) <0.05 (N)	56	N/A	>0.05 (L/E)	N/A	N/A
Question 7	0/0/2/ 3/1	1/1/1/ 2/1	0/1/1/ 3/1	0/0/0/ 3/3	1/4/7/ 9/9	0/0/2/ 8/20	>0.05 (EX/MN) <0.05 (N)	56	N/A	>0.05 (L) <0.05 (E)	26	N/A
Question 8	1/4/1/ 0/0	0/1/4/ 1/0	1/1/1/ 3/0	3/3/0/ 0/0	4/10/3 / 11/2	13/12/ 2/3/0	>0.05 (EX/MN) <0.05 (N)	56	N/A	<0.05 (L/E)	24 26 35	N/A
Question 9	0/0/0/ 4/2	0/0/3/ 3/0	1/1/4/ 0/0	0/0/2/ 1/3	1/11/1 0/6/2	0/2/8/ 12/8	>0.05 (EX/MN) <0.05 (N)	56	N/A	<0.05 (L) >0.05 (E)	15	N/A
Question 10	2/3/0/ 1/0	2/1/2/ 1/0	3/1/1/ 0/1	2/2/1/ 1/0	4/11/9 /6/0	10/16/ 4/0/0	>0.05 (EX/MN) <0.05 (N)	56	N/A	<0.05 (L) >0.05 (E)	35	N/A

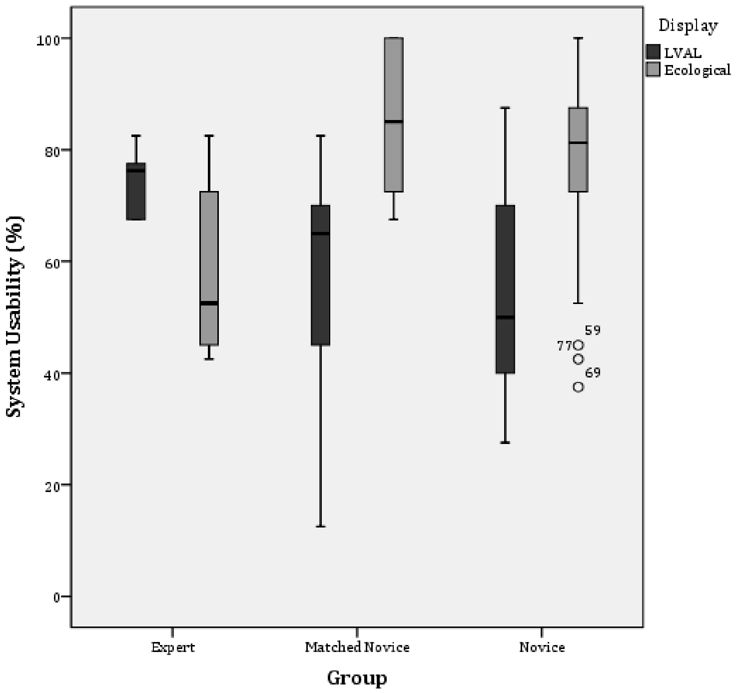


Figure 8-12: System usability (%) calculated using SUS responses for each group subdivided by display

8.5 Conclusions

A follow-up experiment to chapter 7 was conducted to compare a developed ecological STOC validation display against the traditional LVAL interface. Several limitations with the first experiment were addressed, specifically real observed clear times were utilised and the ecological display was significantly developed from the Excel based prototype used previously. The results confirmed many of the findings from chapter 7 with validation being effectively conducted by both experts and novices in both conditions but the ecological display eliciting a number of performance benefits over LVAL. Reliability, workload and usability were improved for novice validators, while experts were not adversely impacted by the change of display and retained comparable accuracy as when using LVAL. Perhaps most significantly the ecological display substantially reduced the number of cycles required to validate, with the benefits associated with the resulting time savings warranting further consideration be given to developing a fully functioning ecological validation display. A limiting factor for the time savings able to be obtained by the ecological display is that it is currently only feasible to validate a single link at a time; chapter 9 will therefore investigate the potential to automate parts of the STOC validation process which could enable multiple links to be validated simultaneously and hence offer even greater savings.

Chapter 9: Development and Evaluation of an Automated STOC Selection Algorithm

9.1 Introduction

In the final stages of the project Siemens expressed an interest in exploring the potential to automate the STOC validation process investigated in chapters 6, 7 and 8. By standardising the process it may be possible to gain advantages over human validators in terms of consistency and efficiency, in particular reducing demands on validators and enabling them to focus on more complex tasks.

The work conducted in chapters 7 and 8 showed that an ecological display was able to overcome the key issues with LVAL, specifically that validation performance was highly reliant on validators' tacit knowledge, was time consuming and could result in variable accuracy, particularly for novice users. The key benefit elicited was a significant reduction in the number of cycles required to validate and hence a beneficial time saving for the validation process as a whole. While these advantages are significant automating STOC validation could provide further advantages in two key areas.

Firstly, automation would entirely negate the need for tacit knowledge within the task. Provided that the automation can be shown to be comparably accurate to manual validation when using the same number of cycles, then the complexity of the task for validators would be significantly reduced, enabling them to focus their time and effort on other areas of the validation process.

Secondly, a key constraint on validation speed is the need to validate links one at a time. The task processes shown in Figure 9-1 (adapted from the strategies analyses in chapters 5 and 6) show that both LVAL and ecological displays require clear time data to be gathered and analysed, resulting in a STOC value being chosen for the current cycle with performance then evaluated over subsequent cycles. Validating multiple links would require these decision selection and action implementation tasks (see Parasuraman, Sheridan, & Wickens, 2000) to be completed before the next link becomes active which is typically unfeasible. A way to overcome this limitation would be to automate some of the analysis and decision-making tasks, enabling validators to focus on measuring queue clear times and then evaluating the node's performance. Ultimately it should be possible to collect all of the required data for an entire junction, with the algorithm then identifying the best STOC values for each link simultaneously and hence provide a significant time saving.

Arguably correct application of automation is its greatest challenge (Parasuraman, 1997); well-designed automation should work alongside human operators to provide assistance where performance could be improved. The issue then becomes how to balance tasks and feedback, such that performance is maximised and the automation trusted (Lee & Moray, 1992). Automation typically copes well with routine, predictable tasks but often lacks the intelligence to deal with abnormal circumstances (Norman, 1990) as has been considered in a variety of transport domains such driving assistance tools (e.g. Stanton, Young, & Walker, 2007; Walker, Stanton, & Young, 2001) and autopilot design (e.g. Harris, 2004; van Marwijk, Borst, Mulder, & van Paasen, 2011).

The STOC validation tasks most suitable for automation are highlighted grey in Figure 9-1, specifically modelled and observed clear times must be compared leading to an updated STOC estimate. It is likely that these tasks can be effectively automated because they are both routine, being identical link to link, and predictable, utilising fixed rules to evaluate performance. This chapter is therefore concerned with developing an algorithm to perform these tasks and then empirically evaluating performance compared to manual validation using LVAL, ecological display and LVAL's existing STOC estimation algorithm. In this way it is intended to establish firstly whether automation can be sufficiently accurate to replicate human validators' performance, and secondly to identify the extent of any benefits and limitations of this approach compared to traditional validation.

9.2 STOC Selection Assistance

9.2.1 Model Error Minimisation

Model Error Minimisation (MEM) is a concept algorithm for selecting a STOC value derived from the ecological STOC validation process shown in Figure 9-1. The premise is that the most accurate STOC value for a link minimises the error between modelled and observed clear times provided that these are valid (i.e. are representative of local traffic conditions and were not impacted by any abnormal events such as a vehicle stalling). By manipulating the STOC value used and measuring the resulting impact on modelled clear times relative to observed values over a number of cycles the most accurate STOC value can be derived. In this way all decision selection tasks are conducted by the algorithm leaving validators to input observed clear times and evaluate the output STOC value (Figure 9-1), providing them with ultimate control over validation. The variables required to calculate STOC based on MEM are shown in Table 9-1 while Table 9-2 details the algorithm itself.

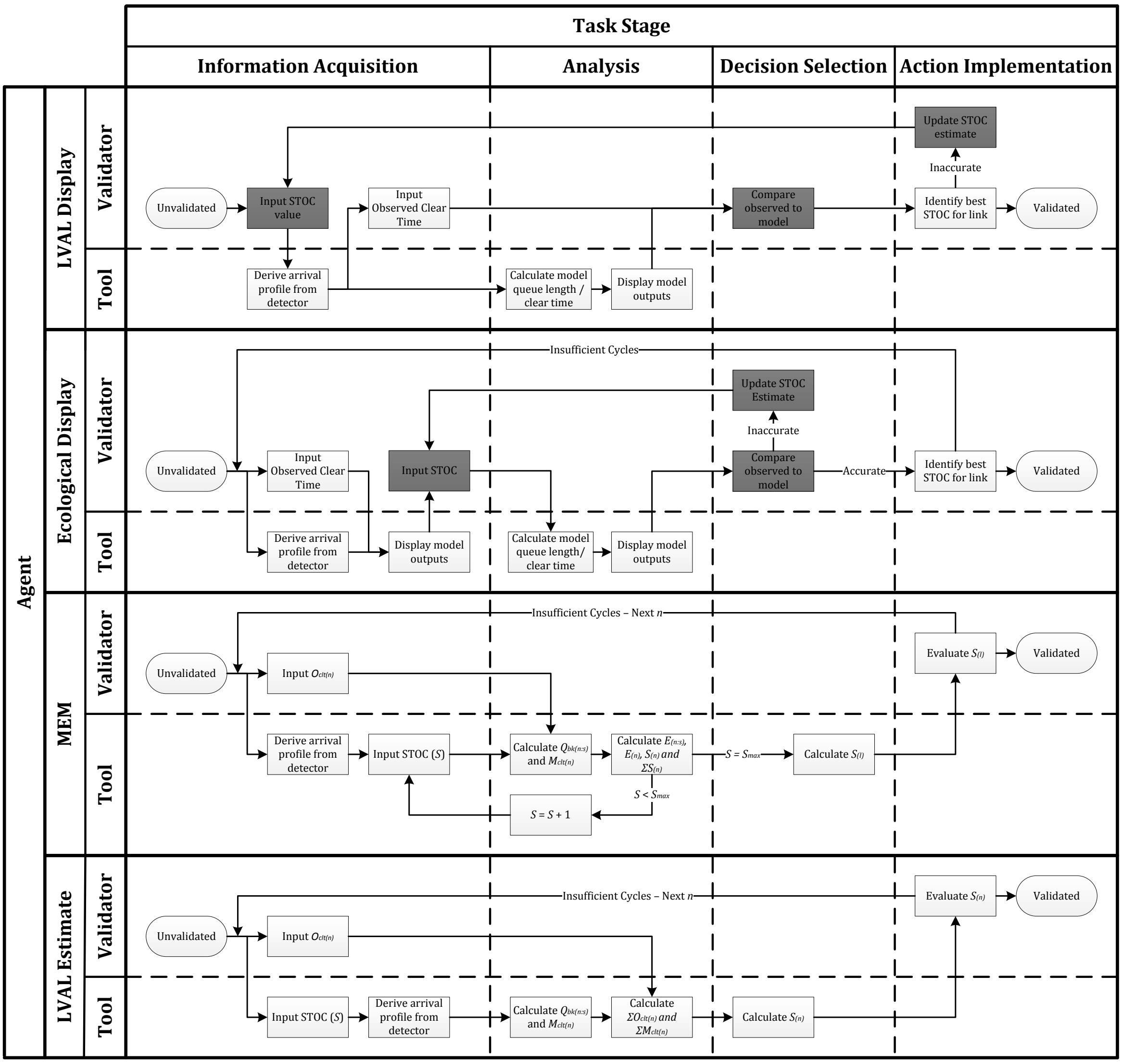


Figure 9-1: LVAL, Ecological, MEM and LVAL Estimate STOC validation processes by agent and task stage with automatable tasks highlighted grey

Table 9-1: Variables used for Model Error Minimisation

Variable	Description
n	Cycle number
$O_{clt(n)}$	Observed Clear Time (measured by validator) for cycle *n*
S	Current STOC value
$Q_{\mathrm{bk}(n:s)}$	Back of Queue (lpu) for cycle *n* at STOC *S*(1)
$M_{clt(n:s)}$	Modelled Clear Time for cycle *n* at STOC *S*
$E_{(n:s)}$	Error between observed and modelled clear times for cycle *n* using STOC *S*
$S_{(n)}$	Cycle's best STOC value(2)
$E_{(n)}$	Smallest error for cycle *n*
$S_{\max}$	Maximum permitted STOC value
$\sum S_{(n)}$	Sum of each cycle's best STOC values
$S_{(\mathrm{l})}$	Link's best STOC value(3)

(1) Back of Queue is the total queue length in lpu at the point when the queue has discharged (e.g. varies based on STOC value used)

(2) Taken to be the lowest STOC value which minimises the total error between Observed and Modelled Clear Times

(3) Taken to be the mean of each cycle's best STOC value rounded to the nearest whole STOC value

Table 9-2: Model Error Minimisation algorithm for each cycle

Variable	Function	Comment
$O_{clt(n)} =$	Input by validator	Validator inputs Observed Clear Time for cycle *n*
$S =$	1	Initial STOC equals 1
1. $M_{clt(n:s)} =$	$\frac{Q_{\text{bk}(n:s)}}{S}$	Calculates Model Clear Time for cycle *n* at STOC *S*
2. $E_{(n:s)} =$	$\lvert O_{clt(n)} - M_{clt(n:s)} \rvert$	Calculates absolute error between cycle *n's* Observed Clear Time and Model Clear Time at STOC *S*
$S_{(n)} =$	S	Initial best STOC value for cycle *n* equals *S*
$E_{(n)} =$	$E_{(n:s)}$	Initial smallest error for cycle *n* equals error produced when STOC equals *S*
3.	**IF $S < S_{max}$ THEN…**	Checks STOC *S* is less than maximum allowed STOC
$S =$	$S + 1$	Increases STOC by 1
	DO 1. AND 2.	Repeats calculation of Model Clear Time and Model Error at new STOC *S*
	ELSE…	
	Go To 4.	Skips calculation of best STOC and smallest error for cycle *n* once maximum STOC is exceeded
	END IF	
	IF $E_{(n:s)} < E_{(n)}$ THEN…	Checks whether Model Error for cycle *n* at STOC *S* is less than cycle *n's* previous smallest error
$S_{(n)} =$	S	Cycle *n's* best STOC equals STOC *S*
$E_{(n)} =$	$E_{(n:s)}$	Cycle *n's* smallest error equals the error produced at STOC *S*
	Go To 3.	Begins loop to test next STOC
	ELSE…	
	Go To 3.	Begins loop to test next STOC
	END IF	
4. $\Sigma S_{(n)} =$	$\Sigma S_{(n)} + S_{(n)}$	Calculates sum of all cycle's best STOC values
$S_{(l)} =$	$\frac{\Sigma S_{(n)}}{n}$	Calculates mean best STOC value for link *l*
	Next Cycle (n)	Starts next cycle

9.2.2 LVAL Estimate

LVAL can provide validators with an estimated STOC value. The LVAL Estimate algorithm identifies the ratio between modelled and observed clear times at the current STOC value and suggests a new STOC by multiplying the current STOC by this ratio. As more cycles of data at a single STOC value are acquired the estimate should become more accurate at the cost of time spent collecting the required data. Similarly to the MEM task process all decision selection tasks are conducted by the algorithm leaving validators to input the observed clear time and evaluate the output STOC (Figure 9-1). The variables required to calculate the LVAL Estimate are shown in Table 9-3 while Table 9-4 details the algorithm itself.

Table 9-3: Variables used to calculate LVAL Estimate

Variable	Description	Initial Value
n	Cycle number	1
c	Cycle count	1
x	Cycles required to update LVAL STOC Estimate	1 to 5
$S_{(n)}$	Cycle's current STOC value	Input by Validator
$O_{clt(n)}$	Observed Clear Time (measured by validator) for cycle n	N/A
ΣO_{clt}	Sum of Observed Clear Times at current STOC value	N/A
$Q_{\text{bk}(n:s)}$	Back of Queue (lpu) for cycle n at STOC S (1)	N/A
$M_{clt(n:s)}$	Modelled Clear Time for cycle n at STOC s	N/A
ΣM_{clt}	Sum of Modelled Clear Times at current STOC value	N/A
$S_{(n+1)}$	Next cycle's recommended STOC value	N/A

(1) Back of Queue is the total queue length in lpu at the point when the queue has discharged (based on a specific STOC value)

Table 9-4: LVAL estimate algorithm for each cycle

	Cycle Count		
Variable	**1**	$\mathbf{1 < c < x}$	**x**
$\Sigma O_{clt} =$	$O_{clt(n)}$	$\Sigma O_{clt} + O_{clt(n)}$	$\Sigma O_{clt} + O_{clt(n)}$
$M_{clt(n:s)} =$	$\frac{Q_{\text{bk}(n:s)}}{S_{(n)}}$	$\frac{Q_{\text{bk}(n:s)}}{S_{(n)}}$	$\frac{Q_{\text{bk}(n:s)}}{S_{(n)}}$
$\Sigma M_{clt} =$	$M_{clt(n)}$	$\Sigma M_{clt} + M_{clt(n)}$	$\Sigma M_{clt} + M_{clt(n)}$
$S_{(n+1)} =$	$S_{(n)}$	$S_{(n)}$	$S_{(n)} * \frac{\Sigma M_{clt}}{\Sigma O_{clt}}$
$c =$	$c + 1$	$c + 1$	1
	Next Cycle (n)		

9.3 Methodology

9.3.1 Participants

Thirty (sixteen male) novices with a mean age of 35.6 (σ = 12.9), all having no experience of SCOOT validation. Data was initially collected as part of the experiment in chapter 8 and was then reanalysed, hence data collection was covered under chapter 8's ethical approval (ethics number 14367).

9.3.2 Equipment

The experiment was undertaken on a laptop with a 15" display. As specified in chapter 8 the interfaces used by participants were produced in Microsoft Excel (version 2010; LVAL) and using the Microsoft .Net Framework (Ecological; see Figure 8-4) with navigation and interaction carried out via keyboard and mouse. Implementation of the automated algorithms was conducted through the production of Excel macros using the .Net Framework.

9.3.3 Experimental Design

The experiment utilised a within-subjects repeated measures design where the factors *display (2)* and *assistance (7)* were varied resulting in fourteen conditions (2x7). The *display* factor consists of the existing LVAL and concept Ecological display developed over the proceeding four chapters (shown in Figure 9-2). The *assistance* factor was divided into seven conditions. Firstly no assistance, in which participants were required to validate links' STOC values manually with the assigned display. Secondly STOC values for each cycle were calculated using MEM, with participants assumed to have used the same number of cycles to validate each link as in the no assistance condition with the relevant display. Lastly LVAL Estimation was used similarly to calculate STOC values for each cycle, however because estimated STOC values are dependent on the starting STOC value each cycle's STOC was considered to be the mean from all possible starting STOCs (one to thirty).

Two dependent measures were considered for this experiment, *final error*, and *average error*. *Final error* was taken to be the mean absolute difference between ultimate STOC value and expert validated value (identified in chapter 8, see Table 9-5) for the links validated in each display condition. *Average error* was similarly calculated but accounts for the mean error across each cycle used, hence describing accuracy over the validation process. The results are detailed in Table 9-7 with graphical depictions of final and average error shown in Figure 9-3 and Figure 9-4 respectively.

This experiment investigates the following hypotheses with each formulated based on the assumption that accuracy will be comparable across all conditions and the findings from chapters 7 and 8.

1. *H1:* MEM's accuracy will be comparable to novice's using either display
2. *H2:* MEM's accuracy will be comparable to LVAL Estimate's
3. *H3:* MEM and LVAL Estimate accuracy will be comparable with either display

9.3.4 Procedure

The experimental procedure for participants using either LVAL or Ecological displays is discussed in chapter 8 with the STOC values produced and number of cycles used for each link recorded for this experiment. STOC values for the automated conditions were then calculated by applying the relevant algorithms to replace each participant generated STOC value with automatically generated values which can then be compared.

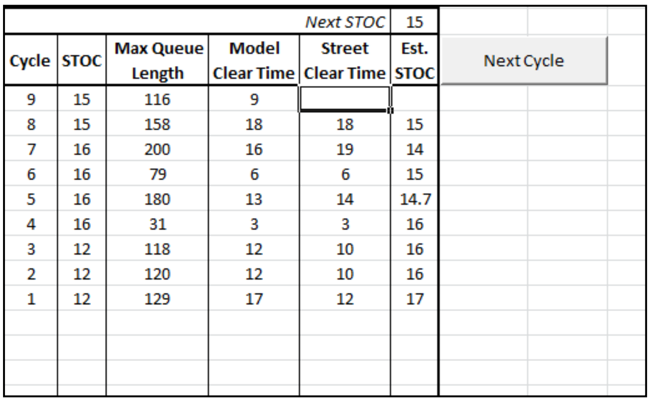
9.3.5 Data Analysis

All data analysis will be conducted using SPSS (version 22) with significance set at 5%. Each dependent measures' normality will be assessed using a Shapiro-Wilk test. Where normality can be assumed an ANOVA test will be used for repeated-measures data comparing within-subjects effects and Wilcoxon-Signed Ranks tests for pairwise comparisons. Conversely where normality cannot be assumed a Friedman test will be used for repeated-measures data comparing within-subjects effects and Wilcoxon-Signed Ranks tests for pairwise comparisons. Effect sizes for all measures will be evaluated using Cohen's d (Cohen, 1988)

Table 9-5: Median expert validated link STOC values

Link					
A	**B**	**C**	**D**	**E**	**F**
7	18	9	22	13	9

LVAL



				Next STOC	15
Cycle	STOC	Max Queue Length	Model Clear Time	Street Clear Time	Est. STOC
9	15	116	9		
8	15	158	18	18	15
7	16	200	16	19	14
6	16	79	6	6	15
5	16	180	13	14	14.7
4	16	31	3	3	16
3	12	118	12	10	16
2	12	120	12	10	16
1	12	129	17	12	17

Ecological

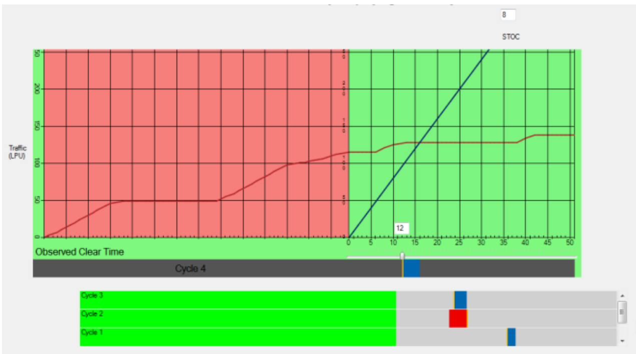


Figure 9-2: STOC validation displays

9.4 Results

Shapiro-Wilk tests on each dependent measure (Table 9-6) rejected the normality assumption, hence non-parametric tests were used as discussed in section 9.2.

Table 9-6: Shapiro-Wilk normality test p values for automated performance measures

	Assistance	LVAL	Ecological
Average Error	None (Novice)	**.000**	**.002**
	MEM	**.008**	**.001**
	LVAL Estimate (1)	**.000**	**.000**
	LVAL Estimate (2)	**.000**	**.001**
	LVAL Estimate (3)	**.004**	**.003**
	LVAL Estimate (4)	**.001**	**.002**
	LVAL Estimate (5)	**.003**	**.001**
Final Error	None (Novice)	**.000**	**.000**
	MEM	**.000**	**.000**
	LVAL Estimate (1)	**.000**	**.000**
	LVAL Estimate (2)	**.000**	**.000**
	LVAL Estimate (3)	**.000**	**.000**
	LVAL Estimate (4)	**.000**	**.000**
	LVAL Estimate (5)	**.000**	**.000**

Table 9-7: Means (standard deviations between parentheses) for automated performance measures

	Assistance	Display	Final Error	Average Error
Response	None	1. LVAL (L)	0.56 (0.77)	1.18 (0.76)
		2. Eco (E)	0.50 (0.66)	0.81 (0.43)
	MEM	3. LVAL (L)	0.53 (0.50)	0.83 (0.46)
		4. Eco (E)	0.84 (0.36)	1.10 (0.59)
	LVAL Estimate (1)	5. LVAL (L)	1.88 (2.19)	2.66 (1.22)
		6. Eco (E)	3.09 (3.48)	3.13 (1.66)
	LVAL Estimate (2)	7. LVAL (L)	1.01 (1.36)	1.85 (1.06)
		8. Eco (E)	1.39 (1.63)	2.69 (1.53)
	LVAL Estimate (3)	9. LVAL (L)	1.06 (1.15)	2.36 (1.40)
		10. Eco (E)	1.26 (1.23)	3.01 (1.67)
	LVAL Estimate (4)	11. LVAL (L)	0.84 (0.78)	2.68 (1.68)
		12. Eco (E)	2.24 (2.27)	3.69 (2.09)
	LVAL Estimate (5)	13. LVAL (L)	1.13 (1.54)	2.65 (1.75)
		14. Eco (E)	2.58 (2.51)	4.01 (2.28)

			Final Error		Average Error	
Within-Subjects Sig.	None/MEM/ LVAL Est. (1-5)	P value	<0.05		<0.005	
		Sig. pairs (Cohen's d)	LVAL	Eco	LVAL	Eco
			1-5 (0.30) 3-5 (0.43) 3-9 (0.19) 5-7 (0.07) 5-9 (0.07) 5-11 (0.09) 5-13 (0.06)	2-6 (0.60) 2-8 (0.24) 2-10 (0.21) 2-12 (0.45) 2-14 (0.52) 4-6 (0.72) 4-12 (0.56) 4-14 (0.66) 6-8 (0.09) 6-10 (0.10) 8-12 (0.10) 8-14 (0.13)	1-5 (0.35) 1-7 (0.16) 1-9 (0.28) 1-11 (0.35) 1-13 (0.34) 3-5 (0.70) 3-7 (0.39) 3-9 (0.57) 3-11 (0.67) 3-13 (0.66) 5-7 (0.12) 5-9 (0.05) 7-11 (0.14) 7-13 (0.14)	2-6 (0.89) 2-8 (0.74) 2-10 (0.85) 2-12 (1.05) 2-14 (1.13) 4-6 (0.60) 4-8 (0.47) 4-10 (0.56) 4-12 (0.74) 4-14 (0.82) 6-8 (0.05) 8-12 (0.12) 8-14 (0.16) 10-12 (0.07) 10-14 (0.11)
	LVAL/Eco	P value	<0.05		<0.005	
		Sig. pairs	3-4 (0.11) 5-6 (0.10) 11-12 (0.31) 13-14 (0.17)		1-2 (0.09) 3-4 (0.11) 5-6 (0.07) 7-8 (0.14) 9-10 (0.09) 11-12 (0.11) 13-14 (0.14)	

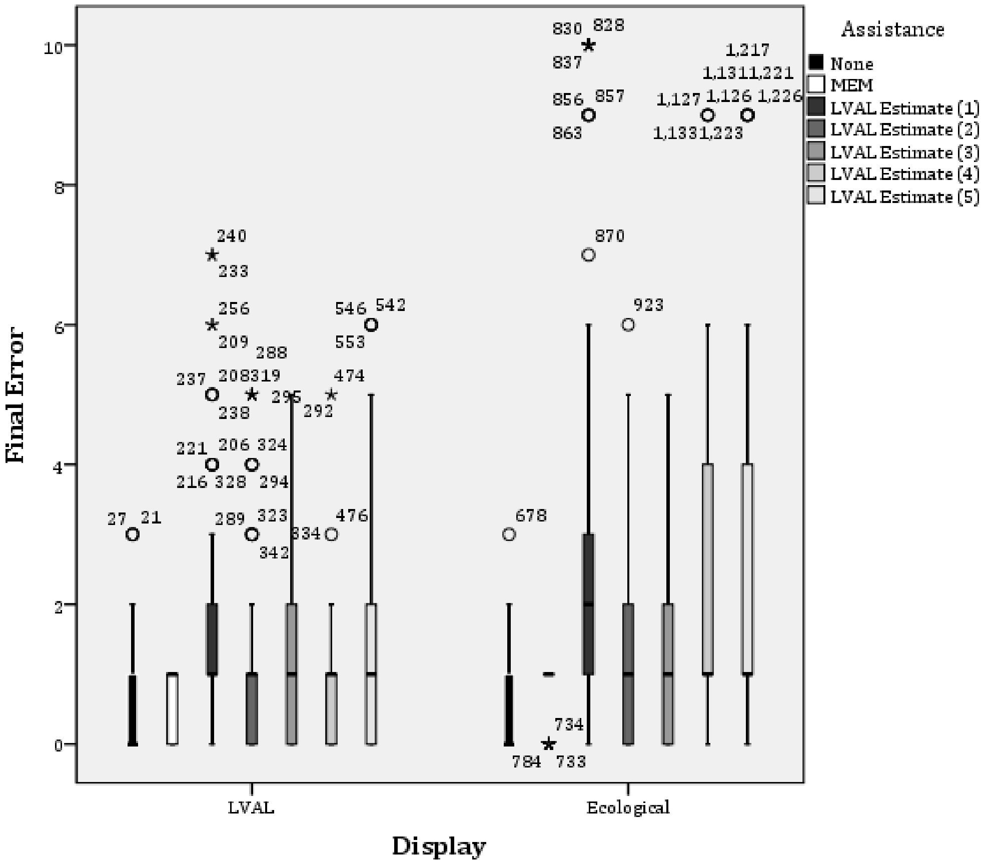


Figure 9-3: Final error for each display subdivided by assistance condition

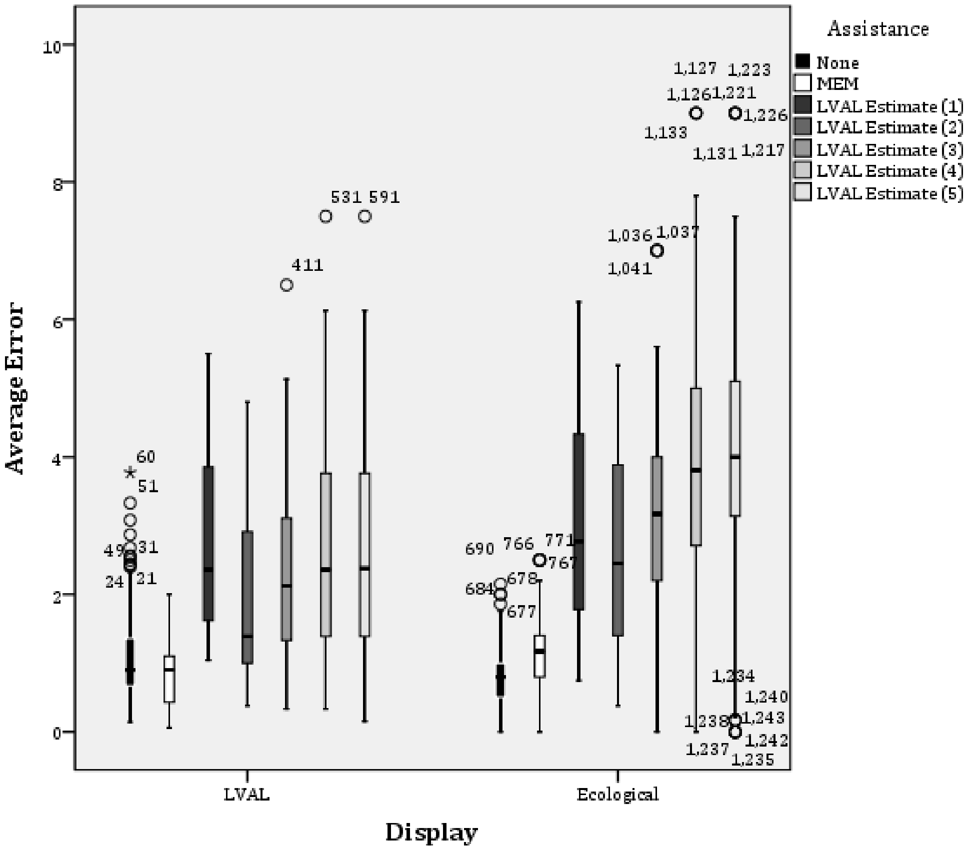


Figure 9-4: Average error for each display subdivided by assistance condition

9.4.1 MEM vs Novice Performance (LVAL)

H1 stated that accuracy would be comparable between MEM and novices and this was confirmed to be the case when using LVAL. In this condition validation required a mean of 13.5 cycles with final errors found to be similar (0.53 and 0.56 STOCs respectively). These error values correspond to a typical final STOC value within a tolerance of one STOC of the expert validated value which according to Siemens' experts would be acceptable at link validation level.

Interestingly MEM's average error was lower than the novice group's (0.83 vs 1.18) which although not found to be significant does suggest that the MEM algorithm was able to converge to an accurate STOC value slightly quicker than the novice group using LVAL.

9.4.2 MEM vs Novice Performance (Ecological)

Novices using the ecological display required on average fewer cycles than when using LVAL (6.4 vs 13.5). In this condition MEM was found to have a higher final error than novices (0.84 vs 0.50) however this increase was not significant, similarly average error was slightly higher (1.10 vs 0.81) suggesting novices using the ecological display were slightly more accurate and converged quicker to an accurate STOC value than MEM. Despite having fewer cycles to calculate STOC, MEM's outputs did remain within the acceptable tolerance of one from the expert validated value retaining comparable performance to novices in support of *H1*.

9.4.3 MEM vs LVAL Estimate Performance

MEM was found to be significantly more accurate in terms of both final and average error compared to each LVAL estimate in both LVAL (final error of 0.53 vs 1.88/1.01/1.06/0.84/1.13; average error of 0.83 vs 2.66/1.85/2.36/2.68/2.65) and Ecological conditions (final error of 0.84 vs 3.09/1.39/1.26/2.24/2.58; average error of 1.10 vs 3.13/2.69/3.01/2.09/4.01). Typically LVAL Estimates based on one data cycle were found to be least accurate while two to three data cycles gave the most accurate results, however even the best LVAL Estimates performed worse than MEM in both display conditions, it is therefore reasonable to reject *H2*, MEM appearing to provide a benefit over LVAL Estimates.

9.4.4 LVAL vs Ecological Performance

The key performance findings from chapter 8's experiment were that the ecological display did not impact novice's final accuracy compared to LVAL but reduced average cycle error (0.81 vs 1.18) and required fewer cycles (6.4 vs 13.5) to validate each link.

In the MEM condition this reduction in cycles caused an increase in both final (0.84 vs 0.53) and average error (1.10 vs 0.83), however this is unlikely to have an impact on real validation performance as STOC values were still returned within the tolerance of one STOC from the expert validated value. This suggests that the MEM algorithm is robust even when a limited number of valid cycles are available, supporting *H3*.

LVAL estimates were similarly found to be less accurate in the ecological display condition for both final and average error. With the exception of estimates based on a single cycle of data STOC values returned by LVAL estimates were within one STOC of the expert validated value in the LVAL condition; however this error increased to an unacceptable maximum of three STOCs from the expert value in the ecological condition. This suggests that, unlike MEM, LVAL estimates cannot be deemed robust when a small number of valid cycles are available; hence *H3* is only supported for MEM.

9.5 Discussion and Conclusions

STOC validation is a critical stage of SCOOT validation (Hunt et al., 1981; Siemens, 2011) but places significant time and tacit knowledge demands on validators when using PC SCOOT. These demands can be overcome through use of an ecological display however a limiting constraint on nodes' validation speed is that component links must be validated one by one.

Multiple link validation would require the task processes associated with analysing clear times and STOC selection to be automated, enabling validators to focus on measuring observed clear times for each component link and then evaluating the node's performance once sufficient data has been obtained. Although these tasks are both routine and predictable and hence are good candidates for automation (Norman, 1990) any automated system is only likely to be accepted if validators trust the system to work effectively and provide some benefit over manual operation (Lee & Moray, 1992). Specifically, the produced STOC values should be comparably accurate to a human validators based on the data available while reducing the demands placed upon them.

This experiment only considered performance in terms of validation accuracy and in this respect the MEM algorithm performed well. When compared to novices using LVAL not only was final accuracy almost identical but a lower average cycle error indicated that the algorithm was likely to be more accurate than novices should fewer cycles have been used. Furthermore, performance was robust when based on fewer cycles and compared to novices using the ecological display. Despite having significantly less source data final validation accuracy was within the acceptable tolerance of one STOC from the expert validated value, although the algorithm converged to an accurate value slower than human validators.

Acceptable performance using the LVAL Estimate algorithm required firstly that estimated STOC values be based on multiple cycles' clear time data, and secondly that there are a sufficiently large number of cycles to complete validation. If these conditions were not met unacceptably large errors were frequently produced, particularly when validation was based on a relatively small number of cycles as occurred in the ecological condition. This lack of robustness severely limits LVAL Estimate's potential given that both humans and MEM could perform better using fewer cycles.

A key feature of both automated systems described in this chapter is that humans remain a key part of the validation process. This ensures that validators are not completely removed from the control loop (Norman, 1990) and relegated to a supervisory monitoring role, from which humans typically perform poorly (Mumaw, Roth, Vicente, & Burns, 2000), heeding the general consensus that automation performs best assisting rather than replacing humans (Norman, 1990).

While it has been shown that automated algorithms can perform satisfactorily compared to human validators, consideration should be given to how such systems could be implemented. Both algorithms as presented within the experiment can be considered 'Hard' automation systems (Young, Stanton, & Harris, 2007), having ultimate authority over humans (i.e. STOC values are generated solely by the automation and validators cannot override these values). This is a marked departure from the 'Soft' approach currently employed by the LVAL Estimate tool as implemented within PC SCOOT, whereby STOC values are suggested by the algorithm but selected by the validator.

Both approaches are valid, however while it would be possible to implement the MEM algorithm as a 'Soft' tool this would require validators to perform decision-making actions after measuring queue clear times and would likely prevent multiple link validation. On the other hand 'Hard' systems are typically highly context sensitive with pre-programmed responses potentially being sub-optimum. While the proceduralised nature of the automated tasks largely negates this issue, care must still be taken to ensure that the source data used is valid given that the algorithm cannot currently distinguish a cycle's validity for itself.

The final issue to consider with implementing an automated validation system is how validators would evaluate the STOC values produced. The key concern is that by automating STOC selection the algorithm has the potential to disconnect node performance, link's STOC values and the conditions observed. To overcome this consideration must be given to what feedback is required by validators and the most appropriate way to display this feedback to ensure the system is both trusted and accepted.

By considering Sheridan and Verplank's (1978) automation taxonomy (Table 9-8) it can be seen that MEM could be implemented at a number of levels. The lowest appropriate level would be that a STOC value is simply suggested and validators approve it (level four) however this could impede the ability to validate multiple links. At higher levels (levels five to eight) the automation would be capable of choosing a STOC value and provide validators with varying options to either veto the decision or see the relevant feedback. The highest levels of automation (nine and ten) require a significantly higher degree of automated intelligence and could result in validators being removed from the control loop (see Norman, 1990) amplifying the issues previously discussed regarding automation and hence are not recommended.

Identifying the most appropriate level to implement MEM as well as the precise nature of the feedback required to evaluate node performance was beyond the scope of this investigation, however this in conjunction with further testing in real world validation scenarios provides a significant opportunity for further work.

Table 9-8: Sheridan and Verplank's automation taxonomy

Level	Description
1	Manual Control, computer offers no assistance, human responsible for all decisions and actions
2	Computer offers a complete set of decision/action alternatives
3	Computer offers a few decision/action alternatives
4	Computer offers one decision/action alternative
5	Computer executes actions with human approval
6	Computer executes actions if not vetoed by human within time limit
7	Computer executes actions and informs human
8	Computer executes action and informs human if asked
9	Computer executes action and informs human only if it decides to
10	Fully Automated, computer acts autonomously, ignoring human

In conclusion, automation of STOC selection could assist validators and potentially enable multiple links to be validated simultaneously, offering significant time savings compared to the current LVAL display. To this end an automated STOC selection algorithm has been developed and tested against human validators, with performance found to be comparable. While this chapter has demonstrated the technical feasibility of such an automated system further investigation is required to examine performance in real validation scenarios as well as to give consideration to how it should be implemented.

Chapter 10: Conclusions and Further Work

10.1 Introduction

The aim of this research was to investigate how application of Human Factors methods could be used to improve performance resulting from the use of technical traffic management and SCOOT validation systems. The main findings in relation to the objectives set out in chapter 1 are described below, with the novel contributions made then discussed. Finally, areas for future work are presented.

10.2 Summary of Findings

The projects' objectives as set out in chapter 1 were as follows;

Three objectives concerned the macro analysis of TMCs:

1. Define and understand the objectives, functions and constraints of traffic management in major transport domains.
2. Define and evaluate the processes, tools and connections utilised by road TMC operators to manage traffic.
3. Investigate system resilience within TMCs through application of Event Analysis of Systematic Teamwork.

Four objectives concerned the micro analysis of SCOOT validation:

1. Define and understand SCOOT validation using PC SCOOT to identify limitations and opportunities for improvement.
2. Develop alternative displays to address the limitations identified for (1) through application of Human Factors interface design techniques.
3. Evaluate the performance of the displays developed for (2).
4. Investigate the potential to employ automation to address the limitations identified for (1).

10.2.1 Traffic Management

The first objective was to define and understand the purposes, functions and constraints of traffic management in major transport domains, which was addressed in chapter 2. A review of the literature revealed that all Traffic Management Centres

(TMCs) are concerned with improving the efficiency and safety of their respective transport network while reducing its negative environmental impacts. While there are similarities in purpose between all four domains the environment imposes specific constraints upon TMCs' operation and directly influences interactions with traffic. That said, the traffic management process itself was found to be relatively similar across domains, all TMCs monitored traffic in real-time and predicted network conditions, decided how to manage traffic and intervened within the network when necessary. Functions arising from this process are also directly comparable between domains; all TMCs incorporate monitoring, decision-making, intervention, feedback and support functions. The specific implementation of these functions is however affected by domains' individual characteristics, in particular monitoring and intervention functions, both being dependent on vehicles' capabilities and traffics' behaviour.

The second objective was to evaluate the processes, tools and connections utilised by road TMC operators to manage traffic, and was addressed in chapters 3 and 4. This was achieved through application of the Event Analysis of Systematic Teamwork (EAST) method in which the domain was explored through construction of a number of graphical networks based on observational data obtained from four urban TMCs, Bristol, Cardiff, Dorset and Nottingham. The congestion management task process was found to be circular with seven distinct phases, monitoring the network for problems, contextualising the scenario, prioritising the scenario, allocating personnel to deal with the scenario, developing strategies to address the scenario and selecting the perceived best option, implementing the strategy, and monitoring the network for feedback regarding the strategies effectiveness. The social networks for each TMC were broadly similar with operators central and required to interact with a wide range of internal and external agents to achieve their goals. Surprisingly, traffic agents were found to be on the periphery of the domain despite being the reason for its existence. This is reflective of the relative lack of control TMCs retain over traffic and the passive nature of many monitoring channels. The information network defined the range of information which is required to manage a scenario. The combined networks showed how information requirements are clustered around task phases and how this influenced the distribution of social agents amongst information nodes. It was found that most social interactions occurred at the beginning and end of the task process, information being gathered from a wide range of agents, decisions made internally by operators based on that information, and then implemented, affecting other agents and hence the road network and external environment. Overall performance is therefore reliant on operators' individual performance and the support provided by TMC systems to facilitate interactions between operators and other agents.

To address the third objective chapter 4 extended the EAST work conducted in chapter 3 by considering how the EAST networks could be used to investigate the domain's resilience both qualitatively and quantitatively. Quantitative analysis within resilience engineering is relatively undeveloped but potentially powerful, enabling systematic assessment and comparison of existing system's strengths and weaknesses, as well as guiding the development of future systems. Failure modes were developed independently of real events by considering which social agents or communications links could fail with the EAST networks then adjusted accordingly, enabling the method to be applied proactively. A quantitative assessment of resilience was then produced by considering how the domain's Social Network Analysis (SNA) metrics changed as a result of failure modes, identifying which combinations of failures were likely to be most disruptive to the system's operation. Road TMCs were found to have resilient qualities, most failure modes having a relatively small impact on expected system performance, with the greatest impacts requiring complex and unlikely compound failures. This resilience can be attributed to a flexible task process, wide information distribution, an abundance of information sources and redundancy of critical agents.

10.2.2 SCOOT Validation

Following adjustment of the project focus, from macro analysis of TMCs to micro analysis of the systems used to validate SCOOT, objective three was to define and understand SCOOT validation using PC SCOOT to identify limitations and opportunities for improvement, and was addressed in chapter 5. A complete five phase Cognitive Work Analysis (CWA) was applied to comprehensively assess the domain, each phase providing insights into the validation process and a number of areas suitable for development were proposed. In Work Domain Analysis (WDA) an Abstraction Hierarchy (AH) was used to identify the validation functions which were found to be highly proceduralised each focusing on specific values, either preventing bias, correct detector setup, accuracy of assumption parameters or accuracy of the SCOOT model. Through Control Task Analysis (ConTA) validation was shown to be conducted either on-site or from an office when extensive CCTV coverage is available; however parameter measurement, SaTuration OCcupancy (STOC) estimation and validation functions (e.g. detector accuracy, staging and STOC) are recommended to be done on-site owing to the need for sufficient situational awareness which is difficult to achieve remotely. Decision-making was also considered with two system goals identified, to match the SCOOT model to on-street conditions or to adjust it to account for other local factors (e.g. political directives). System states were shown to differ in complexity in terms of the information required to diagnose them but the task processes utilised to address system states were found to be highly proceduralised. Expert behaviour was considered with several expert leaps identified within the Decision Ladder linking a system state or target state to a task or procedure, explaining how experienced validators intuitively know the correct strategy to employ once the system or target state is identified. The proceduralised nature of functions was further examined through Strategies Analysis (StrA) in which the majority of functions were found to have set procedures when using PC SCOOT, although the strategies for certain functions (e.g. staging and detector accuracy validation) varied depending on the specific PC SCOOT display used. It was demonstrated that this rigidity arose from the way SCOOT operates and hence cannot be adapted; however improvements could be elicited by enabling validators to do the existing tasks more effectively. Social Organisation and Cooperation Analysis (SOCA) considered how validators and PC SCOOT interact in pursuit of validation goals, with validators being responsible for most high-level decision-making while PC SCOOT acts to provide information and implement changes. Given that it is unlikely PC SCOOT's intelligence can be radically increased at least in the short-term it was suggested that developments should focus on enabling validators to make decisions and complete functions more accurately and efficiently. Finally, a Skills, Rules and Knowledge (SRK) inventory for Worker Competencies Analysis (WCA) identified the Skill-, Rule- and Knowledge-Based Behaviours (SBB/RBB/KBB) observed for each function, it was found that the existing technical system is based around procedural RBB with limited support for SBB or KBB with an argument made to better support all three behaviours in order to elicit performance improvements. Ultimately three key areas were identified for further development, to improve the efficiency of preparing a site to be validated, redesign displays concerned with parameter measurement, and to apply Ecological Interface Design (EID) to validation displays in order to better support all behaviours as identified in the SRK inventory.

The fourth objective was to develop an alternative display through application of Human Factors interface design techniques, and was addressed in chapter 6. Based on the recommendations in chapter 5 and consultation with Siemens it was decided to investigate STOC validation in more detail and apply EID to produce an alternative display addressing the limitations identified with the PC SCOOT's Link VALidation (LVAL) display. A second complete CWA was used to evaluate the STOC validation process, consider the support provided by LVAL and the representations from each phase influenced the development of an alternative ecological design. Primary interface functions were identified through interrogation of the WDA's AH, while spatial, temporal and decisional constraints for each validation agent were considered using ConTA and SOCA. WCA described the modes of cognitive control exhibited by validators for the most complex functions of comparing clear times and judging data validity. Finally StrA was used to model the task process using LVAL and give consideration to the support provided. LVAL was found to rely on validator's tacit knowledge regarding the task process and domain mechanics; hence a concept ecological interface was proposed which utilised graphical depiction of the source data and domain constraints as well as enabled direct manipulation of the STOC value consistent with the principles of EID.

The fifth objective was to evaluate the performance of the proposed ecological display, and was addressed in chapters 7 and 8 through two empirical experiments. The first experiment compared validation performance using the concept ecological display against two of PC SCOOT's interfaces and considered the role of experience on performance. The experimental interfaces were created using Microsoft Excel with traffic data obtained from Reading and clear times adjusted to lead to particular STOC values. Subjects consisted of three participant groups, twelve experienced validators, twelve novices age and gender matched to the expert group, and an unmatched group of thirty novices. The validation task was completed accurately by both experts and novices using all three displays however the ecological interface provided a number of performance benefits. Difficulties experienced by novices using traditional interfaces were overcome, enabling them to access less demanding rule- and skill-based behaviours which resulted in performance being normalised in the ecological condition between participant groups. Validation was also faster using the ecological interface with significant reductions in the number of cycles required elicited by all groups. Subjective assessments of workload and usability showed that the ecological design had a positive impact on novices but did not affect experts, suggesting that the traditional displays are initially hard to use but this can be overcome with training.

The second experiment followed a similar procedure to the first and was intended to address several limitations with the first experiment, specifically real observed clear times were obtained from Bristol and the ecological display was significantly developed from the Excel based prototype used in the first experiment. The results confirmed many of the findings with validation being effectively conducted by both experts and novices in both conditions but the ecological display eliciting a number of performance benefits over LVAL. Reliability, workload and usability were improved for novice validators, while experts were not adversely impacted by the change of display and retained comparable accuracy as when using LVAL. Most significantly, the ecological display substantially reduced the number of cycles required to validate, with the potential time savings due to this alone warranting further consideration be given to developing a fully functioning ecological validation display.

The sixth objective was to investigate the potential to employ automation within SCOOT validation, based on discussions with Siemens and the work conducted in chapters 6 to 8 it was decided to investigate whether STOC selection could be automated. In addition to providing general assistance to validators it was suggested that by automating some of the decision-making tasks validators would be able to focus on gathering the required data and hence could validate multiple links simultaneously which would provide significant time savings. Consideration was given to the validation task processes associated with STOC validation using both LVAL and ecological displays with an automated STOC selection algorithm developed based on the principle of minimising the error between modelled and observed clear times (Model Error Minimisation (MEM)). The algorithm was then tested against novices' performance in chapter 8 using both LVAL and the ecological display. Performance was considered in terms of validation accuracy and in this respect the MEM algorithm performed well. When compared to novices using LVAL not only was final accuracy almost identical but a lower average cycle error indicated that the algorithm was likely to be more accurate than novices should fewer cycles have been used. Furthermore, performance was robust when based on fewer cycles and compared to novices using the ecological display. Despite having significantly less source data final validation accuracy was within an acceptable tolerance (one STOC from the expert validated value) although the algorithm converged to an accurate value slower than human validators. While the technical feasibility of automated STOC validation was demonstrated, further investigations are required to consider the accuracy in real validation scenarios and the most effective implementation method of such a system before it could be commercialised.

10.3 Novel Contributions of the Work

The novel contributions of the work are summarised as follows.

10.3.1 Traffic Management

Definition and improved understanding of traffic management's objectives, functions and constraints in all major transport domains

The objectives, functions and constraints of traffic management in road, rail, maritime and air domains were identified and compared by conducting a literature review. Objectives were found to be comparable, all traffic management aiming to improve safety and efficiency whilst reducing environmental impact of their respective transport network. Similarly, functions were found to be largely comparable, all TMCs monitoring real-time and predicted network conditions, deciding how to manage traffic and intervening within the network when necessary. The specific implementation of each of these functions was found to be dependent on each domain's individual characteristics. In particular governing how traffic can be monitored and interacted with. While comparative studies have previously been conducted, this work represents a useful extension by considering the similarities and differences between all four major transport domains.

Assessment of congestion management in urban TMCs

In order to better understand how urban TMCs manage congestion in practice the road traffic management domain was modelled using EAST. Four different TMCs were visited (Bristol, Cardiff, Dorset and Nottingham) with a number of congestion scenarios observed and this observational data used to inform construction of primary task, social and information networks as well as combined networks. The task process and information requirements were found to be comparable between TMCs but each centre's capabilities were influenced by their social construction. It was found that successful management of scenarios relies on operators' ability to interact with a wide range of technical and social agents to gather information regarding the road network, and once management decisions have been made having the ability to influence traffic effectively again by utilising a range of intermediary agents including a number of technical systems. The work provides a useful insight into how congestion is managed in practice and highlights some of the challenges faced to design effective TMC systems, for example the distributed nature of information within the domain and the disconnect between TMC and traffic being managed.

Application of the EAST method to quantitatively and qualitatively assess resilience

Quantitative analysis within resilience engineering is relatively undeveloped but potentially powerful, enabling systematic assessment and comparison of existing systems' strengths and weaknesses, as well as guiding the development of future systems. EAST enables comprehensive assessment of domains in terms of the tasks undertaken, agents, communications links and information utilised, and the interactions between these elements. The method was extended to consider the impacts of failure within the system with these findings used as an indicator of operational resilience. Failure modes were able to be developed independently from any event that may or may not have occurred in reality, enabling the method to be applied proactively. The graphical nature of EAST enabled both qualitative and, through the calculation of SNA metrics, quantitative assessment of the domain addressing the need for quantitative methods within resilience engineering. In addition to these methodological developments the work added to the insights provided in chapter 3, demonstrating that a flexible task process, wide information distribution, an abundance of information sources and redundancy of critical agents provided a degree of resilience within a TMC.

10.3.2 SCOOT Validation

Assessment of SCOOT validation using PC SCOOT

Siemens are a leading provider of SCOOT systems worldwide however while their PC SCOOT UTC product is functional for the purposes of SCOOT validation system it has not evolved to take advantage of advances in display equipment or considered human performance in its design. To provide better understanding of the validation domain, and particularly how PC SCOOT is utilised for validation, a full five phase CWA was applied to comprehensively assess the domain, with representations produced based on data collected from experienced SCOOT validators. Key validation functions were mapped and the tasks' highly proceduralised nature was revealed. PC SCOOT was shown to provide limited support to validators, relying extensively on validators' tacit knowledge of task processes and domain mechanics. In addition to providing detailed knowledge about SCOOT validation several key areas in which PC SCOOT could be developed were identified with the insights provided by this assessment being useful for their future implementation.

Development of an ecological STOC validation tool with consideration of each CWA representation's design role

An alternative STOC validation display was produced through application of EID in order to address the limitations identified with PC SCOOT's LVAL display. The opportunity to utilise all five CWA phases was utilised to produce the ecological display with the contributions of each phase discussed in detail as a useful practical case study for practitioners wishing to use the technique. WDA's AH was used to define the primary interface functions, validation agents' spatial, temporal and decisional constraints were identified through ConTA and SOCA while WCA described the modes of cognitive control exhibited within the most complex functions. StrA was used to consider how LVAL was used to conduct validation with the findings from all phases then used to infer potential weaknesses with LVAL and inform application of the fundamental EID design principles to produce the concept ecological STOC validation display.

Evaluation of STOC validation performance using ecological and traditional displays

To test the concept ecological STOC validation display two empirical experiments were conducted to investigate performance compared to traditional displays used by PC SCOOT and to evaluate the role of experience on performance with each display. The first experiment utilised a basic ecological condition and was constrained by a number of experimental limitations which were largely accounted for in the second experiment, for example by using a more developed ecological display. Both objective and subjective performance measures were considered including accuracy, time spent validating, perceived workload and perceived usability. The experiments showed that use of an ecological display could elicit performance benefits over traditional displays, most notably a reduction in the number of cycles required to validate. This work represents a novel contribution to the EID literature through application in a new domain. Many of the findings correlated with those obtained in more established domains, for example a reduction in response time observed using ecological displays. The work also improves understanding of STOC validation, for example by showing that while novices are accurate using LVAL, use of the ecological display can overcome difficulties experienced using the traditional display and enables them to emulate experts in terms of overall performance.

Development and evaluation of an automated STOC validation algorithm

Although time savings for STOC validation were shown to be elicited through use of an ecological display a key constraint on obtaining further savings is the need to validate links one at a time. Overcoming this limitation requires automation of some of the analysis and decision-making tasks enabling validators to focus on measuring queue clear times and then evaluating performance. Through interrogation of the ecological STOC validation strategy an automated algorithm to select STOC values was developed based on the principles of minimising the error between modelled and observed clear times. Empirical evaluation of this algorithm demonstrated not only the technical feasibility of the algorithm but showed that accuracy was comparable to that observed in human validators and significantly better than the existing STOC estimation algorithm present in PC SCOOT. This development is likely to be of significant value to Siemens, offering a completely new approach to STOC validation which could for the first time enable multiple links to be validated simultaneously, providing significant time savings, as well as acting as a potential stop gap measure to implementation of a complete ecological display.

10.4 Limitations and Areas for Further Work

The research has fulfilled the objectives set out in chapter 1, however further research is required to address additional questions raised by the work and to investigate new opportunities which could not be conducted within the thesis.

10.4.1 Application of EAST to additional TMCs and utilisation to influence design

The EAST analysis presented in chapter 3 provided a comprehensive assessment of congestion management in urban TMCs. While this work provides a useful insight into how congestion is managed in practice and highlights some of the challenges faced to design effective TMC systems there are several limitations and potential opportunities to address. Firstly, while the TMCs modelled represent a reasonable cross section of urban traffic management in the UK, no very large TMCs, inter-urban control centres or TMCs from other territories were considered. Therefore a significant portion of road traffic management was not accounted for which could be considered in future work to better define those characteristics which are common to all TMCs and those which represent idiosyncrasies of the centres visited. Secondly, no attempt to quantify TMC's respective performance was made; this would be required before reasonable recommendations regarding TMCs structure could be made. Thirdly, while some of the challenges facing designers of TMCs' technical systems were identified additional work is required to consider how these insights can be reflected within system design to improve performance.

10.4.2 Further development of EAST as a tool to investigate resilience

Quantitative analysis of resilience is relatively undeveloped however chapter 4 demonstrated how EAST could be utilised to investigate operational resilience by modelling a domain and applying failure modes. While the method produced useful insights into the domain there are several questions to be addressed before it can be considered a useful tool in resilience engineering. Firstly, how can the validity of the predictions be evaluated empirically? The method relies on production of possible failure modes and modelling their impacts on the domain, therefore consideration must be given to how these theoretical impacts compare to real failures. Secondly, can the insights provided be used to influence system design? The work presented served to model the traffic management domain and thus infer its resilient qualities, however to be useful the method must go beyond this theoretical evaluation to produce useable design guidance. This could be achieved by demonstrating that a system is less resilient as compared to its contemporaries or a theoretical alternative. Thirdly, can it be empirically validated that application of design guidance resulting from the method elicits improved resilience? This last question is perhaps the most important because resilience engineering can only be considered to be effective if real improvements can be demonstrated.

10.4.3 Development and field testing of an ecological STOC validation display

The experiments presented in chapters 7 and 8 provide compelling evidence demonstrating the effectiveness of the developed ecological display compared to PC SCOOT's LVAL display and justifying its continued development. Of course, the experimental process used in both experiments cannot entirely replicate real validation conditions and so further testing is required to address this limitation. To conduct field tests the interface must be developed from the prototype design produced in this research to a fully functioning prototype with the ability to interact with SCOOT's on-street hardware. This would enable field trials to be conducted and a more ecologically valid comparison to LVAL to be obtained; in particular it would overcome the need to have predetermined source data enabling performance to be examined with the 'messy' data reflective of the real world. It is only through this type of evaluation that the ecological benefits proposed through this work can be confirmed.

10.4.4 Application of EID to additional SCOOT validation functions

As demonstrated in chapter 5 SCOOT validation consists of a number of distinct functions each conducted using one or more PC SCOOT displays. These key functions include measuring the required parameters, verification of detector association and validation of detector accuracy, staging and STOC. Time constraints on the project meant that it was only possible to develop one of these functions, STOC validation, however many of the issues identified with PC SCOOT's LVAL display are applicable to each of these functions. While the performance improvements provided through application of EID to STOC validation are compelling, validation functions cannot be considered in isolation, therefore the full benefit of the approach is only likely to be realised if applied to the entire validation domain. This will require significant further investigation representing a complete overhaul of validation, however it is hoped that the work presented in this thesis provides a useful case study through which the necessary developments can be made.

10.4.5 Development and further testing of the MEM STOC selection algorithm

Development of the MEM algorithm is at a very early stage and while results from the experiment conducted in chapter 9 are encouraging, extensive further testing is required before it could be implemented commercially. The algorithm's accuracy must first be confirmed by comparing its performance to real validation scenarios, this would be relatively easy, requiring only that the necessary detector outputs and clear times are recorded in the field with the resulting outputs from the algorithm and validators then compared. Secondly, as discussed in chapter 9 the algorithm could be implemented in several different ways representing various levels of automation. It is not known what level would be most effective or appropriate, therefore further investigations are required to evaluate performance using all potential levels of the algorithm and to establish the social acceptance of each method of implementation. Thirdly, while it was suggested that the algorithm could enable multiple links to be validated simultaneously this has not been demonstrated empirically, therefore further testing is required to identify whether this is both technically possible and sufficiently accurate to provide a benefit over manual validation.

10.5 Concluding Remarks

The aim of this project has been to investigate how application of Human Factors techniques can be used to improve performance resulting from the use of technical traffic management systems at macro (whole systems) and micro (individual person-technology systems) levels. To achieve this the domains of traffic management and SCOOT validation were comprehensively assessed through literature reviews, EAST and CWA in order to improve the knowledge of how these domains work in practice, to identify limitations with the technical systems used within each domain and to develop solutions to these limitations. Development of the STOC validation function was the focus of these solutions with EID applied to develop an alternative display which was then evaluated against traditional displays. Finally, by using insights obtained into the STOC validation process an automated STOC selection algorithm was developed which has the potential to redefine how validation is conducted. In this way a wide range of learning outcomes have been produced which will be of use for researchers wishing to conduct further work within the domain as well as for the project sponsor Siemens who will also benefit from the physical outputs produced.

Appendix A: NASA Task Load Index Questionnaire

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Appendix B: System Usability Scale Questionnaire

1) I think that I would like to use this system frequently				
Strongly Disagree 1	2	3	4	Strongly Agree 5

2) I found the system unnecessarily complex				
Strongly Disagree 1	2	3	4	Strongly Agree 5

3) I thought the system was easy to use				
Strongly Disagree 1	2	3	4	Strongly Agree 5

4) I think that I would need the support of a technical person to be able to use this system				
Strongly Disagree 1	2	3	4	Strongly Agree 5

5) I found the various functions in this system were well integrated				
Strongly Disagree 1	2	3	4	Strongly Agree 5

6) I thought there was too much inconsistency in this system				
Strongly Disagree 1	2	3	4	Strongly Agree 5

7) I would imagine that most people would learn to use this system very quickly				
Strongly Disagree 1	2	3	4	Strongly Agree 5

8) I found the system very cumbersome to use				
Strongly Disagree 1	2	3	4	Strongly Agree 5

9) I felt very confident using the system				
Strongly Disagree 1	2	3	4	Strongly Agree 5

10) I needed to learn a lot of things before I could get going with this system				
Strongly Disagree 1	2	3	4	Strongly Agree 5

Appendix C: Demographic Data for Chapter 7

Group	Participant	Gender	Age, Years	Experience, Years
Expert	1	M	61	30
	2	M	57	30
	3	M	32	5
	4	M	50	20
	5	M	40	17
	6	M	31	3
	7	M	54	28
	8	F	34	6
	9	M	37	4
	10	M	58	8
	11	M	56	5
	12	F	31	6
		Total	541	162
		Mean	45.08	13.50
		SD	11.94	10.86
Matched Novice	1	M	63	N/A
	2	M	53	N/A
	3	M	56	N/A
	4	M	55	N/A
	5	M	32	N/A
	6	M	33	N/A
	7	M	42	N/A
	8	M	60	N/A
	9	F	34	N/A
	10	M	61	N/A
	11	M	29	N/A
	12	F	29	N/A
		Total	541	N/A
		Mean	45.60	N/A
		SD	13.62	N/A
Novice	1	F	60	N/A
	2	F	31	N/A
	3	M	47	N/A
	4	F	20	N/A
	5	F	56	N/A
	6	F	23	N/A
	7	F	37	N/A
	8	M	19	N/A
	9	F	25	N/A

Group	Participant	Gender	Age, Years	Experience, Years
	10	F	53	N/A
	11	F	42	N/A
	12	F	44	N/A
	13	F	20	N/A
	14	F	54	N/A
	15	M	54	N/A
	16	M	27	N/A
	17	F	23	N/A
	18	F	27	N/A
	19	F	46	N/A
Novice	20	M	24	N/A
	21	M	50	N/A
	22	M	18	N/A
	23	M	20	N/A
	24	M	24	N/A
	25	M	40	N/A
	26	M	33	N/A
	27	F	36	N/A
	28	M	27	N/A
	29	F	22	N/A
	30	M	26	N/A
		Total	1028	N/A
		Mean	34.27	N/A
		SD	13.21	N/A

Appendix D: Participant Information Sheet for Chapter 7

Study Title: Empirical assessment of an ecological tool for STOC validation

Researcher: Joshua Price **Ethics number**: 11917

Please read this information carefully before deciding to take part in this research. If you are happy to participate you will be asked to sign a consent form.

What is the research about?

This is a doctorate research project in collaboration between the University of Southampton and Siemens.

Many traffic light systems utilise a technique called SCOOT (Split Cycle Offset Optimisation Technique) to adjust timings based on real-time traffic data from road sensors and a model of traffic behaviour. To ensure accuracy the model must be tailored to local conditions at each SCOOT site (node). A key parameter is STOC (the discharge rate of traffic over a stop line) which is validated by comparing real traffic flows to the model's output using a computerised tool called LVAL which provides model outputs and assists the calculation of the correct STOC value.

LVAL's interface is constrained by historical technical limitations. This study aims to investigate whether an ecologically designed graphical interface could provide performance improvements over the exisiting system, in terms of the speed validation can be completed and accuracy, in both experienced and novice populations. To acomplish this an MS Excel based STOC validation simulator has been developed to test three validation interfaces in a controlled environment.

Why have I been chosen?

You have been approached because you are either 1) an experienced SCOOT engineer or 2) are a novice at SCOOT validation.

What will happen to me if I take part?

Basic personal details will be taken (age, gender and validation experience). You will then undertake a brief training period to familiarise yourself with the validation process using the simulator. Once you are comfortable using the simulator you will be required to validate 9 separate nodes, 3 for each validation interface. The interfaces are as follows…

1) LVAL – a tabular interface which provides the model clear time, a mechanism to input the observed clear time and an estimate of the correct STOC value.
2) MCM – similar to LVAL but provides additional feedback through clear times for multiple STOC values.
3) Ecological – a graphical interface enabling clear times from limitless STOC values to be compared to the observed clear time

After completing each interface you will be asked to complete a subjective workload assessment and usability questionnaire. Each condition should take no more than 15 minutes. Once all three interfaces have been completed the experiment is complete, this should take no longer than 1hr.

Are there any benefits in my taking part?

Your participation will hopefully aid in the development of better systems for use in SCOOT validation.

Are there any risks involved?

Typical office working environment risks only.

Will my participation be confidential?

The research will comply with the Data Protection Act. All data collected will only be used for this study, will be coded to ensure participant anonymity and kept on a password protected computer.

What happens if I change my mind?

You may withdraw from the study at any time without your legal rights being affected.

What happens if something goes wrong?

If you have any cause of concern or complaint with this research you can contact the research governance manager (rgoinfo@soton.ac.uk, 02380 595058)

Where can I get more information?

Researcher: Joshua Price – [redacted]
Supervisor: Neville Stanton – [redacted]
Siemens contact: Ian Snell – [redacted]

Appendix E: Consent Form for Chapter 7

Study title: Empirical assessment of an ecological tool for STOC validation

Researcher name: Joshua Price

Ethics reference: 11917

Please initial the box(es) if you agree with the statement(s):

I have read and understood the information sheet (v1.0) and have had the opportunity to ask questions about the study.	☐
I agree to take part in this research project and agree for my data to be used for the purpose of this study	☐
I understand my participation is voluntary and I may withdraw at any time without my legal rights being affected	☐
I am happy to be contacted regarding follow up studies arising from this research.	☐

Data Protection

I understand that information collected about me during my participation in this study will be stored on a password protected computer and that this information will only be used for the purpose of this study. All files containing any personal data will be made anonymous.

Name of participant (print name)…………………………………………………

Signature of participant………………………………………………………………..

Date…………………………………………………………………………………

Appendix F: Shapiro-Wilk Test Statistics for Assessing Dependent Measure's Normality (Chapter 7)

F.1 Performance

F.1.1 Final Validation Error

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.287	12	.007	.792	12	.008
MatLVAL	.351	12	.000	.641	12	.000
NovLVAL	.409	12	.000	.453	12	.000
ExpMCM	.281	12	.010	.776	12	.005
MatMCM	.328	12	.001	.724	12	.001
NovMCM	.320	12	.001	.646	12	.000
ExpEco	.273	12	.014	.714	12	.001
MatEco	.276	12	.012	.727	12	.002
NovEco	.352	12	.000	.728	12	.002

a. Lilliefors Significance Correction

F.1.2 Mean Cycle Validation Error

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.152	12	.200*	.955	12	.707
MatLVAL	.113	12	.200*	.949	12	.621
NovLVAL	.158	12	.200*	.899	12	.154
ExpMCM	.238	12	.059	.739	12	.002
MatMCM	.265	12	.020	.889	12	.115
NovMCM	.264	12	.020	.866	12	.058
ExpEco	.237	12	.062	.887	12	.108
MatEco	.137	12	.200*	.937	12	.464
NovEco	.156	12	.200*	.890	12	.116

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

F.1.3 Mean Time Spent Per Cycle

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.227	12	.087	.857	12	.044
MatLVAL	.354	12	.000	.553	12	.000
NovLVAL	.240	12	.055	.782	12	.006
ExpMCM	.184	12	.200*	.856	12	.043
MatMCM	.244	12	.048	.773	12	.005
NovMCM	.173	12	.200*	.919	12	.275
ExpEco	.228	12	.084	.857	12	.045
MatEco	.211	12	.146	.856	12	.044
NovEco	.177	12	.200*	.908	12	.203

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

F.1.4 Cycles Required

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.157	12	.200*	.927	12	.352
MatLVAL	.140	12	.200*	.951	12	.648
NovLVAL	.251	12	.035	.886	12	.104
ExpMCM	.243	12	.049	.874	12	.074
MatMCM	.213	12	.139	.926	12	.343
NovMCM	.262	12	.023	.760	12	.003
ExpEco	.153	12	.200*	.955	12	.716
MatEco	.205	12	.177	.887	12	.108
NovEco	.312	12	.002	.730	12	.002

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

F.2 System Use

F.2.1 Total Ecological STOC Adjustments Per Cycle

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpEco	.192	12	.200*	.924	12	.318
MatEco	.113	12	.200*	.976	12	.963
NovEco	.219	12	.116	.851	12	.038

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

F.2.2 LVAL Estimated STOC Error

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.183	12	.200*	.849	12	.036
MatLVAL	.178	12	.200*	.890	12	.117
NovLVAL	.193	12	.200*	.914	12	.239
ExpMCM	.233	12	.072	.877	12	.081
MatMCM	.210	12	.149	.845	12	.032
NovMCM	.145	12	.200*	.930	12	.378

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

F.2.3 Mean STOC Adjustment

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.229	12	.081	.787	12	.007
MatLVAL	.228	12	.084	.872	12	.069
NovLVAL	.180	12	.200*	.873	12	.071
ExpMCM	.214	12	.136	.863	12	.053
MatMCM	.276	12	.012	.680	12	.001
NovMCM	.195	12	.200*	.904	12	.177
ExpEco	.158	12	.200*	.902	12	.167
MatEco	.175	12	.200*	.910	12	.210
NovEco	.171	12	.200*	.914	12	.237

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

F.3 Workload

F.3.1 Overall Workload

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.211	12	.146	.907	12	.197
MatLVAL	.190	12	.200*	.940	12	.498
NovLVAL	.202	12	.191	.898	12	.148
ExpMCM	.193	12	.200*	.889	12	.116
MatMCM	.114	12	.200*	.978	12	.972
NovMCM	.186	12	.200*	.899	12	.154
ExpEco	.277	12	.012	.829	12	.020
MatEco	.186	12	.200*	.907	12	.198
NovEco	.173	12	.200*	.884	12	.100

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

F.3.2 Mental Demand

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.244	12	.047	.833	12	.023
MatLVAL	.191	12	.200*	.913	12	.235
NovLVAL	.204	12	.181	.895	12	.138
ExpMCM	.178	12	.200*	.928	12	.355
MatMCM	.192	12	.200*	.907	12	.193
NovMCM	.186	12	.200*	.926	12	.340
ExpEco	.152	12	.200*	.935	12	.435
MatEco	.183	12	.200*	.945	12	.561
NovEco	.206	12	.171	.904	12	.181

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

F.3.3 Physical Demand

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.316	12	.002	.702	12	.001
MatLVAL	.341	12	.000	.721	12	.001
NovLVAL	.209	12	.157	.871	12	.067
ExpMCM	.242	12	.051	.791	12	.007
MatMCM	.225	12	.094	.841	12	.028
NovMCM	.253	12	.033	.833	12	.023
ExpEco	.263	12	.021	.764	12	.004
MatEco	.312	12	.002	.779	12	.005
NovEco	.184	12	.200*	.898	12	.149

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

F.3.4 Temporal Demand

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.210	12	.150	.947	12	.592
MatLVAL	.333	12	.001	.757	12	.003
NovLVAL	.315	12	.002	.724	12	.001
ExpMCM	.116	12	.200*	.944	12	.553
MatMCM	.231	12	.076	.828	12	.020
NovMCM	.252	12	.034	.774	12	.005
ExpEco	.175	12	.200*	.910	12	.212
MatEco	.229	12	.081	.772	12	.005
NovEco	.185	12	.200*	.912	12	.226

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

F.3.5 Perceived Performance

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.219	12	.118	.900	12	.157
MatLVAL	.164	12	.200*	.882	12	.094
NovLVAL	.173	12	.200*	.914	12	.243
ExpMCM	.218	12	.119	.841	12	.029
MatMCM	.227	12	.089	.913	12	.231
NovMCM	.150	12	.200*	.892	12	.124
ExpEco	.219	12	.117	.872	12	.070
MatEco	.255	12	.030	.863	12	.053
NovEco	.158	12	.200*	.927	12	.346

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

F.3.6 Perceived Effort

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.253	12	.033	.795	12	.008
MatLVAL	.146	12	.200*	.946	12	.586
NovLVAL	.216	12	.128	.842	12	.029
ExpMCM	.182	12	.200*	.943	12	.540
MatMCM	.185	12	.200*	.895	12	.137
NovMCM	.242	12	.051	.901	12	.163
ExpEco	.147	12	.200*	.937	12	.456
MatEco	.214	12	.134	.905	12	.182
NovEco	.228	12	.085	.873	12	.070

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

F.3.7 Perceived Frustration

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.324	12	.001	.721	12	.001
MatLVAL	.227	12	.088	.805	12	.011
NovLVAL	.238	12	.058	.880	12	.088
ExpMCM	.307	12	.003	.755	12	.003
MatMCM	.175	12	.200*	.887	12	.107
NovMCM	.173	12	.200*	.941	12	.514
ExpEco	.320	12	.001	.846	12	.032
MatEco	.176	12	.200*	.865	12	.056
NovEco	.257	12	.027	.778	12	.005

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

F.4 Usability

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.162	12	.200*	.937	12	.464
MatLVAL	.230	12	.080	.856	12	.043
NovLVAL	.112	12	.200*	.976	12	.963
ExpMCM	.211	12	.147	.913	12	.234
MatMCM	.180	12	.200*	.900	12	.158
NovMCM	.126	12	.200*	.951	12	.646
ExpEco	.271	12	.015	.888	12	.110
MatEco	.189	12	.200*	.868	12	.062
NovEco	.156	12	.200*	.968	12	.892

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Appendix G: Test Statistics for Performance Measures (Chapter 7)

G.1 Final Validation Error

G.1.1 Within-Subjects

Expert

Friedman Test

Ranks

	Mean Rank
LVAL	2.21
MCM	1.96
Ecological	1.83

Test Statistics[a]

N	12
Chi-Square	1.556
df	2
Asymp. Sig.	.459

a. Friedman Test

Matched Novice

Friedman Test

Ranks

	Mean Rank
LVAL	2.08
MCM	1.96
Ecological	1.96

Test Statistics[a]

N	12
Chi-Square	.162
df	2
Asymp. Sig.	.922

a. Friedman Test

Novice

Friedman Test

Ranks

	Mean Rank
LVAL	1.95
MCM	2.22
Ecological	1.83

Test Statistics[a]

N	30
Chi-Square	3.159
df	2
Asymp. Sig.	.206

a. Friedman Test

G.1.2 Between-Subjects (Paired)

LVAL

Ranks

		N	Mean Rank	Sum of Ranks
Matched - Expert	Negative Ranks	4[a]	4.25	17.00
	Positive Ranks	5[b]	5.60	28.00
	Ties	3[c]		
	Total	12		

a. Matched < Expert
b. Matched > Expert
c. Matched = Expert

Test Statistics[a]

	Matched - Expert
Z	-.660[b]
Asymp. Sig. (2-tailed)	.509

a. Wilcoxon Signed Ranks Test
b. Based on negative ranks.

MCM

Ranks

		N	Mean Rank	Sum of Ranks
Matched - Expert	Negative Ranks	5[a]	4.20	21.00
	Positive Ranks	4[b]	6.00	24.00
	Ties	3[c]		
	Total	12		

a. Matched < Expert
b. Matched > Expert
c. Matched = Expert

Test Statistics[a]

	Matched - Expert
Z	-.180[b]
Asymp. Sig. (2-tailed)	.857

a. Wilcoxon Signed Ranks Test
b. Based on negative ranks.

Ecological

Ranks

		N	Mean Rank	Sum of Ranks
Matched - Expert	Negative Ranks	4[a]	4.00	16.00
	Positive Ranks	4[b]	5.00	20.00
	Ties	4[c]		
	Total	12		

a. Matched < Expert
b. Matched > Expert
c. Matched = Expert

Test Statistics[a]

	Matched - Expert
Z	-.289[b]
Asymp. Sig. (2-tailed)	.773

a. Wilcoxon Signed Ranks Test
b. Based on negative ranks.

G.1.3 Between-Subjects (Independent)

Expert – Novice (LVAL)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	23.63	283.50
	2	30	20.65	619.50
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	154.500
Wilcoxon W	619.500
Z	-.783
Asymp. Sig. (2-tailed)	.433
Exact Sig. [2*(1-tailed Sig.)]	.483[b]

a. Grouping Variable: Condition
b. Not corrected for ties.

Matched Novice – Novice (LVAL)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	24.08	289.00
	2	30	20.47	614.00
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	149.000
Wilcoxon W	614.000
Z	-.946
Asymp. Sig. (2-tailed)	.344
Exact Sig. [2*(1-tailed Sig.)]	.401[b]

a. Grouping Variable: Condition

b. Not corrected for ties.

Expert – Novice (MCM)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	18.54	222.50
	2	30	22.68	680.50
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	144.500
Wilcoxon W	222.500
Z	-1.042
Asymp. Sig. (2-tailed)	.297
Exact Sig. [2*(1-tailed Sig.)]	.328[b]

a. Grouping Variable: Condition

b. Not corrected for ties.

Matched Novice – Novice (MCM)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	18.38	220.50
	2	30	22.75	682.50
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	142.500
Wilcoxon W	220.500
Z	-1.103
Asymp. Sig. (2-tailed)	.270
Exact Sig. [2*(1-tailed Sig.)]	.301[b]

a. Grouping Variable: Condition

b. Not corrected for ties.

Expert – Novice (Ecological)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	22.00	264.00
	2	30	21.30	639.00
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	174.000
Wilcoxon W	639.000
Z	-.187
Asymp. Sig. (2-tailed)	.852
Exact Sig. [2*(1-tailed Sig.)]	.880[b]

a. Grouping Variable: Condition

b. Not corrected for ties.

Matched Novice – Novice (Ecological)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	22.75	273.00
	2	30	21.00	630.00
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	165.000
Wilcoxon W	630.000
Z	-.467
Asymp. Sig. (2-tailed)	.641
Exact Sig. [2*(1-tailed Sig.)]	.690[b]

a. Grouping Variable: Condition

b. Not corrected for ties.

G.2 Mean Cycle Validation Error

G.2.1 Within-Subjects

Expert

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	10.143	2	5.071	8.978	.001
Within Groups	18.641	33	.565		
Total	28.784	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value

Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	-.21833	.30684	1.000	-.9922	.5556
	3	1.00083*	.30684	.008	.2269	1.7747
2	1	.21833	.30684	1.000	-.5556	.9922
	3	1.21917*	.30684	.001	.4453	1.9931
3	1	-1.00083*	.30684	.008	-1.7747	-.2269
	2	-1.21917*	.30684	.001	-1.9931	-.4453

*. The mean difference is significant at the 0.05 level.

Matched Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	21.571	2	10.785	8.782	.001
Within Groups	40.528	33	1.228		
Total	62.098	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value

Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	-.15917	.45242	1.000	-1.3003	.9819
	3	1.55667*	.45242	.005	.4156	2.6978
2	1	.15917	.45242	1.000	-.9819	1.3003
	3	1.71583*	.45242	.002	.5747	2.8569
3	1	-1.55667*	.45242	.005	-2.6978	-.4156
	2	-1.71583*	.45242	.002	-2.8569	-.5747

*. The mean difference is significant at the 0.05 level.

Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	47.596	2	23.798	26.248	.000
Within Groups	78.880	87	.907		
Total	126.476	89			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	-.19033	.24585	1.000	-.7905	.4098
	3	1.43867*	.24585	.000	.8385	2.0388
2	1	.19033	.24585	1.000	-.4098	.7905
	3	1.62900*	.24585	.000	1.0288	2.2292
3	1	-1.43867*	.24585	.000	-2.0388	-.8385
	2	-1.62900*	.24585	.000	-2.2292	-1.0288

*. The mean difference is significant at the 0.05 level.

G.2.2 Between-Subjects (Paired)

LVAL

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	1.3817	12	.79774	.23029
	Matched	2.0575	12	.98134	.28329

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.542	.069

Paired Samples Test

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Expert - Matched	-.67583	.86627	.25007	-1.22624	-.12543	-2.703	11	.021

MCM

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	1.6000	12	.98916	.28555
	Matched	2.2167	12	1.60562	.46350

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.126	.696

Paired Samples Test

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Expert - Matched	-.61667	1.77648	.51283	-1.74539	.51206	-1.202	11	.254

Ecological

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	.3808	12	.28257	.08157
	Matched	.5008	12	.37855	.10928

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.025	.939

Paired Samples Test

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Expert - Matched	-.12000	.46669	.13472	-.41652	.17652	-.891	11	.392

G.2.3 Between-Subjects (Independent)

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	1.3817	.79774	.23029
	2	30	2.0093	1.14090	.20830

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.796	.188	-1.737	40	.090	-.62767	.36127	-1.35782	.10249
	Equal variances not assumed			-2.021	28.999	.053	-.62767	.31052	-1.26275	.00742

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	2.0575	.98134	.28329
	2	30	2.0093	1.14090	.20830

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.267	.608	.128	40	.899	.04817	.37549	-.71073	.80707
	Equal variances not assumed			.137	23.504	.892	.04817	.35163	-.67836	.77470

Expert – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	1.6000	.98916	.28555
	2	30	2.1997	1.09196	.19936

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.667	.419	-1.649	40	.107	-.59967	.36366	-1.33465	.13531
	Equal variances not assumed			-1.722	22.326	.099	-.59967	.34826	-1.32129	.12196

Matched Novice – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	2.2167	1.60562	.46350
	2	30	2.1997	1.09196	.19936

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	4.893	.033	.040	40	.969	.01700	.42845	-.84892	.88292
	Equal variances not assumed			.034	15.249	.974	.01700	.50456	-1.05692	1.09092

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	.3808	.28257	.08157
	2	30	.5707	.47536	.08679

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	5.215	.028	-1.289	40	.205	-.18983	.14722	-.48738	.10772
	Equal variances not assumed			-1.594	33.646	.120	-.18983	.11910	-.43198	.05231

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	.5008	.37855	.10928
	2	30	.5707	.47536	.08679

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.195	.281	-.454	40	.653	-.06983	.15398	-.38104	.24138
	Equal variances not assumed			-.500	25.417	.621	-.06983	.13955	-.35700	.21733

G.3 Mean Time Spent Per Cycle

G.3.1 Within-Subjects

Expert

Friedman Test

Ranks

	Mean Rank
LVAL	1.17
MCM	1.83
Ecological	3.00

Test Statistics[a]

N	12
Chi-Square	20.667
df	2
Asymp. Sig.	.000

a. Friedman Test

Test Statistics[a]

	MCM - LVAL	Ecological - LVAL	Ecological - MCM
Z	-2.485[b]	-3.061[b]	-3.061[b]
Asymp. Sig. (2-tailed)	.013	.002	.002

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

Matched Novice

Friedman Test

Ranks

	Mean Rank
LVAL	1.29
MCM	1.83
Ecological	2.88

Test Statistics[a]

N	12
Chi-Square	16.578
df	2
Asymp. Sig.	.000

a. Friedman Test

Test Statistics[a]

	MCM - LVAL	Ecological - LVAL	Ecological - MCM
Z	-1.786[b]	-2.941[b]	-2.398[b]
Asymp. Sig. (2-tailed)	.074	.003	.016

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

Novice

Friedman Test

Ranks

	Mean Rank
LVAL	1.28
MCM	1.78
Ecological	2.93

Test Statistics[a]

N	30
Chi-Square	43.311
df	2
Asymp. Sig.	.000

a. Friedman Test

Test Statistics[a]

	MCM - LVAL	Ecological - LVAL	Ecological - MCM
Z	-2.371[b]	-4.789[b]	-4.479[b]
Asymp. Sig. (2-tailed)	.018	.000	.000

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

G.3.2 Between-Subjects (Paired)

LVAL

Ranks

		N	Mean Rank	Sum of Ranks
Matched - Expert	Negative Ranks	2[a]	3.75	7.50
	Positive Ranks	10[b]	7.05	70.50
	Ties	0[c]		
	Total	12		

a. Matched < Expert

b. Matched > Expert

c. Matched = Expert

Test Statistics[a]

	Matched - Expert
Z	-2.485[b]
Asymp. Sig. (2-tailed)	.013

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

MCM

Ranks

		N	Mean Rank	Sum of Ranks
Matched - Expert	Negative Ranks	2[a]	5.00	10.00
	Positive Ranks	8[b]	5.63	45.00
	Ties	2[c]		
	Total	12		

a. Matched < Expert

b. Matched > Expert

c. Matched = Expert

Test Statistics[a]

	Matched - Expert
Z	-1.786[b]
Asymp. Sig. (2-tailed)	.074

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

Ecological

Ranks

		N	Mean Rank	Sum of Ranks
Matched - Expert	Negative Ranks	8[a]	13.50	108.00
	Positive Ranks	21[b]	15.57	327.00
	Ties	1[c]		
	Total	30		

a. Matched < Expert

b. Matched > Expert

c. Matched = Expert

Test Statistics[a]

	Matched - Expert
Z	-2.371[b]
Asymp. Sig. (2-tailed)	.018

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

G.3.3 Between – Independent

Expert – Novice (LVAL)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	21.50	258.00
	2	30	21.50	645.00
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	180.000
Wilcoxon W	645.000
Z	.000
Asymp. Sig. (2-tailed)	1.000
Exact Sig. [2*(1-tailed Sig.)]	1.000[b]

a. Grouping Variable: Condition

b. Not corrected for ties.

Matched Novice – Novice (LVAL)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	24.42	293.00
	2	30	20.33	610.00
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	145.000
Wilcoxon W	610.000
Z	-.980
Asymp. Sig. (2-tailed)	.327
Exact Sig. [2*(1-tailed Sig.)]	.342[b]

a. Grouping Variable: Condition

b. Not corrected for ties.

Expert – Novice (MCM)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	19.75	237.00
	2	30	22.20	666.00
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	159.000
Wilcoxon W	237.000
Z	-.588
Asymp. Sig. (2-tailed)	.557
Exact Sig. [2*(1-tailed Sig.)]	.573[b]

a. Grouping Variable: Condition

b. Not corrected for ties.

Matched Novice – Novice (MCM)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	26.29	315.50
	2	30	19.58	587.50
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	122.500
Wilcoxon W	587.500
Z	-1.606
Asymp. Sig. (2-tailed)	.108
Exact Sig. [2*(1-tailed Sig.)]	.110[b]

a. Grouping Variable: Condition

b. Not corrected for ties.

Expert – Novice (Ecological)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	25.38	304.50
	2	30	19.95	598.50
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	133.500
Wilcoxon W	598.500
Z	-1.298
Asymp. Sig. (2-tailed)	.194
Exact Sig. [2*(1-tailed Sig.)]	.198[b]

a. Grouping Variable: Condition

b. Not corrected for ties.

Matched Novice – Novice (Ecological)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	21.96	263.50
	2	30	21.32	639.50
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	174.500
Wilcoxon W	639.500
Z	-.153
Asymp. Sig. (2-tailed)	.878
Exact Sig. [2*(1-tailed Sig.)]	.880[b]

a. Grouping Variable: Condition

b. Not corrected for ties.

G.4 Cycles Required

G.4.1 Within-Subjects

Expert

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	105.640	2	52.820	3.374	.046
Within Groups	516.557	33	15.653		
Total	622.197	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value

Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	1.47333	1.61520	1.000	-2.6005	5.5472
	3	4.13917*	1.61520	.045	.0653	8.2130
2	1	-1.47333	1.61520	1.000	-5.5472	2.6005
	3	2.66583	1.61520	.325	-1.4080	6.7397
3	1	-4.13917*	1.61520	.045	-8.2130	-.0653
	2	-2.66583	1.61520	.325	-6.7397	1.4080

*. The mean difference is significant at the 0.05 level.

Matched Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	97.153	2	48.576	3.377	.046
Within Groups	474.725	33	14.386		
Total	571.877	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	2	.33250	1.54842	1.000	-3.5729	4.2379
	3	3.63917	1.54842	.075	-.2663	7.5446
2	1	-.33250	1.54842	1.000	-4.2379	3.5729
	3	3.30667	1.54842	.121	-.5988	7.2121
3	1	-3.63917	1.54842	.075	-7.5446	.2663
	2	-3.30667	1.54842	.121	-7.2121	.5988

Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	483.683	2	241.841	7.637	.001
Within Groups	2755.171	87	31.669		
Total	3238.854	89			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	2	1.17667	1.45301	1.000	-2.3704	4.7237
	3	5.39933*	1.45301	.001	1.8523	8.9464
2	1	-1.17667	1.45301	1.000	-4.7237	2.3704
	3	4.22267*	1.45301	.014	.6756	7.7697
3	1	-5.39933*	1.45301	.001	-8.9464	-1.8523
	2	-4.22267*	1.45301	.014	-7.7697	-.6756

*. The mean difference is significant at the 0.05 level.

G.4.2 Between-Subjects (Paired)

LVAL

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	9.7225	12	4.21745	1.21747
	Matched	10.5000	12	4.18149	1.20709

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	-.160	.619

Paired Samples Test

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Expert - Matched	-.77750	6.39695	1.84664	-4.84193	3.28693	-.421	11	.682

MCM

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	8.2492	12	4.78438	1.38113
	Matched	10.1675	12	4.26725	1.23185

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	-.067	.836

Paired Samples Test

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Expert - Matched	-1.91833	6.62086	1.91128	-6.12503	2.28836	-1.004	11	.337

Ecological

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	5.5833	12	2.50650	.72356
	Matched	6.8608	12	2.73176	.78859

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	-.003	.993

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Expert - Matched	-1.27750	3.71242	1.07168	-3.63626	1.08126	-1.192	11	.258

G.4.3 Between-Subjects (Independent)

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	9.7225	4.21745	1.21747
	2	30	13.1993	6.45234	1.17803

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Response	Equal variances assumed	1.056	.310	-1.719	40	.093	-3.47683	2.02289	-7.56525	.61159
	Equal variances not assumed			-2.052	30.949	.049	-3.47683	1.69411	-6.93222	-.02145

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	10.5000	4.18149	1.20709
	2	30	13.1993	6.45234	1.17803

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Response	Equal variances assumed	1.397	.244	-1.336	40	.189	-2.69933	2.02050	-6.78291	1.38424
	Equal variances not assumed			-1.600	31.197	.120	-2.69933	1.68666	-6.13842	.73975

Expert – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	8.2492	4.78438	1.38113
	2	30	12.0227	4.83766	.88323

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Response	Equal variances assumed	.115	.736	-2.291	40	.027	-3.77350	1.64739	-7.10300	-.44400
	Equal variances not assumed			-2.302	20.534	.032	-3.77350	1.63940	-7.18753	-.35947

Matched Novice – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	10.1675	4.26725	1.23185
	2	30	12.0227	4.83766	.88323

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.000	.987	-1.159	40	.253	-1.85517	1.60116	-5.09123	1.38090
	Equal variances not assumed			-1.224	22.919	.233	-1.85517	1.51577	-4.99138	1.28105

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	5.5833	2.50650	.72356
	2	30	7.8000	5.47451	.99950

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	3.009	.091	-1.340	40	.188	-2.21667	1.65425	-5.56004	1.12670
	Equal variances not assumed			-1.796	39.071	.080	-2.21667	1.23392	-4.71236	.27902

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	6.8608	2.73176	.78859
	2	30	7.8000	5.47451	.99950

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.755	.193	-.564	40	.576	-.93917	1.66566	-4.30558	2.42725
	Equal variances not assumed			-.738	37.763	.465	-.93917	1.27314	-3.51703	1.63870

Appendix H: Test Statistics for System Use Measures (Chapter 7)

H.1 Total Ecological STOC Adjustments Per Cycle

H.1.1 Between-Subjects (Paired)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	23.6658	12	12.05889	3.48110
	Matched	30.5000	12	12.63024	3.64604

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.839	.001

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Expert - Matched	-6.83417	7.02365	2.02755	-11.29678	-2.37155	-3.371	11	.006

H.1.2 Between-Subjects (Independent)

<u>Expert - Novice</u>

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	23.6658	12.05889	3.48110
	2	30	41.7557	23.28373	4.25101

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Response	Equal variances assumed	3.149	.084	-2.545	40	.015	-18.08983	7.10780	-32.45523	-3.72444
	Equal variances not assumed			-3.292	37.032	.002	-18.08983	5.49446	-29.22235	-6.95732

<u>Matched Novice - Novice</u>

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	30.5000	12.63024	3.64604
	2	30	41.7557	23.28373	4.25101

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Response	Equal variances assumed	2.861	.099	-1.577	40	.123	-11.25567	7.13956	-25.68526	3.17393
	Equal variances not assumed			-2.010	36.000	.052	-11.25567	5.60042	-22.61384	.10250

H.2 Estimated STOC Error

H.2.1 Within-Subjects

Expert

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	LVAL	1.7508	12	.89507	.25839
	MCM	1.8625	12	1.10000	.31754

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	LVAL & MCM	12	.544	.067

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	LVAL - MCM	-.11167	.96902	.27973	-.72735	.50402	-.399	11	.697

Matched Novice

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	LVAL	1.8117	12	1.03007	.29736
	MCM	1.8483	12	1.42096	.41020

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	LVAL & MCM	12	.563	.057

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	LVAL - MCM	-.03667	1.19674	.34547	-.79704	.72371	-.106	11	.917

Novice

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	LVAL	1.4523	30	.94442	.17243
	MCM	2.1977	30	1.28856	.23526

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	LVAL & MCM	30	.202	.283

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	LVAL - MCM	-.74533	1.43513	.26202	-1.28122	-.20945	-2.845	29	.008

H.2.2 Between-Subjects (Paired)

LVAL

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	1.7508	12	.89507	.25839
	Matched	1.8117	12	1.03007	.29736

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.660	.019

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Expert - Matched	-.06083	.80304	.23182	-.57106	.44940	-.262	11	.798

MCM

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	1.8625	12	1.10000	.31754
	Matched	1.8483	12	1.42096	.41020

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.254	.425

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Expert - Matched	.01417	1.56006	.45035	-.97705	1.00538	.031	11	.975

H.2.3 Between-Subjects (Independent)

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	1.7508	.89507	.25839
	2	30	1.4523	.94442	.17243

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Response	Equal variances assumed	.016	.899	.939	40	.354	.29850	.31803	-.34427	.94127
	Equal variances not assumed			.961	21.371	.347	.29850	.31063	-.34682	.94382

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	1.8117	1.03007	.29736
	2	30	1.4523	.94442	.17243

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Response	Equal variances assumed	.701	.407	1.086	40	.284	.35933	.33088	-.30941	1.02807
	Equal variances not assumed			1.045	18.833	.309	.35933	.34373	-.36054	1.07920

Expert – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	1.8625	1.10000	.31754
	2	30	2.1977	1.28856	.23526

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Response	Equal variances assumed	.441	.510	-.792	40	.433	-.33517	.42339	-1.19088	.52055
	Equal variances not assumed			-.848	23.683	.405	-.33517	.39520	-1.15139	.48106

Matched Novice – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	1.8483	1.42096	.41020
	2	30	2.1977	1.28856	.23526

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.000	1.000	-.771	40	.445	-.34933	.45301	-1.26491	.56624
	Equal variances not assumed			-.739	18.661	.469	-.34933	.47287	-1.34028	.64162

H.3 Mean STOC adjustment

H.3.1 Within-Subjects

Expert

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.361	2	1.180	1.648	.208
Within Groups	23.632	33	.716		
Total	25.993	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	-.13083	.34548	1.000	-1.0022	.7405
	3	.46583	.34548	.560	-.4055	1.3372
2	1	.13083	.34548	1.000	-.7405	1.0022
	3	.59667	.34548	.281	-.2747	1.4680
3	1	-.46583	.34548	.560	-1.3372	.4055
	2	-.59667	.34548	.281	-1.4680	.2747

Matched Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	25.951	2	12.976	2.782	.076
Within Groups	153.927	33	4.664		
Total	179.878	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	-.56167	.88171	1.000	-2.7855	1.6622
	3	1.45333	.88171	.326	-.7705	3.6772
2	1	.56167	.88171	1.000	-1.6622	2.7855
	3	2.01500	.88171	.087	-.2089	4.2389
3	1	-1.45333	.88171	.326	-3.6772	.7705
	2	-2.01500	.88171	.087	-4.2389	.2089

Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	41.049	2	20.525	10.691	.000
Within Groups	167.025	87	1.920		
Total	208.075	89			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	.66533	.35776	.199	-.2080	1.5387
	3	1.64433*	.35776	.000	.7710	2.5177
2	1	-.66533	.35776	.199	-1.5387	.2080
	3	.97900*	.35776	.023	.1057	1.8523
3	1	-1.64433*	.35776	.000	-2.5177	-.7710
	2	-.97900*	.35776	.023	-1.8523	-.1057

*. The mean difference is significant at the 0.05 level.

H.3.2 Between-Subjects (Paired)

LVAL

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	1.0533	12	.97359	.28105
	Matched	2.0800	12	1.46387	.42258

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.173	.591

Paired Samples Test

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Expert - Matched	-1.02667	1.61167	.46525	-2.05067	-.00266	-2.207	11	.050

MCM

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	1.1842	12	.96662	.27904
	Matched	2.6417	12	3.39316	.97952

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	-.217	.499

Paired Samples Test

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Expert - Matched	-1.45750	3.72421	1.07509	-3.82375	.90875	-1.356	11	.202

Ecological

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	.5875	12	.51590	.14893
	Matched	.6267	12	.58041	.16755

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.403	.194

Paired Samples Test

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Expert - Matched	-.03917	.60131	.17358	-.42122	.34289	-.226	11	.826

H.3.3 Between-Subjects (Independent)

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	1.0533	.97359	.28105
	2	30	2.4807	2.08303	.38031

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	5.224	.028	-2.264	40	.029	-1.42733	.63041	-2.70144	-.15322
	Equal variances not assumed			-3.018	38.809	.004	-1.42733	.47289	-2.38399	-.47068

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	2.0800	1.46387	.42258
	2	30	2.4807	2.08303	.38031

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	2.130	.152	-.607	40	.547	-.40067	.66012	-1.73482	.93349
	Equal variances not assumed			-.705	28.855	.487	-.40067	.56852	-1.56366	.76233

Expert – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	1.1842	.96662	.27904
	2	30	1.8153	.99338	.18137

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.194	.662	-1.874	40	.068	-.63117	.33681	-1.31189	.04956
	Equal variances not assumed			-1.897	20.846	.072	-.63117	.33280	-1.32357	.06124

Matched Novice – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	2.6417	3.39316	.97952
	2	30	1.8153	.99338	.18137

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	8.610	.006	1.228	40	.227	.82633	.67295	-.53375	2.18641
	Equal variances not assumed			.830	11.762	.423	.82633	.99617	-1.34902	3.00168

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	.5875	.51590	.14893
	2	30	.8363	.65855	.12023

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	2.352	.133	-1.170	40	.249	-.24883	.21265	-.67862	.18096
	Equal variances not assumed			-1.300	25.848	.205	-.24883	.19140	-.64238	.14472

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	.6267	.58041	.16755
	2	30	.8363	.65855	.12023

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.786	.381	-.962	40	.342	-.20967	.21793	-.65011	.23078
	Equal variances not assumed			-1.017	22.939	.320	-.20967	.20623	-.63634	.21701

Appendix I: Test Statistics for Workload Measures (Chapter 7)

I.1 Overall Workload

I.1.1 Within-Subjects

Expert

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	87.389	2	43.694	.209	.812
Within Groups	6887.583	33	208.715		
Total	6974.972	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	2	-2.75000	5.89795	1.000	-17.6259	12.1259
	3	-3.66667	5.89795	1.000	-18.5425	11.2092
2	1	2.75000	5.89795	1.000	-12.1259	17.6259
	3	-.91667	5.89795	1.000	-15.7925	13.9592
3	1	3.66667	5.89795	1.000	-11.2092	18.5425
	2	.91667	5.89795	1.000	-13.9592	15.7925

Matched Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1194.056	2	597.028	2.845	.072
Within Groups	6924.250	33	209.826		
Total	8118.306	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	2	-6.33333	5.91362	.876	-21.2488	8.5821
	3	7.75000	5.91362	.597	-7.1654	22.6654
2	1	6.33333	5.91362	.876	-8.5821	21.2488
	3	14.08333	5.91362	.069	-.8321	28.9988
3	1	-7.75000	5.91362	.597	-22.6654	7.1654
	2	-14.08333	5.91362	.069	-28.9988	.8321

Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5040.467	2	2520.233	14.587	.000
Within Groups	15031.133	87	172.772		
Total	20071.600	89			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	2	-5.83333	3.39383	.268	-14.1182	2.4515
	3	12.13333*	3.39383	.002	3.8485	20.4182
2	1	5.83333	3.39383	.268	-2.4515	14.1182
	3	17.96667*	3.39383	.000	9.6818	26.2515
3	1	-12.13333*	3.39383	.002	-20.4182	-3.8485
	2	-17.96667*	3.39383	.000	-26.2515	-9.6818

*. The mean difference is significant at the 0.05 level.

I.1.2 Between-Subjects (Paired)

LVAL

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	25.3333	12	13.17252	3.80258
	Matched	32.8333	12	16.50253	4.76387

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.535	.073

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Expert - Matched	-7.50000	14.60697	4.21667	-16.78083	1.78083	-1.779	11	.103

MCM

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	28.0833	12	15.05420	4.34577
	Matched	39.1667	12	14.41485	4.16121

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.614	.034

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Expert - Matched	-11.08333	12.95768	3.74056	-19.31625	-2.85042	-2.963	11	.013

Ecological

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	29.0000	12	15.03330	4.33974
	Matched	25.0833	12	12.22113	3.52794

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.133	.681

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Expert - Matched	3.91667	18.07287	5.21719	-7.56629	15.39962	.751	11	.469

I.1.3 Between-Subjects (Independent)

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	25.3333	13.17252	3.80258
	2	30	36.1667	13.98049	2.55248

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Response	Equal variances assumed	.063	.803	-2.304	40	.026	-10.83333	4.70097	-20.33434	-1.33232
	Equal variances not assumed			-2.365	21.491	.027	-10.83333	4.57982	-20.34436	-1.32231

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	32.8333	16.50253	4.76387
	2	30	36.1667	13.98049	2.55248

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.582	.216	-.663	40	.511	-3.33333	5.02688	-13.49304	6.82637
	Equal variances not assumed			-.617	17.670	.545	-3.33333	5.40459	-14.70317	8.03651

Expert – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	28.0833	15.05420	4.34577
	2	30	42.0000	13.43182	2.45230

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.056	.815	-2.932	40	.006	-13.91667	4.74668	-23.51007	-4.32326
	Equal variances not assumed			-2.789	18.413	.012	-13.91667	4.98994	-24.38333	-3.45000

Matched Novice – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	39.1667	14.41485	4.16121
	2	30	42.0000	13.43182	2.45230

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.080	.778	-.605	40	.549	-2.83333	4.68258	-12.29717	6.63051
	Equal variances not assumed			-.587	19.094	.564	-2.83333	4.83006	-12.93939	7.27273

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	29.0000	15.03330	4.33974
	2	30	24.0333	11.93512	2.17905

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.616	.437	1.131	40	.265	4.96667	4.39312	-3.91216	13.84549
	Equal variances not assumed			1.023	16.840	.321	4.96667	4.85609	-5.28621	15.21954

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	25.0833	12.22113	3.52794
	2	30	24.0333	11.93512	2.17905

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.072	.790	.256	40	.799	1.05000	4.10372	-7.24392	9.34392
	Equal variances not assumed			.253	19.896	.803	1.05000	4.14663	-7.60264	9.70264

I.2 Mental Demand

I.2.1 Within-Subjects

Expert

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	176.389	2	88.194	.198	.821
Within Groups	14662.500	33	444.318		
Total	14838.889	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	-2.50000	8.60541	1.000	-24.2047	19.2047
	3	-5.41667	8.60541	1.000	-27.1213	16.2880
2	1	2.50000	8.60541	1.000	-19.2047	24.2047
	3	-2.91667	8.60541	1.000	-24.6213	18.7880
3	1	5.41667	8.60541	1.000	-16.2880	27.1213
	2	2.91667	8.60541	1.000	-18.7880	24.6213

Matched Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3654.167	2	1827.083	3.145	.056
Within Groups	19170.833	33	580.934		
Total	22825.000	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	-14.16667	9.83984	.478	-38.9848	10.6515
	3	10.41667	9.83984	.892	-14.4015	35.2348
2	1	14.16667	9.83984	.478	-10.6515	38.9848
	3	24.58333	9.83984	.053	-.2348	49.4015
3	1	-10.41667	9.83984	.892	-35.2348	14.4015
	2	-24.58333	9.83984	.053	-49.4015	.2348

Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	11623.889	2	5811.944	12.227	.000
Within Groups	41354.167	87	475.335		
Total	52978.056	89			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-13.50000	5.62930	.056	-27.2420	.2420
	3	14.33333*	5.62930	.038	.5914	28.0753
2	1	13.50000	5.62930	.056	-.2420	27.2420
	3	27.83333*	5.62930	.000	14.0914	41.5753
3	1	-14.33333*	5.62930	.038	-28.0753	-.5914
	2	-27.83333*	5.62930	.000	-41.5753	-14.0914

*. The mean difference is significant at the 0.05 level.

I.2.2 Between-Subjects (Paired)

LVAL

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	32.9167	12	19.12380	5.52057
	Matched	39.5833	12	29.26822	8.44901

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	-.046	.886

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Expert - Matched	-6.66667	35.69653	10.30470	-29.34716	16.01383	-.647	11	.531

MCM

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	35.4167	12	22.60916	6.52670
	Matched	53.7500	12	22.67608	6.54602

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.436	.157

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Expert - Matched	-18.33333	24.05801	6.94495	-33.61906	-3.04760	-2.640	11	.023

Ecological

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	38.3333	12	21.35558	6.16482
	Matched	29.1667	12	19.28652	5.56754

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.349	.265

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Expert - Matched	9.16667	23.24116	6.70914	-5.60006	23.93340	1.366	11	.199

I.2.3 Between-Subjects (Independent)

<u>Expert – Novice (LVAL)</u>

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	32.9167	19.12380	5.52057
	2	30	44.0000	23.46678	4.28443

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.670	.204	-1.451	40	.154	-11.08333	7.63627	-26.51682	4.35015
	Equal variances not assumed			-1.586	24.825	.125	-11.08333	6.98806	-25.48065	3.31398

<u>Matched Novice – Novice (LVAL)</u>

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	39.5833	29.26822	8.44901
	2	30	44.0000	23.46678	4.28443

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.037	.315	-.513	40	.611	-4.41667	8.60597	-21.80998	12.97664
	Equal variances not assumed			-.466	16.959	.647	-4.41667	9.47323	-24.40710	15.57377

<u>Expert – Novice (MCM)</u>

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	35.4167	22.60916	6.52670
	2	30	57.5000	20.37366	3.71971

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.086	.770	-3.077	40	.004	-22.08333	7.17702	-36.58862	-7.57804
	Equal variances not assumed			-2.940	18.563	.009	-22.08333	7.51226	-37.83174	-6.33493

<u>Matched Novice – Novice (MCM)</u>

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	53.7500	22.67608	6.54602
	2	30	57.5000	20.37366	3.71971

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.668	.419	-.522	40	.605	-3.75000	7.18379	-18.26897	10.76897
	Equal variances not assumed			-.498	18.518	.624	-3.75000	7.52905	-19.53628	12.03628

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	38.3333	21.35558	6.16482
	2	30	29.6667	21.45297	3.91676

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.043	.837	1.184	40	.243	8.66667	7.31845	-6.12447	23.45781
	Equal variances not assumed			1.187	20.411	.249	8.66667	7.30384	-6.54922	23.88255

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	29.1667	19.28652	5.56754
	2	30	29.6667	21.45297	3.91676

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.128	.722	-.070	40	.944	-.50000	7.13175	-14.91380	13.91380
	Equal variances not assumed			-.073	22.493	.942	-.50000	6.80724	-14.59944	13.59944

I.3 Physical Demand

I.3.1 Within-Subjects

Expert

Friedman Test

Ranks

	Mean Rank
LVAL	1.92
MCM	2.08
Ecological	2.00

Test Statistics[a]

N	12
Chi-Square	.333
df	2
Asymp. Sig.	.846

a. Friedman Test

Matched Novice

Friedman Test

Ranks

	Mean Rank
LVAL	1.83
MCM	1.96
Ecological	2.21

Test Statistics[a]

N	12
Chi-Square	2.333
df	2
Asymp. Sig.	.311

a. Friedman Test

Novice

Friedman Test

Ranks

	Mean Rank
LVAL	2.17
MCM	1.82
Ecological	2.02

Test Statistics[a]

N	30
Chi-Square	3.895
df	2
Asymp. Sig.	.143

a. Friedman Test

I.3.2 Between – Paired

LVAL

Ranks

		N	Mean Rank	Sum of Ranks
Matched - Expert	Negative Ranks	4[a]	4.50	18.00
	Positive Ranks	3[b]	3.33	10.00
	Ties	5[c]		
	Total	12		

a. Matched < Expert

b. Matched > Expert

c. Matched = Expert

Test Statistics[a]

	Matched - Expert
Z	-.679[b]
Asymp. Sig. (2-tailed)	.497

a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.

MCM

Ranks

		N	Mean Rank	Sum of Ranks
Matched - Expert	Negative Ranks	5[a]	6.40	32.00
	Positive Ranks	4[b]	3.25	13.00
	Ties	3[c]		
	Total	12		

a. Matched < Expert

b. Matched > Expert

c. Matched = Expert

Test Statistics[a]

	Matched - Expert
Z	-1.131[b]
Asymp. Sig. (2-tailed)	.258

a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.

Ecological

Ranks

		N	Mean Rank	Sum of Ranks
Matched - Expert	Negative Ranks	5[a]	6.10	30.50
	Positive Ranks	4[b]	3.63	14.50
	Ties	3[c]		
	Total	12		

a. Matched < Expert

b. Matched > Expert

c. Matched = Expert

Test Statistics[a]

	Matched - Expert
Z	-.953[b]
Asymp. Sig. (2-tailed)	.341

a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.

I.3.3 Between – Independent

Expert – Novice (LVAL)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	20.04	240.50
	2	30	22.08	662.50
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	162.500
Wilcoxon W	240.500
Z	-.511
Asymp. Sig. (2-tailed)	.609
Exact Sig. [2*(1-tailed Sig.)]	.631[b]

a. Grouping Variable: Condition

b. Not corrected for ties.

Matched Novice – Novice (LVAL)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	17.96	215.50
	2	30	22.92	687.50
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	137.500
Wilcoxon W	215.500
Z	-1.243
Asymp. Sig. (2-tailed)	.214
Exact Sig. [2*(1-tailed Sig.)]	.240[b]

a. Grouping Variable: Condition

b. Not corrected for ties.

Expert – Novice (MCM)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	23.79	285.50
	2	30	20.58	617.50
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	152.500
Wilcoxon W	617.500
Z	-.809
Asymp. Sig. (2-tailed)	.418
Exact Sig. [2*(1-tailed Sig.)]	.449[b]

a. Grouping Variable: Condition

b. Not corrected for ties.

Matched Novice – Novice (MCM)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	22.21	266.50
	2	30	21.22	636.50
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	171.500
Wilcoxon W	636.500
Z	-.251
Asymp. Sig. (2-tailed)	.802
Exact Sig. [2*(1-tailed Sig.)]	.815[b]

a. Grouping Variable: Condition

b. Not corrected for ties.

Expert – Novice (Ecological)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	22.13	265.50
	2	30	21.25	637.50
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	172.500
Wilcoxon W	637.500
Z	-.218
Asymp. Sig. (2-tailed)	.828
Exact Sig. [2*(1-tailed Sig.)]	.837[b]

a. Grouping Variable: Condition

b. Not corrected for ties.

Matched Novice – Novice (Ecological)

Ranks

	Condition	N	Mean Rank	Sum of Ranks
Response	1	12	20.42	245.00
	2	30	21.93	658.00
	Total	42		

Test Statistics[a]

	Response
Mann-Whitney U	167.000
Wilcoxon W	245.000
Z	-.377
Asymp. Sig. (2-tailed)	.706
Exact Sig. [2*(1-tailed Sig.)]	.731[b]

a. Grouping Variable: Condition

b. Not corrected for ties.

I.4 Temporal Demand

I.4.1 Within-Subjects

Expert

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	18.056	2	9.028	.030	.971
Within Groups	9972.917	33	302.210		
Total	9990.972	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value

Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	-1.66667	7.09706	1.000	-19.5670	16.2336
	3	-.41667	7.09706	1.000	-18.3170	17.4836
2	1	1.66667	7.09706	1.000	-16.2336	19.5670
	3	1.25000	7.09706	1.000	-16.6503	19.1503
3	1	.41667	7.09706	1.000	-17.4836	18.3170
	2	-1.25000	7.09706	1.000	-19.1503	16.6503

Matched Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	18.056	2	9.028	.017	.983
Within Groups	17122.917	33	518.876		
Total	17140.972	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	1.66667	9.29943	1.000	-21.7885	25.1218
	3	1.25000	9.29943	1.000	-22.2051	24.7051
2	1	-1.66667	9.29943	1.000	-25.1218	21.7885
	3	-.41667	9.29943	1.000	-23.8718	23.0385
3	1	-1.25000	9.29943	1.000	-24.7051	22.2051
	2	.41667	9.29943	1.000	-23.0385	23.8718

Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2361.667	2	1180.833	3.758	.027
Within Groups	27338.333	87	314.234		
Total	29700.000	89			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	-1.83333	4.57700	1.000	-13.0065	9.3398
	3	9.83333	4.57700	.103	-1.3398	21.0065
2	1	1.83333	4.57700	1.000	-9.3398	13.0065
	3	11.66667*	4.57700	.038	.4935	22.8398
3	1	-9.83333	4.57700	.103	-21.0065	1.3398
	2	-11.66667*	4.57700	.038	-22.8398	-.4935

*. The mean difference is significant at the 0.05 level.

I.4.2 Between-Subjects (Paired)

LVAL

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	28.3333	12	16.56027	4.78054
	Matched	25.0000	12	23.54879	6.79795

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.676	.016

Paired Samples Test

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Expert - Matched	3.33333	17.36419	5.01261	-7.69935	14.36601	.665	11	.520

MCM

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	30.0000	12	19.18806	5.53912
	Matched	23.3333	12	20.48651	5.91395

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.480	.114

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Expert - Matched	6.66667	20.26342	5.84954	-6.20809	19.54143	1.140	11	.279

Ecological

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	28.7500	12	16.25437	4.69223
	Matched	23.7500	12	24.13268	6.96651

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.077	.813

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Expert - Matched	5.00000	28.04218	8.09508	-12.81715	22.81715	.618	11	.549

I.4.3 Between-Subjects (Independent)

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	28.3333	16.56027	4.78054
	2	30	27.6667	18.51064	3.37956

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Response	Equal variances assumed	2.210	.145	.108	40	.914	.66667	6.14659	-11.75605	13.08939
	Equal variances not assumed			.114	22.601	.910	.66667	5.85448	-11.45610	12.78943

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	25.0000	23.54879	6.79795
	2	30	27.6667	18.51064	3.37956

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Response	Equal variances assumed	.054	.818	-.390	40	.699	-2.66667	6.83912	-16.48905	11.15572
	Equal variances not assumed			-.351	16.722	.730	-2.66667	7.59168	-18.70403	13.37069

Expert – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	30.0000	19.18806	5.53912
	2	30	29.5000	21.34891	3.89776

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.398	.532	.070	40	.944	.50000	7.09673	-13.84302	14.84302
	Equal variances not assumed			.074	22.498	.942	.50000	6.77306	-13.52845	14.52845

Matched Novice – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	23.3333	20.48651	5.91395
	2	30	29.5000	21.34891	3.89776

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.277	.601	-.855	40	.398	-6.16667	7.21223	-20.74314	8.40980
	Equal variances not assumed			-.871	21.120	.394	-6.16667	7.08289	-20.89122	8.55789

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	28.7500	16.25437	4.69223
	2	30	17.8333	12.01173	2.19303

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	2.742	.106	2.401	40	.021	10.91667	4.54757	1.72569	20.10765
	Equal variances not assumed			2.108	16.040	.051	10.91667	5.17942	-.06098	21.89432

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	23.7500	24.13268	6.96651
	2	30	17.8333	12.01173	2.19303

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	9.344	.004	1.065	40	.293	5.91667	5.55776	-5.31599	17.14932
	Equal variances not assumed			.810	13.239	.432	5.91667	7.30353	-9.83277	21.66610

I.5 Perceived Performance

I.5.1 Within-Subjects

Expert

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.556	2	2.778	.014	.986
Within Groups	6700.000	33	203.030		
Total	6705.556	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	.00000	5.81708	1.000	-14.6719	14.6719
	3	-.83333	5.81708	1.000	-15.5052	13.8386
2	1	.00000	5.81708	1.000	-14.6719	14.6719
	3	-.83333	5.81708	1.000	-15.5052	13.8386
3	1	.83333	5.81708	1.000	-13.8386	15.5052
	2	.83333	5.81708	1.000	-13.8386	15.5052

Matched Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1672.222	2	836.111	1.847	.174
Within Groups	14935.417	33	452.588		
Total	16607.639	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-7.50000	8.68513	1.000	-29.4057	14.4057
	3	9.16667	8.68513	.897	-12.7391	31.0724
2	1	7.50000	8.68513	1.000	-14.4057	29.4057
	3	16.66667	8.68513	.191	-5.2391	38.5724
3	1	-9.16667	8.68513	.897	-31.0724	12.7391
	2	-16.66667	8.68513	.191	-38.5724	5.2391

Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6323.889	2	3161.944	8.964	.000
Within Groups	30688.333	87	352.739		
Total	37012.222	89			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-2.33333	4.84933	1.000	-14.1713	9.5046
	3	16.50000*	4.84933	.003	4.6621	28.3379
2	1	2.33333	4.84933	1.000	-9.5046	14.1713
	3	18.83333*	4.84933	.001	6.9954	30.6713
3	1	-16.50000*	4.84933	.003	-28.3379	-4.6621
	2	-18.83333*	4.84933	.001	-30.6713	-6.9954

*. The mean difference is significant at the 0.05 level.

I.5.2 Between-Subjects (Paired)

LVAL

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	25.8333	12	12.76240	3.68419
	Matched	43.7500	12	20.68432	5.97105

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	-.194	.546

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Expert - Matched	-17.91667	26.32475	7.59930	-34.64261	-1.19072	-2.358	11	.038

MCM

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	25.8333	12	16.89988	4.87858
	Matched	51.2500	12	21.54541	6.21962

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.259	.416

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Expert - Matched	-25.41667	23.68912	6.83846	-40.46801	-10.36532	-3.717	11	.003

Ecological

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	26.6667	12	12.67304	3.65839
	Matched	34.5833	12	21.58054	6.22977

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	-.172	.594

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Expert - Matched	-7.91667	26.83776	7.74739	-24.96856	9.13523	-1.022	11	.329

I.5.3 Between-Subjects (Independent)

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	25.8333	12.76240	3.68419
	2	30	47.1667	20.58135	3.75762

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Response	Equal variances assumed	4.780	.035	-3.329	40	.002	-21.33333	6.40738	-34.28313	-8.38354
	Equal variances not assumed			-4.054	32.464	.000	-21.33333	5.26241	-32.04651	-10.62016

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	43.7500	20.68432	5.97105
	2	30	47.1667	20.58135	3.75762

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.011	.919	-.485	40	.630	-3.41667	7.03956	-17.64414	10.81081
	Equal variances not assumed			-.484	20.234	.633	-3.41667	7.05501	-18.12225	11.28892

Expert – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	25.8333	16.89988	4.87858
	2	30	49.5000	19.79855	3.61470

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.358	.553	-3.638	40	.001	-23.66667	6.50526	-36.81429	-10.51905
	Equal variances not assumed			-3.898	23.685	.001	-23.66667	6.07179	-36.20704	-11.12629

Matched Novice – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	51.2500	21.54541	6.21962
	2	30	49.5000	19.79855	3.61470

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.059	.809	.252	40	.802	1.75000	6.93170	-12.25948	15.75948
	Equal variances not assumed			.243	18.869	.810	1.75000	7.19373	-13.31372	16.81372

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	26.6667	12.67304	3.65839
	2	30	30.6667	15.57702	2.84396

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.446	.508	-.789	40	.435	-4.00000	5.06719	-14.24117	6.24117
	Equal variances not assumed			-.863	24.867	.396	-4.00000	4.63378	-13.54604	5.54604

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	34.5833	21.58054	6.22977
	2	30	30.6667	15.57702	2.84396

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.979	.167	.658	40	.515	3.91667	5.95529	-8.11942	15.95275
	Equal variances not assumed			.572	15.802	.575	3.91667	6.84822	-10.61568	18.44902

I.6 Perceived Effort

I.6.1 Within-Subjects

Expert

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	466.667	2	233.333	1.054	.360
Within Groups	7308.333	33	221.465		
Total	7775.000	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	-6.66667	6.07542	.841	-21.9902	8.6568
	3	-8.33333	6.07542	.538	-23.6568	6.9902
2	1	6.66667	6.07542	.841	-8.6568	21.9902
	3	-1.66667	6.07542	1.000	-16.9902	13.6568
3	1	8.33333	6.07542	.538	-6.9902	23.6568
	2	1.66667	6.07542	1.000	-13.6568	16.9902

Matched Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4968.056	2	2484.028	4.652	.017
Within Groups	17620.833	33	533.965		
Total	22588.889	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	-13.33333	9.43367	.501	-37.1271	10.4604
	3	15.41667	9.43367	.335	-8.3771	39.2104
2	1	13.33333	9.43367	.501	-10.4604	37.1271
	3	28.75000*	9.43367	.014	4.9563	52.5437
3	1	-15.41667	9.43367	.335	-39.2104	8.3771
	2	-28.75000*	9.43367	.014	-52.5437	-4.9563

*. The mean difference is significant at the 0.05 level.

Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8211.667	2	4105.833	8.537	.000
Within Groups	41840.833	87	480.929		
Total	50052.500	89			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	2	-13.16667	5.66233	.067	-26.9893	.6559
	3	10.16667	5.66233	.228	-3.6559	23.9893
2	1	13.16667	5.66233	.067	-.6559	26.9893
	3	23.33333*	5.66233	.000	9.5107	37.1559
3	1	-10.16667	5.66233	.228	-23.9893	3.6559
	2	-23.33333*	5.66233	.000	-37.1559	-9.5107

*. The mean difference is significant at the 0.05 level.

I.6.2 Between-Subjects (Paired)

LVAL

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	25.8333	12	13.28590	3.83531
	Matched	41.2500	12	26.55398	7.66547

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.538	.071

Paired Samples Test

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Expert - Matched	-15.41667	22.40722	6.46841	-29.65353	-1.17980	-2.383	11	.036

MCM

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	32.5000	12	14.53835	4.19686
	Matched	54.5833	12	24.35144	7.02965

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.530	.077

Paired Samples Test

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Expert - Matched	-22.08333	20.72091	5.98161	-35.24877	-8.91790	-3.692	11	.004

Ecological

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	34.1667	12	16.62874	4.80031
	Matched	25.8333	12	17.42951	5.03147

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.277	.383

Paired Samples Test

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Expert - Matched	8.33333	20.48651	5.91395	-4.68317	21.34984	1.409	11	.186

I.6.3 Between-Subjects (Independent)

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	25.8333	13.28590	3.83531
	2	30	42.8333	23.44044	4.27962

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	9.812	.003	-2.354	40	.024	-17.00000	7.22065	-31.59349	-2.40651
	Equal variances not assumed			-2.958	34.915	.006	-17.00000	5.74671	-28.66747	-5.33253

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	41.2500	26.55398	7.66547
	2	30	42.8333	23.44044	4.27962

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.023	.880	-.190	40	.850	-1.58333	8.31246	-18.38345	15.21678
	Equal variances not assumed			-.180	18.253	.859	-1.58333	8.77921	-20.00944	16.84278

Expert – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	32.5000	14.53835	4.19686
	2	30	56.0000	20.94327	3.82370

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.888	.177	-3.548	40	.001	-23.50000	6.62429	-36.88819	-10.11181
	Equal variances not assumed			-4.139	29.207	.000	-23.50000	5.67753	-35.10827	-11.89173

Matched Novice – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	54.5833	24.35144	7.02965
	2	30	56.0000	20.94327	3.82370

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.978	.329	-.189	40	.851	-1.41667	7.49167	-16.55790	13.72457
	Equal variances not assumed			-.177	17.878	.861	-1.41667	8.00229	-18.23706	15.40373

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	34.1667	16.62874	4.80031
	2	30	32.6667	21.32399	3.89321

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.776	.190	.218	40	.829	1.50000	6.87987	-12.40474	15.40474
	Equal variances not assumed			.243	25.969	.810	1.50000	6.18062	-11.20519	14.20519

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	25.8333	17.42951	5.03147
	2	30	32.6667	21.32399	3.89321

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.778	.383	-.984	40	.331	-6.83333	6.94317	-20.86601	7.19934
	Equal variances not assumed			-1.074	24.750	.293	-6.83333	6.36182	-19.94246	6.27580

I.7 Perceived Frustration

I.7.1 Within-Subjects

Expert

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	162.500	2	81.250	.144	.867
Within Groups	18662.500	33	565.530		
Total	18825.000	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	-3.75000	9.70850	1.000	-28.2369	20.7369
	3	-5.00000	9.70850	1.000	-29.4869	19.4869
2	1	3.75000	9.70850	1.000	-20.7369	28.2369
	3	-1.25000	9.70850	1.000	-25.7369	23.2369
3	1	5.00000	9.70850	1.000	-19.4869	29.4869
	2	1.25000	9.70850	1.000	-23.2369	25.7369

Matched Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1493.056	2	746.528	1.076	.353
Within Groups	22895.833	33	693.813		
Total	24388.889	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	2	-2.08333	10.75340	1.000	-29.2057	25.0390
	3	12.50000	10.75340	.760	-14.6224	39.6224
2	1	2.08333	10.75340	1.000	-25.0390	29.2057
	3	14.58333	10.75340	.553	-12.5390	41.7057
3	1	-12.50000	10.75340	.760	-39.6224	14.6224
	2	-14.58333	10.75340	.553	-41.7057	12.5390

Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	11633.889	2	5816.944	12.590	.000
Within Groups	40195.000	87	462.011		
Total	51828.889	89			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	2	-5.83333	5.54984	.888	-19.3813	7.7147
	3	20.66667*	5.54984	.001	7.1187	34.2147
2	1	5.83333	5.54984	.888	-7.7147	19.3813
	3	26.50000*	5.54984	.000	12.9520	40.0480
3	1	-20.66667*	5.54984	.001	-34.2147	-7.1187
	2	-26.50000*	5.54984	.000	-40.0480	-12.9520

*. The mean difference is significant at the 0.05 level.

I.7.2 Between-Subjects (Paired)

LVAL

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	24.5833	12	23.59298	6.81071
	Matched	37.9167	12	30.78210	8.88603

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.565	.056

Paired Samples Test

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Expert - Matched	-13.33333	26.14065	7.54615	-29.94231	3.27564	-1.767	11	.105

MCM

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	28.3333	12	23.38738	6.75136
	Matched	40.0000	12	28.52431	8.23426

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	.300	.344

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Expert - Matched	-11.66667	30.99365	8.94709	-31.35909	8.02576	-1.304	11	.219

Ecological

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	29.5833	12	24.35144	7.02965
	Matched	25.4167	12	17.89595	5.16612

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	-.088	.785

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Expert - Matched	4.16667	31.46667	9.08365	-15.82630	24.15964	.459	11	.655

I.7.3 Between-Subjects (Independent)

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	24.5833	23.59298	6.81071
	2	30	41.8333	23.13690	4.22420

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Response	Equal variances assumed	.340	.563	-2.171	40	.036	-17.25000	7.94590	-33.30926	-1.19074
	Equal variances not assumed			-2.152	19.970	.044	-17.25000	8.01434	-33.96923	-.53077

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	37.9167	30.78210	8.88603
	2	30	41.8333	23.13690	4.22420

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Response	Equal variances assumed	4.680	.037	-.450	40	.655	-3.91667	8.69937	-21.49874	13.66541
	Equal variances not assumed			-.398	16.219	.696	-3.91667	9.83897	-24.75147	16.91814

Expert – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	28.3333	23.38738	6.75136
	2	30	47.6667	23.84336	4.35318

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.650	.425	-2.386	40	.022	-19.33333	8.10153	-35.70713	-2.95954
	Equal variances not assumed			-2.407	20.691	.026	-19.33333	8.03312	-36.05431	-2.61236

Matched Novice – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	40.0000	28.52431	8.23426
	2	30	47.6667	23.84336	4.35318

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.214	.277	-.890	40	.379	-7.66667	8.61338	-25.07495	9.74162
	Equal variances not assumed			-.823	17.490	.422	-7.66667	9.31414	-27.27595	11.94261

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	29.5833	24.35144	7.02965
	2	30	21.1667	16.79919	3.06710

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	2.955	.093	1.285	40	.206	8.41667	6.54948	-4.82032	21.65366
	Equal variances not assumed			1.097	15.375	.289	8.41667	7.66962	-7.89606	24.72940

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	25.4167	17.89595	5.16612
	2	30	21.1667	16.79919	3.06710

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.346	.559	.727	40	.471	4.25000	5.84343	-7.56001	16.06001
	Equal variances not assumed			.707	19.216	.488	4.25000	6.00798	-8.31531	16.81531

Appendix J: Test Statistics for System Usability Measures (Chapter 7)

J.1 Overall System Usability

J.1.1 Within-Subjects

Expert

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	239.931	2	119.965	.355	.704
Within Groups	11149.479	33	337.863		
Total	11389.410	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	6.25000	7.50403	1.000	-12.6768	25.1768
	3	2.29167	7.50403	1.000	-16.6351	21.2184
2	1	-6.25000	7.50403	1.000	-25.1768	12.6768
	3	-3.95833	7.50403	1.000	-22.8851	14.9684
3	1	-2.29167	7.50403	1.000	-21.2184	16.6351
	2	3.95833	7.50403	1.000	-14.9684	22.8851

Matched Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4148.264	2	2074.132	4.792	.015
Within Groups	14282.813	33	432.813		
Total	18431.076	35			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	7.70833	8.49326	1.000	-13.7135	29.1301
	3	-17.91667	8.49326	.128	-39.3385	3.5051
2	1	-7.70833	8.49326	1.000	-29.1301	13.7135
	3	-25.62500*	8.49326	.015	-47.0468	-4.2032
3	1	17.91667	8.49326	.128	-3.5051	39.3385
	2	25.62500*	8.49326	.015	4.2032	47.0468

*. The mean difference is significant at the 0.05 level.

Novice

ANOVA

Value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9286.667	2	4643.333	16.522	.000
Within Groups	24450.833	87	281.044		
Total	33737.500	89			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Value
Bonferroni

(I) Condtion	(J) Condtion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	7.66667	4.32854	.240	-2.9000	18.2333
	3	-16.66667*	4.32854	.001	-27.2333	-6.1000
2	1	-7.66667	4.32854	.240	-18.2333	2.9000
	3	-24.33333*	4.32854	.000	-34.9000	-13.7667
3	1	16.66667*	4.32854	.001	6.1000	27.2333
	2	24.33333*	4.32854	.000	13.7667	34.9000

*. The mean difference is significant at the 0.05 level.

J.1.2 Between-Subjects (Paired)

LVAL

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	68.7500	12	17.07271	4.92847
	Matched	59.1667	12	21.03388	6.07196

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	-.011	.973

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Expert - Matched	9.58333	27.23703	7.86265	-7.72225	26.88892	1.219	11	.248

MCM

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	62.5000	12	18.27815	5.27645
	Matched	51.4583	12	23.60803	6.81505

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	-.129	.689

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Expert - Matched	11.04167	31.66692	9.14145	-9.07853	31.16187	1.208	11	.252

Ecological

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Expert	66.4583	12	19.69824	5.68639
	Matched	77.0833	12	17.28219	4.98894

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Expert & Matched	12	-.026	.935

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Expert - Matched	-10.62500	26.54595	7.66316	-27.49149	6.24149	-1.387	11	.193

J.1.3 Between-Subjects (Independent)

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	68.7500	17.07271	4.92847
	2	30	61.1667	17.07909	3.11820

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Response	Equal variances assumed	.021	.886	1.300	40	.201	7.58333	5.83302	-4.20564	19.37231
	Equal variances not assumed			1.300	20.333	.208	7.58333	5.83206	-4.56936	19.73603

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	59.1667	21.03388	6.07196
	2	30	61.1667	17.07909	3.11820

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.550	.463	-.321	40	.750	-2.00000	6.23434	-14.60007	10.60007
	Equal variances not assumed			-.293	17.115	.773	-2.00000	6.82582	-16.39383	12.39383

Expert – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	62.5000	18.27815	5.27645
	2	30	53.5000	19.04622	3.47735

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.002	.960	1.399	40	.170	9.00000	6.43445	-4.00450	22.00450
	Equal variances not assumed			1.424	21.119	.169	9.00000	6.31925	-4.13708	22.13708

Matched Novice – Novice (MCM)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	51.4583	23.60803	6.81505
	2	30	53.5000	19.04622	3.47735

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	2.015	.163	-.293	40	.771	-2.04167	6.96883	-16.12620	12.04287
	Equal variances not assumed			-.267	17.035	.793	-2.04167	7.65094	-18.18119	14.09785

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	66.4583	19.69824	5.68639
	2	30	77.8333	13.73602	2.50784

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.997	.324	-2.134	40	.039	-11.37500	5.32992	-22.14717	-.60283
	Equal variances not assumed			-1.830	15.473	.087	-11.37500	6.21485	-24.58644	1.83644

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	12	77.0833	17.28219	4.98894
	2	30	77.8333	13.73602	2.50784

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	2.777	.103	-.148	40	.883	-.75000	5.05386	-10.96423	9.46423
	Equal variances not assumed			-.134	16.853	.895	-.75000	5.58380	-12.53860	11.03860

J.2 SUS Question 1 Responses

J.2.1 Within-Subjects

Expert

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	5	Total
Condition	Ecological	1	1	4	4	2	12
	LVAL	0	2	3	6	1	12
	MCM	0	2	4	5	1	12
Total		1	5	11	15	4	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.482[a]	8	.901
Likelihood Ratio	3.696	8	.883
N of Valid Cases	36		

a. 12 cells (80.0%) have expected count less than 5. The minimum expected count is .33.

Matched Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	5	Total
Condition	Ecological	0	2	5	4	1	12
	LVAL	4	1	4	3	0	12
	MCM	4	2	2	4	0	12
Total		8	5	11	11	1	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.855[a]	8	.448
Likelihood Ratio	10.683	8	.220
N of Valid Cases	36		

a. 15 cells (100.0%) have expected count less than 5. The minimum expected count is .33.

Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	5	Total
Condition	Ecological	1	1	6	12	10	30
	LVAL	3	9	6	0	0	18
	MCM	3	11	8	8	0	30
Total		7	21	20	20	10	78

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	36.945[a]	8	.000
Likelihood Ratio	47.347	8	.000
N of Valid Cases	78		

a. 9 cells (60.0%) have expected count less than 5. The minimum expected count is 1.62.

J.2.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	5	Total
Condition	Expert	0	2	3	6	1	12
	Matched	4	1	4	3	0	12
Total		4	3	7	9	1	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.476[a]	4	.166
Likelihood Ratio	8.434	4	.077
N of Valid Cases	24		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	0	2	3	6	1	12
	Novice	3	9	11	7	0	30
Total		3	11	14	13	1	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.601[a]	4	.159
Likelihood Ratio	7.331	4	.119
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .29.

Matched Novice - Novice

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Matched	4	1	4	3	12
	Novice	3	9	11	7	30
Total		7	10	15	10	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.527[a]	3	.210
Likelihood Ratio	4.578	3	.205
N of Valid Cases	42		

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is 2.00.

J.2.3 Between-Subjects (MCM)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	0	2	4	5	1	12
	Matched	4	2	2	4	0	12
Total		4	4	6	9	1	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.778[a]	4	.216
Likelihood Ratio	7.722	4	.102
N of Valid Cases	24		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert - Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	0	2	4	5	1	12
	Novice	3	11	8	8	0	30
Total		3	13	12	13	1	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.564[a]	4	.234
Likelihood Ratio	6.493	4	.165
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .29.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Matched	4	2	2	4	12
	Novice	3	11	8	8	30
Total		7	13	10	12	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.401[a]	3	.221
Likelihood Ratio	4.247	3	.236
N of Valid Cases	42		

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is 2.00.

J.2.4 Between-Subjects (Ecological)

Expert - Matched Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	1	1	4	4	2	12
	Matched	0	2	5	4	1	12
Total		1	3	9	8	3	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.778[a]	4	.777
Likelihood Ratio	2.177	4	.703
N of Valid Cases	24		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert - Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	1	1	4	4	2	12
	Novice	1	1	6	12	10	30
Total		2	2	10	16	12	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.473[a]	4	.649
Likelihood Ratio	2.441	4	.655
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .57.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Matched	0	2	5	4	1	12
	Novice	1	1	6	12	10	30
Total		1	3	11	16	11	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.215[a]	4	.184
Likelihood Ratio	6.581	4	.160
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .29.

J.3 SUS Question 2 Responses

J.3.1 Within-Subjects

Expert

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Ecological	0	8	1	2	1	12
	LVAL	3	6	3	0	0	12
	MCM	0	7	2	3	0	12
Total		3	21	6	5	1	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	12.086[a]	8	.147
Likelihood Ratio	14.378	8	.072
N of Valid Cases	36		

a. 12 cells (80.0%) have expected count less than 5. The minimum expected count is .33.

Matched Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Ecological	5	6	0	1	0	12
	LVAL	1	7	3	0	1	12
	MCM	0	7	1	3	1	12
Total		6	20	4	4	2	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	15.100[a]	8	.057
Likelihood Ratio	18.081	8	.021
N of Valid Cases	36		

a. 12 cells (80.0%) have expected count less than 5. The minimum expected count is .67.

Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Ecological	9	16	4	1	0	30
	LVAL	3	17	1	0	0	21
	MCM	3	7	9	9	2	30
Total		15	40	14	10	2	81

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	32.492[a]	8	.000
Likelihood Ratio	34.809	8	.000
N of Valid Cases	81		

a. 8 cells (53.3%) have expected count less than 5. The minimum expected count is .52.

J.3.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	5	
Condition	Expert	3	6	3	0	12
	Matched	1	7	3	1	12
Total		4	13	6	1	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.077[a]	3	.557
Likelihood Ratio	2.510	3	.474
N of Valid Cases	24		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is .50.

Expert - Novice

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Expert	3	6	3	0	12
	Novice	3	17	5	5	30
Total		6	23	8	5	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.732[a]	3	.292
Likelihood Ratio	4.950	3	.176
N of Valid Cases	42		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is 1.43.

Matched Novice - Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Matched	1	7	3	0	1	12
	Novice	3	17	5	5	0	30
Total		4	24	8	5	1	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.842[a]	4	.304
Likelihood Ratio	6.196	4	.185
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .29.

J.3.3 Between-Subjects (MCM)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Expert	7	2	3	0	12
	Matched	7	1	3	1	12
Total		14	3	6	1	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.333[a]	3	.721
Likelihood Ratio	1.726	3	.631
N of Valid Cases	24		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is .50.

Expert - Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	0	7	2	3	0	12
	Novice	3	7	9	9	2	30
Total		3	14	11	12	2	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.807[a]	4	.214
Likelihood Ratio	6.919	4	.140
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .57.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Matched	0	7	1	3	1	12
	Novice	3	7	9	9	2	30
Total		3	14	10	12	3	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.148[a]	4	.188
Likelihood Ratio	7.030	4	.134
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .86.

J.3.4 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	0	8	1	2	1	12
	Matched	5	6	0	1	0	12
Total		5	14	1	3	1	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.619[a]	4	.107
Likelihood Ratio	10.331	4	.035
N of Valid Cases	24		

a. 8 cells (80.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	0	8	1	2	1	12
	Novice	9	16	4	1	0	30
Total		9	24	5	3	1	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.680[a]	4	.070
Likelihood Ratio	10.879	4	.028
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .29.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Matched	5	6	0	1	12
	Novice	9	16	4	1	30
Total		14	22	4	2	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.418[a]	3	.490
Likelihood Ratio	3.451	3	.327
N of Valid Cases	42		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .57.

J.4 SUS Question 3 Responses

J.4.1 Within-Subjects

Expert

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Ecological	3	2	4	3	12
	LVAL	0	2	6	4	12
	MCM	1	4	6	1	12
Total		4	8	16	8	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.750[a]	6	.345
Likelihood Ratio	7.747	6	.257
N of Valid Cases	36		

a. 9 cells (75.0%) have expected count less than 5. The minimum expected count is 1.33.

Matched Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Ecological	0	1	3	3	5	12
	LVAL	0	2	4	5	1	12
	MCM	1	4	4	3	0	12
Total		1	7	11	11	6	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.909[a]	8	.155
Likelihood Ratio	12.856	8	.117
N of Valid Cases	36		

a. 15 cells (100.0%) have expected count less than 5. The minimum expected count is .33.

Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Ecological	0	0	4	11	15	30
	LVAL	1	5	4	17	3	30
	MCM	1	9	7	9	4	30
Total		2	14	15	37	22	90

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	25.816[a]	8	.001
Likelihood Ratio	29.253	8	.000
N of Valid Cases	90		

a. 6 cells (40.0%) have expected count less than 5. The minimum expected count is .67.

J.4.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Expert	0	2	6	4	12
	Matched	2	4	5	1	12
Total		2	6	11	5	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.558[a]	3	.207
Likelihood Ratio	5.471	3	.140
N of Valid Cases	24		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is 1.00.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	0	0	2	6	4	12
	Novice	1	5	4	17	3	30
Total		1	5	6	23	7	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.336[a]	4	.255
Likelihood Ratio	6.653	4	.155
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .29.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Matched	0	2	4	5	1	12
	Novice	1	5	4	17	3	30
Total		1	7	8	22	4	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.593[a]	4	.628
Likelihood Ratio	2.708	4	.608
N of Valid Cases	42		

a. 6 cells (60.0%) have expected count less than 5. The minimum expected count is .29.

J.4.3 Between-Subjects (MCM)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	0	1	4	6	1	12
	Matched	1	4	4	3	0	12
Total		1	5	8	9	1	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.800[a]	4	.308
Likelihood Ratio	5.719	4	.221
N of Valid Cases	24		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	0	1	4	6	1	12
	Novice	1	9	7	9	4	30
Total		1	10	11	15	5	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.557[a]	4	.469
Likelihood Ratio	4.138	4	.388
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .29.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Matched	1	4	4	3	0	12
	Novice	1	9	7	9	4	30
Total		2	13	11	12	4	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.483[a]	4	.648
Likelihood Ratio	3.517	4	.475
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .57.

J.4.4 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Expert	3	2	4	3	12
	Matched	1	3	3	5	12
Total		4	5	7	8	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.843[a]	3	.606
Likelihood Ratio	1.897	3	.594
N of Valid Cases	24		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is 2.00.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Expert	3	2	4	3	12
	Novice	0	4	11	15	30
Total		3	6	15	18	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.843[a]	3	.031
Likelihood Ratio	8.999	3	.029
N of Valid Cases	42		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .86.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Matched	1	3	3	5	12
	Novice	0	4	11	15	30
Total		1	7	14	20	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.675[a]	3	.299
Likelihood Ratio	3.652	3	.302
N of Valid Cases	42		

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is .29.

J.5 SUS Question 4 Responses

J.5.1 Within-Subjects

Expert

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Ecological	4	6	1	1	12
	LVAL	4	5	3	0	12
	MCM	3	6	2	1	12
Total		11	17	6	2	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.299[a]	6	.890
Likelihood Ratio	2.977	6	.812
N of Valid Cases	36		

a. 9 cells (75.0%) have expected count less than 5. The minimum expected count is .67.

Matched Novice

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Ecological	7	3	1	1	12
	LVAL	4	4	3	1	12
	MCM	3	5	0	4	12
Total		14	12	4	6	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.857[a]	6	.182
Likelihood Ratio	9.360	6	.154
N of Valid Cases	36		

a. 12 cells (100.0%) have expected count less than 5. The minimum expected count is 1.33.

Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Ecological	13	8	7	1	1	30
	LVAL	4	11	6	8	1	30
	MCM	5	10	6	7	2	30
Total		22	29	19	16	4	90

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.099[a]	8	.108
Likelihood Ratio	14.221	8	.076
N of Valid Cases	90		

a. 3 cells (20.0%) have expected count less than 5. The minimum expected count is 1.33.

J.5.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Expert	4	5	3	0	12
	Matched	4	4	3	1	12
Total		8	9	6	1	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.111[a]	3	.774
Likelihood Ratio	1.498	3	.683
N of Valid Cases	24		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	5	Total
Condition	Expert	4	5	3	0	0	12
	Novice	4	11	6	8	1	30
Total		8	16	9	8	1	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.556[a]	4	.235
Likelihood Ratio	7.832	4	.098
N of Valid Cases	42		

a. 6 cells (60.0%) have expected count less than 5. The minimum expected count is .29.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	5	Total
Condition	Matched	4	4	3	1	0	12
	Novice	4	11	6	8	1	30
Total		8	15	9	9	1	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.671[a]	4	.452
Likelihood Ratio	4.031	4	.402
N of Valid Cases	42		

a. 6 cells (60.0%) have expected count less than 5. The minimum expected count is .29.

J.5.3 Between-Subjects (MCM)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	Total
Condition	Expert	3	6	2	1	12
	Matched	3	5	0	4	12
Total		6	11	2	5	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.891[a]	3	.273
Likelihood Ratio	4.791	3	.188
N of Valid Cases	24		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is 1.00.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	5	Total
Condition	Expert	3	6	2	1	0	12
	Novice	5	10	6	7	2	30
Total		8	16	8	8	2	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.800[a]	4	.592
Likelihood Ratio	3.474	4	.482
N of Valid Cases	42		

a. 6 cells (60.0%) have expected count less than 5. The minimum expected count is .57.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	5	Total
Condition	Matched	3	5	0	4	0	12
	Novice	5	10	6	7	2	30
Total		8	15	6	11	2	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.006[a]	4	.405
Likelihood Ratio	6.154	4	.188
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .57.

J.5.4 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	Total
Condition	Expert	4	6	1	1	12
	Matched	7	3	1	1	12
Total		11	9	2	2	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.818[a]	3	.611
Likelihood Ratio	1.848	3	.605
N of Valid Cases	24		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is 1.00.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	5	Total
Condition	Expert	4	6	1	1	0	12
	Novice	13	8	7	1	1	30
Total		17	14	8	2	1	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.474[a]	4	.482
Likelihood Ratio	3.782	4	.436
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .29.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	5	Total
Condition	Matched	7	3	1	1	0	12
	Novice	13	8	7	1	1	30
Total		20	11	8	2	1	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.277[a]	4	.685
Likelihood Ratio	2.665	4	.615
N of Valid Cases	42		

a. 6 cells (60.0%) have expected count less than 5. The minimum expected count is .29.

J.6 SUS Question 5 Responses

J.6.1 Within-Subjects

Expert

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Ecological	3	5	4	0	12
	LVAL	2	3	7	0	12
	MCM	2	5	4	1	12
Total		7	13	15	1	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.101[a]	6	.663
Likelihood Ratio	4.268	6	.640
N of Valid Cases	36		

a. 9 cells (75.0%) have expected count less than 5. The minimum expected count is .33.

Matched Novice

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Ecological	2	4	3	3	12
	LVAL	1	7	4	0	12
	MCM	1	6	4	1	12
Total		4	17	11	4	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.005[a]	6	.543
Likelihood Ratio	5.807	6	.445
N of Valid Cases	36		

a. 9 cells (75.0%) have expected count less than 5. The minimum expected count is 1.33.

Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Ecological	0	0	7	17	6	30
	LVAL	0	4	13	10	3	30
	MCM	1	5	16	6	2	30
Total		1	9	36	33	11	90

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	18.167[a]	8	.020
Likelihood Ratio	21.250	8	.007
N of Valid Cases	90		

a. 9 cells (60.0%) have expected count less than 5. The minimum expected count is .33.

J.6.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response			Total
		2	3	4	
Condition	Expert	2	3	7	12
	Matched	1	7	4	12
Total		3	10	11	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.752[a]	2	.253
Likelihood Ratio	2.814	2	.245
N of Valid Cases	24		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 1.50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Expert	2	3	7	0	12
	Novice	4	13	10	3	30
Total		6	16	17	3	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.346[a]	3	.341
Likelihood Ratio	4.139	3	.247
N of Valid Cases	42		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is .86.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Matched	1	7	4	0	12
	Novice	4	13	10	3	30
Total		5	20	14	3	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.785[a]	3	.618
Likelihood Ratio	2.601	3	.457
N of Valid Cases	42		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .86.

J.6.3 Between-Subjects (MCM)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Expert	2	5	4	1	12
	Matched	1	6	4	1	12
Total		3	11	8	2	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.424[a]	3	.935
Likelihood Ratio	.431	3	.934
N of Valid Cases	24		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is 1.00.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	0	2	5	4	1	12
	Novice	1	5	16	6	2	30
Total		1	7	21	10	3	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.307[a]	4	.860
Likelihood Ratio	1.547	4	.818
N of Valid Cases	42		

a. 6 cells (60.0%) have expected count less than 5. The minimum expected count is .29.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Matched	0	1	6	4	1	12
	Novice	1	5	16	6	2	30
Total		1	6	22	10	3	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.508[a]	4	.825
Likelihood Ratio	1.787	4	.775
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .29.

J.6.4 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Expert	3	5	4	0	12
	Matched	2	4	3	3	12
Total		5	9	7	3	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.454[a]	3	.327
Likelihood Ratio	4.615	3	.202
N of Valid Cases	24		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is 1.50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Expert	3	5	4	0	12
	Novice	0	7	17	6	30
Total		3	12	21	6	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.842[a]	3	.008
Likelihood Ratio	13.504	3	.004
N of Valid Cases	42		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .86.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Matched	2	4	3	3	12
	Novice	0	7	17	6	30
Total		2	11	20	9	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.232[a]	3	.065
Likelihood Ratio	7.468	3	.058
N of Valid Cases	42		

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is .57.

J.7 SUS Question 6 Responses

J.7.1 Within-Subjects

Expert

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Ecological	2	7	3	0	12
	LVAL	0	7	5	0	12
	MCM	1	5	4	2	12
Total		3	19	12	2	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.921[a]	6	.328
Likelihood Ratio	8.111	6	.230
N of Valid Cases	36		

a. 9 cells (75.0%) have expected count less than 5. The minimum expected count is .67.

Matched Novice

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Ecological	6	6	0	0	12
	LVAL	3	2	5	2	12
	MCM	3	4	4	1	12
Total		12	12	9	3	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	10.167[a]	6	.118
Likelihood Ratio	13.689	6	.033
N of Valid Cases	36		

a. 12 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

Novice

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Ecological	9	16	5	0	30
	LVAL	7	9	11	3	30
	MCM	3	10	11	6	30
Total		19	35	27	9	90

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	14.071[a]	6	.029
Likelihood Ratio	16.866	6	.010
N of Valid Cases	90		

a. 3 cells (25.0%) have expected count less than 5. The minimum expected count is 3.00.

J.7.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Expert	0	7	5	0	12
	Matched	3	2	5	2	12
Total		3	9	10	2	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.778[a]	3	.051
Likelihood Ratio	9.873	3	.020
N of Valid Cases	24		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is 1.00.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	Total
Condition	Expert	0	7	5	0	12
	Novice	7	9	11	3	30
Total		7	16	16	3	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.862[a]	3	.118
Likelihood Ratio	8.450	3	.038
N of Valid Cases	42		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .86.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	Total
Condition	Matched	3	2	5	2	12
	Novice	7	9	11	3	30
Total		10	11	16	5	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.968[a]	3	.809
Likelihood Ratio	1.001	3	.801
N of Valid Cases	42		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is 1.43.

J.7.3 Between-Subjects (MCM)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	Total
Condition	Expert	1	5	4	2	12
	Matched	3	4	4	1	12
Total		4	9	8	3	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.444[a]	3	.695
Likelihood Ratio	1.498	3	.683
N of Valid Cases	24		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is 1.50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	Total
Condition	Expert	1	5	4	2	12
	Novice	3	10	11	6	30
Total		4	15	15	8	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.268[a]	3	.966
Likelihood Ratio	.266	3	.966
N of Valid Cases	42		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is 1.14.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Matched	3	4	4	1	12
	Novice	3	10	11	6	30
Total		6	14	15	7	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.077[a]	3	.557
Likelihood Ratio	2.046	3	.563
N of Valid Cases	42		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is 1.71.

J.7.4 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response			Total
		1	2	3	
Condition	Expert	2	7	3	12
	Matched	6	6	0	12
Total		8	13	3	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.077[a]	2	.079
Likelihood Ratio	6.329	2	.042
N of Valid Cases	24		

a. 4 cells (66.7%) have expected count less than 5. The minimum expected count is 1.50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response			Total
		1	2	3	
Condition	Expert	2	7	3	12
	Novice	9	16	5	30
Total		11	23	8	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.933[a]	2	.627
Likelihood Ratio	.971	2	.615
N of Valid Cases	42		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 2.29.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response			Total
		1	2	3	
Condition	Matched	6	6	0	12
	Novice	9	16	5	30
Total		15	22	5	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.978[a]	2	.226
Likelihood Ratio	4.282	2	.118
N of Valid Cases	42		

a. 3 cells (50.0%) have expected count less than 5. The minimum expected count is 1.43.

J.8 SUS Question 7 Responses

J.8.1 Within-Subjects

Expert

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Ecological	1	1	1	6	3	12
	LVAL	1	2	2	4	3	12
	MCM	1	2	2	3	4	12
Total		3	5	5	13	10	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.077[a]	8	.979
Likelihood Ratio	2.126	8	.977
N of Valid Cases	36		

a. 15 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

Matched Novice

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Ecological	0	2	3	7	12
	LVAL	2	1	5	4	12
	MCM	4	2	4	2	12
Total		6	5	12	13	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.823[a]	6	.251
Likelihood Ratio	9.468	6	.149
N of Valid Cases	36		

a. 12 cells (100.0%) have expected count less than 5. The minimum expected count is 1.67.

Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Ecological	0	1	0	16	13	30
	LVAL	1	3	2	18	6	30
	MCM	1	5	5	11	8	30
Total		2	9	7	45	27	90

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.717[a]	8	.089
Likelihood Ratio	16.154	8	.040
N of Valid Cases	90		

a. 9 cells (60.0%) have expected count less than 5. The minimum expected count is .67.

J.8.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	1	2	2	4	3	12
	Matched	0	2	1	5	4	12
Total		1	4	3	9	7	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.587[a]	4	.811
Likelihood Ratio	1.981	4	.739
N of Valid Cases	24		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	5	Total
Condition	Expert	1	2	2	4	3	12
	Novice	1	3	2	18	6	30
Total		2	5	4	22	9	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.934[a]	4	.569
Likelihood Ratio	2.887	4	.577
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .57.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	5	Total
Condition	Matched	0	2	1	5	4	12
	Novice	1	3	2	18	6	30
Total		1	5	3	23	10	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.919[a]	4	.751
Likelihood Ratio	2.160	4	.706
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .29.

J.8.3 Between-Subjects (MCM)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	5	Total
Condition	Expert	1	2	2	3	4	12
	Matched	0	4	2	4	2	12
Total		1	6	4	7	6	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.476[a]	4	.649
Likelihood Ratio	2.889	4	.577
N of Valid Cases	24		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	5	Total
Condition	Expert	1	2	2	3	4	12
	Novice	1	5	5	11	8	30
Total		2	7	7	14	12	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.933[a]	4	.920
Likelihood Ratio	.906	4	.924
N of Valid Cases	42		

a. 6 cells (60.0%) have expected count less than 5. The minimum expected count is .57.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Matched	0	4	2	4	2	12
	Novice	1	5	5	11	8	30
Total		1	9	7	15	10	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.898[a]	4	.755
Likelihood Ratio	2.108	4	.716
N of Valid Cases	42		

a. 6 cells (60.0%) have expected count less than 5. The minimum expected count is .29.

J.8.4 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	1	1	1	6	3	12
	Matched	0	0	2	3	7	12
Total		1	1	3	9	10	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.933[a]	4	.294
Likelihood Ratio	5.777	4	.216
N of Valid Cases	24		

a. 8 cells (80.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	1	1	1	6	3	12
	Novice	0	1	0	16	13	30
Total		1	2	1	22	16	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.224[a]	4	.183
Likelihood Ratio	6.258	4	.181
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .29.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Matched	0	2	3	7	12
	Novice	1	0	16	13	30
Total		1	2	19	20	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.326[a]	3	.062
Likelihood Ratio	7.783	3	.051
N of Valid Cases	42		

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is .29.

J.9 SUS Question 8 Responses

J.9.1 Within-Subjects

Expert

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Ecological	1	7	2	1	1	12
	LVAL	0	7	4	1	0	12
	MCM	0	4	6	2	0	12
Total		1	18	12	4	1	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.500[a]	8	.484
Likelihood Ratio	8.031	8	.430
N of Valid Cases	36		

a. 12 cells (80.0%) have expected count less than 5. The minimum expected count is .33.

Matched Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Ecological	6	5	1	0	0	12
	LVAL	3	6	1	2	0	12
	MCM	4	2	2	3	1	12
Total		13	13	4	5	1	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.377[a]	8	.398
Likelihood Ratio	10.226	8	.250
N of Valid Cases	36		

a. 15 cells (100.0%) have expected count less than 5. The minimum expected count is .33.

Novice

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Ecological	10	17	1	2	30
	LVAL	3	16	5	6	30
	MCM	5	7	9	9	30
Total		18	40	15	17	90

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	19.636[a]	6	.003
Likelihood Ratio	21.516	6	.001
N of Valid Cases	90		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 5.00.

J.9.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Expert	0	7	4	1	12
	Matched	3	6	1	2	12
Total		3	13	5	3	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.210[a]	3	.157
Likelihood Ratio	6.503	3	.090
N of Valid Cases	24		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is 1.50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Expert	0	7	4	1	12
	Novice	3	16	5	6	30
Total		3	23	9	7	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.050[a]	3	.384
Likelihood Ratio	3.881	3	.275
N of Valid Cases	42		

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is .86.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Matched	3	6	1	2	12
	Novice	3	16	5	6	30
Total		6	22	6	8	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.835[a]	3	.607
Likelihood Ratio	1.751	3	.626
N of Valid Cases	42		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is 1.71.

J.9.3 Between-Subjects (MCM)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	0	4	6	2	0	12
	Matched	4	2	2	3	1	12
Total		4	6	8	5	1	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.867[a]	4	.097
Likelihood Ratio	9.905	4	.042
N of Valid Cases	24		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Expert	0	4	6	2	12
	Novice	5	7	9	9	30
Total		5	11	15	11	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.869[a]	3	.276
Likelihood Ratio	5.213	3	.157
N of Valid Cases	42		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is 1.43.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Matched	4	2	2	3	1	12
	Novice	5	7	9	9	0	30
Total		9	9	11	12	1	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.446[a]	4	.349
Likelihood Ratio	4.428	4	.351
N of Valid Cases	42		

a. 6 cells (60.0%) have expected count less than 5. The minimum expected count is .29.

J.9.4 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	1	7	2	1	1	12
	Matched	6	5	1	0	0	12
Total		7	12	3	1	1	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.238[a]	4	.182
Likelihood Ratio	7.410	4	.116
N of Valid Cases	24		

a. 8 cells (80.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	1	7	2	1	1	12
	Novice	10	17	1	2	0	30
Total		11	24	3	3	1	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.716[a]	4	.152
Likelihood Ratio	6.940	4	.139
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .29.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	4	
Condition	Matched	6	5	1	0	12
	Novice	10	17	1	2	30
Total		16	22	2	2	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.243[a]	3	.523
Likelihood Ratio	2.730	3	.435
N of Valid Cases	42		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .57.

J.10 SUS Question 9 Responses

J.10.1 Within-Subjects

Expert

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Ecological	0	3	8	1	12
	LVAL	1	2	4	5	12
	MCM	1	4	5	2	12
Total		2	9	17	8	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.446[a]	6	.375
Likelihood Ratio	6.955	6	.325
N of Valid Cases	36		

a. 9 cells (75.0%) have expected count less than 5. The minimum expected count is .67.

Matched Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Ecological	0	3	2	4	3	12
	LVAL	1	2	4	4	1	12
	MCM	2	2	4	4	0	12
Total		3	7	10	12	4	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.586[a]	8	.582
Likelihood Ratio	8.211	8	.413
N of Valid Cases	36		

a. 15 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Ecological	0	1	4	15	10	30
	LVAL	1	4	11	12	2	30
	MCM	2	13	9	5	1	30
Total		3	18	24	32	13	90

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	34.418[a]	8	.000
Likelihood Ratio	35.806	8	.000
N of Valid Cases	90		

a. 6 cells (40.0%) have expected count less than 5. The minimum expected count is 1.00.

J.10.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	0	1	2	4	5	12
	Matched	1	2	4	4	1	12
Total		1	3	6	8	6	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.667[a]	4	.323
Likelihood Ratio	5.317	4	.256
N of Valid Cases	24		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	0	1	2	4	5	12
	Novice	1	4	11	12	2	30
Total		1	5	13	16	7	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.088[a]	4	.088
Likelihood Ratio	7.718	4	.102
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .29.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Matched	1	2	4	4	1	12
	Novice	1	4	11	12	2	30
Total		2	6	15	16	3	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.677[a]	4	.954
Likelihood Ratio	.633	4	.959
N of Valid Cases	42		

a. 8 cells (80.0%) have expected count less than 5. The minimum expected count is .57.

J.10.3 Between-Subjects (MCM)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	0	1	4	5	2	12
	Matched	2	2	4	4	0	12
Total		2	3	8	9	2	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.444[a]	4	.349
Likelihood Ratio	5.996	4	.199
N of Valid Cases	24		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	0	1	4	5	2	12
	Novice	2	13	9	5	1	30
Total		2	14	13	10	3	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.364[a]	4	.079
Likelihood Ratio	9.319	4	.054
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .57.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Matched	2	2	4	4	0	12
	Novice	2	13	9	5	1	30
Total		4	15	13	9	1	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.149[a]	4	.386
Likelihood Ratio	4.516	4	.341
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .29.

J.10.4 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Expert	0	3	8	1	12
	Matched	3	2	4	3	12
Total		3	5	12	4	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.533[a]	3	.137
Likelihood Ratio	6.766	3	.080
N of Valid Cases	24		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is 1.50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Expert	0	3	8	1	12
	Novice	1	4	15	10	30
Total		1	7	23	11	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.580[a]	3	.311
Likelihood Ratio	4.272	3	.234
N of Valid Cases	42		

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is .29.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response				Total
		2	3	4	5	
Condition	Matched	3	2	4	3	12
	Novice	1	4	15	10	30
Total		4	6	19	13	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.010[a]	3	.171
Likelihood Ratio	4.516	3	.211
N of Valid Cases	42		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is 1.14.

J.11 SUS Question 10 Responses

J.11.1 Within-Subjects

Expert

Condition * Response Crosstabulation

Count

		Response				Total
		1	2	3	5	
Condition	Ecological	5	3	4	0	12
	LVAL	2	6	3	1	12
	MCM	3	3	5	1	12
Total		10	12	12	2	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.400[a]	6	.623
Likelihood Ratio	4.920	6	.554
N of Valid Cases	36		

a. 12 cells (100.0%) have expected count less than 5. The minimum expected count is .67.

Matched Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Ecological	6	2	4	0	0	12
	LVAL	3	5	3	1	0	12
	MCM	4	4	2	1	1	12
Total		13	11	9	2	1	36

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.016[a]	8	.645
Likelihood Ratio	6.930	8	.544
N of Valid Cases	36		

a. 15 cells (100.0%) have expected count less than 5. The minimum expected count is .33.

Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Ecological	9	12	6	3	0	30
	LVAL	6	14	3	4	3	30
	MCM	2	13	5	8	2	30
Total		17	39	14	15	5	90

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.107[a]	8	.196
Likelihood Ratio	12.982	8	.112
N of Valid Cases	90		

a. 6 cells (40.0%) have expected count less than 5. The minimum expected count is 1.67.

J.11.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	2	6	3	0	1	12
	Matched	3	5	3	1	0	12
Total		5	11	6	1	1	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.291[a]	4	.682
Likelihood Ratio	3.065	4	.547
N of Valid Cases	24		

a. 8 cells (80.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	2	6	3	0	1	12
	Novice	6	14	3	4	3	30
Total		8	20	6	4	4	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.045[a]	4	.550
Likelihood Ratio	4.006	4	.405
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is 1.14.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Matched	3	5	3	1	0	12
	Novice	6	14	3	4	3	30
Total		9	19	6	5	3	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.877[a]	4	.579
Likelihood Ratio	3.575	4	.467
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .86.

J.11.3 Between-Subjects (MCM)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	3	3	5	0	1	12
	Matched	4	4	2	1	1	12
Total		7	7	7	1	2	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.571[a]	4	.632
Likelihood Ratio	3.001	4	.558
N of Valid Cases	24		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response					Total
		1	2	3	4	5	
Condition	Expert	3	3	5	0	1	12
	Novice	2	13	5	8	2	30
Total		5	16	10	8	3	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.660[a]	4	.070
Likelihood Ratio	10.400	4	.034
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .86.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	5	Total
Condition	Matched	4	4	2	1	1	12
	Novice	2	13	5	8	2	30
Total		6	17	7	9	3	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.856[a]	4	.210
Likelihood Ratio	5.592	4	.232
N of Valid Cases	42		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .86.

J.11.4 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	Total
Condition	Expert	5	3	4	12
	Matched	6	2	4	12
Total		11	5	8	24

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.291[a]	2	.865
Likelihood Ratio	.292	2	.864
N of Valid Cases	24		

a. 4 cells (66.7%) have expected count less than 5. The minimum expected count is 2.50.

Expert – Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	Total
Condition	Expert	5	3	4	0	12
	Novice	9	12	6	3	30
Total		14	15	10	3	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.730[a]	3	.435
Likelihood Ratio	3.533	3	.316
N of Valid Cases	42		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .86.

Matched Novice – Novice

Condition * Response Crosstabulation

Count

		Response 1	2	3	4	Total
Condition	Matched	6	2	4	0	12
	Novice	9	12	6	3	30
Total		15	14	10	3	42

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.200[a]	3	.241
Likelihood Ratio	5.121	3	.163
N of Valid Cases	42		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .86.

Appendix K: Demographic Data for Chapter 8

Group	Participant	Gender	Age, Years	Experience, Years
Expert	1	M	33	6
	2	M	52	30
	3	M	58	5
	4	M	55	25
	5	F	35	7
	6	F	31	6
		Mean	44.0	15.0
		SD	12.3	10.5
Matched Novice	1	M	57	N/A
	2	M	53	N/A
	3	M	56	N/A
	4	M	32	N/A
	5	F	37	N/A
	6	F	32	N/A
		Mean	44.5	N/A
		SD	12.1	N/A
Novice	1	F	20	N/A
	2	F	24	N/A
	3	M	40	N/A
	4	F	32	N/A
	5	M	34	N/A
	6	M	41	N/A
	7	F	23	N/A
	8	F	20	N/A
	9	F	54	N/A
	10	F	35	N/A
	11	F	47	N/A
	12	M	25	N/A
	13	M	28	N/A
	14	M	47	N/A
	15	F	28	N/A
	16	M	39	N/A
	17	F	25	N/A
	18	F	27	N/A
	19	M	46	N/A
	20	M	27	N/A
	21	M	24	N/A
	22	M	61	N/A
	23	F	45	N/A

Group	Participant	Gender	Age, Years	Experience, Years
Novice	24	M	28	N/A
	25	F	37	N/A
	26	M	19	N/A
	27	M	60	N/A
	28	M	22	N/A
	29	F	53	N/A
	30	M	57	N/A
		Mean	35.6	N/A
		SD	12.9	N/A

Appendix L: Participant Information Sheet for Chapter 8

Study Title: Further empirical assessment of an ecological STOC validation tool

Researcher: Joshua Price **Ethics number**: 14367

Please read this information carefully before deciding to take part in this research. If you are happy to participate you will be asked to sign a consent form.

What is the research about?
This is a doctorate research project in collaboration between the University of Southampton and Siemens.

Many adaptive traffic light systems utilise a technique called SCOOT (Split Cycle Offset Optimisation Technique) to adjust timings based on real-time traffic data from detectors and a model of traffic behaviour. To ensure accuracy the model must be tailored to local conditions at each junction. A key parameter is SaTuration OCcupancy (STOC), the discharge rate of traffic over the stop line on green, which is validated by comparing the observed time for a traffic queue to clear to a modelled time using a tool called LVAL which provides the model output.

LVAL's interface is textual, requiring you to compare observed and modelled clear times, adjusting the STOC value used until both values are consistently similar. This study aims to investigate whether a graphical interface could provide performance improvements over LVAL, in terms of speed, accuracy and difficulty, for both experienced validators and novices.

Why have I been chosen?
You have been approached because you are either 1) an experienced SCOOT engineer or 2) are a novice at SCOOT validation.

What will happen to me if I take part?
Basic personal details will be taken (age, gender and validation experience) for the purpose of calculating sample statistics.

The experiment involves two conditions…

1) LVAL – a textual interface which provides the model clear time, a mechanism to input the observed clear time and an estimate of the correct STOC value.
2) Ecological – a graphical interface which provides the source data from a detector, enables the STOC value to be changed and displays the effect on model clear time compared to the observed value.

In each condition you will first be shown how to use the interface and have an opportunity to practice with it. Once you are comfortable you will be required to validate three junctions and complete a subjective workload assessment and usability questionnaire.

The process will be repeated for the second condition, each should take no more than 20 minutes.

Total experimental time should not exceed 1hr.

Are there any benefits in my taking part?

Your participation will hopefully aid in the development of better systems for use in SCOOT validation.

Are there any risks involved?

Typical office working environment risks only.

Will my participation be confidential?

The research will comply with the Data Protection Act. All data collected will only be used for this study, will be coded to ensure participant anonymity and kept on a password protected computer.

What happens if I change my mind?

You may withdraw from the study at any time without your legal rights being affected.

What happens if something goes wrong?

If you have any cause of concern or complaint with this research you can contact the research governance manager (rgoinfo@soton.ac.uk, 02380 595058)

Where can I get more information?

Researcher: Joshua Price – [redacted]

Supervisor: Neville Stanton – [redacted]

Siemens contact: Ian Snell – [redacted]

Appendix M:Consent Form for Chapter 8

Study title: Further empirical assessment of an ecological STOC validation tool

Researcher name: Joshua Price

Ethics reference: 14367

Please initial the box(es) if you agree with the statement(s):

I have read and understood the information sheet (v1.0) and have had the opportunity to ask questions about the study	☐
I agree to take part in this research project and agree for my data to be used for the purpose of this study	☐
I understand my participation is voluntary and I may withdraw at any time without my legal rights being affected	☐

Data Protection

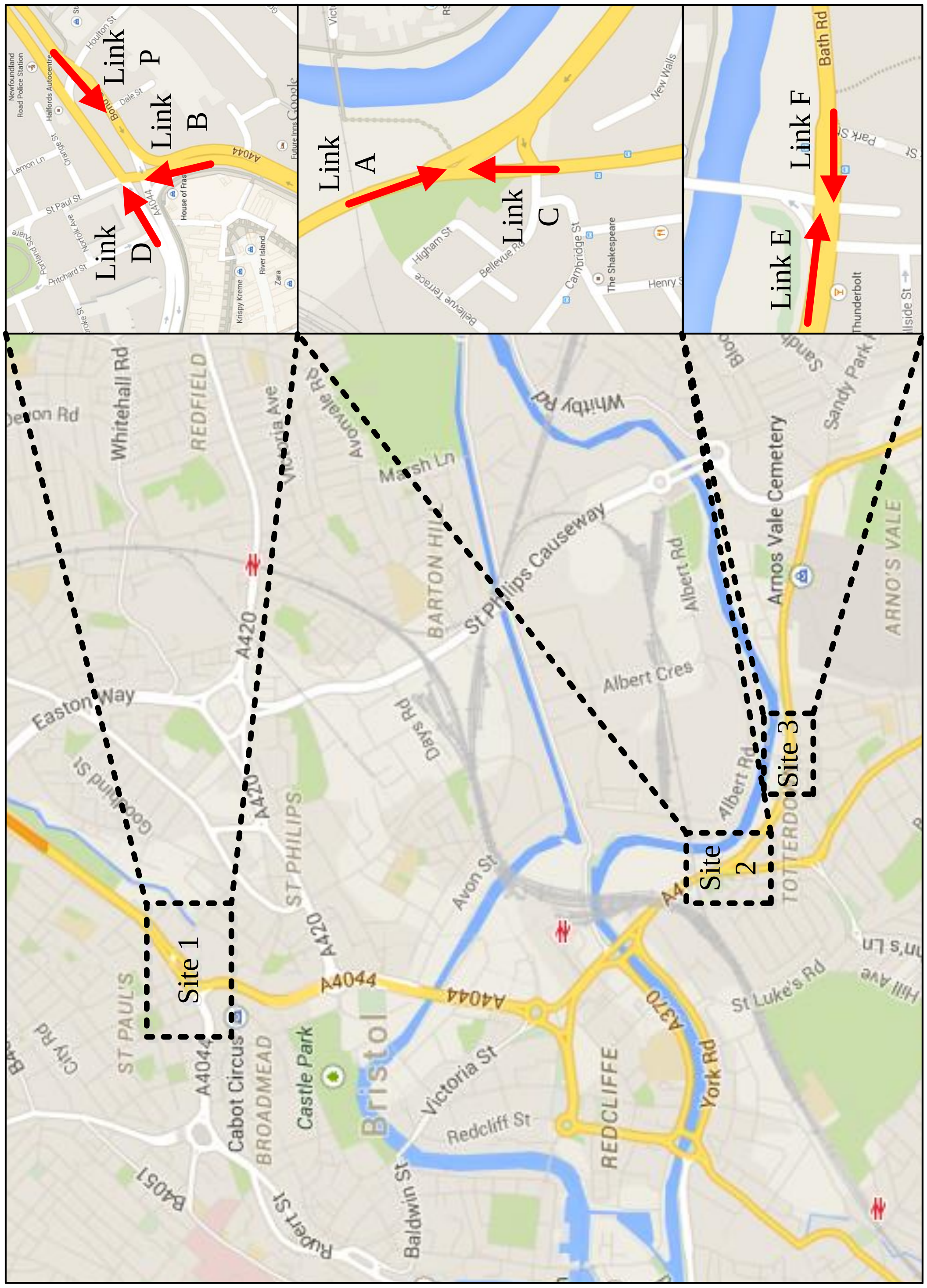
I understand that information collected about me during my participation in this study will be stored on a password protected computer and that this information will only be used for the purpose of this study. All files containing any personal data will be made anonymous.

Name of participant (print name)……………………………………………………

Signature of participant……………………………………………………………..

Date……………………………………………………………………………………

Appendix N: Source Data Location Plan for Chapter 8



Appendix O: Observed Clear Time Data for Chapter 8

O.1.1 Practice Link

Cycle	Observed Clear Time (sec)	Cycle	Observed Clear Time (sec)
1	13	14	9
2	9	15	12
3	12	16	9
4	5	17	8
5	15	18	13
6	6	19	10
7	21	20	7
8	17	21	8
9	10	22	9
10	8	23	6
11	6	24	7
12	5	25	10
13	9		

O.1.2 Link A

Cycle	Observed Clear Time (sec)	Cycle	Observed Clear Time (sec)
1	34	14	5
2	15	15	8
3	18	16	20
4	20	17	7
5	24	18	22
6	13	19	13
7	14	20	23
8	10	21	31
9	24	22	16
10	17	23	9
11	16	24	18
12	24	25	8
13	29		

O.1.3 Link B

Cycle	Observed Clear Time (sec)	Cycle	Observed Clear Time (sec)
1	18	14	32
2	21	15	23
3	9	16	18
4	24	17	8
5	33	18	18
6	14	19	20
7	20	20	14
8	7	21	15
9	27	22	14
10	20	23	30
11	15	24	21
12	17	25	20
13	21		

O.1.4 Link C

Cycle	Observed Clear Time (sec)	Cycle	Observed Clear Time (sec)
1	10	14	23
2	31	15	25
3	12	16	22
4	20	17	34
5	33	18	45
6	34	19	19
7	26	20	47
8	23	21	34
9	18	22	13
10	30	23	36
11	31	24	37
12	27	25	35
13	21		

O.1.5 Link D

Cycle	Observed Clear Time (sec)	Cycle	Observed Clear Time (sec)
1	11	14	8
2	12	15	12
3	5	16	11
4	14	17	9
5	8	18	10
6	12	19	6
7	8	20	10
8	6	21	7
9	6	22	11
10	11	23	14
11	7	24	12
12	6	25	17
13	9		

O.1.6 Link E

Cycle	Observed Clear Time (sec)	Cycle	Observed Clear Time (sec)
1	18	14	4
2	20	15	20
3	18	16	22
4	27	17	12
5	19	18	25
6	8	19	12
7	8	20	13
8	10	21	6
9	20	22	11
10	8	23	17
11	11	24	27
12	12	25	10
13	13		

O.1.7 Link F

Cycle	Observed Clear Time (sec)	Cycle	Observed Clear Time (sec)
1	4	14	17
2	25	15	18
3	22	16	18
4	14	17	7
5	20	18	5
6	9	19	23
7	25	20	36
8	12	21	13
9	9	22	7
10	12	23	21
11	7	24	14
12	19	25	16
13	22		

Appendix P: Shapiro-Wilk Test Statistics for Assessing Dependent Measure's Normality (Chapter 8)

P.1 Performance

P.1.1 Final Validation Error

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.181	6	.200*	.935	6	.623
MatLVAL	.151	6	.200*	.976	6	.931
NovLVAL	.151	6	.200*	.951	6	.749
ExpEco	.273	6	.184	.837	6	.124
MatEco	.193	6	.200*	.904	6	.396
NovEco	.241	6	.200*	.866	6	.212

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

P.1.2 Mean Cycle Validation Error

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.242	6	.200*	.908	6	.425
MatLVAL	.236	6	.200*	.890	6	.319
NovLVAL	.210	6	.200*	.942	6	.679
ExpEco	.197	6	.200*	.919	6	.498
MatEco	.261	6	.200*	.835	6	.119
NovEco	.251	6	.200*	.865	6	.208

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

P.1.3 Mean Time Spent Per Cycle

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.214	6	.200*	.938	6	.643
MatLVAL	.333	6	.036	.708	6	.007
NovLVAL	.231	6	.200*	.840	6	.129
ExpEco	.265	6	.200*	.941	6	.668
MatEco	.167	6	.200*	.980	6	.954
NovEco	.368	6	.011	.679	6	.004

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

P.1.4 Cycles Required

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.250	6	.200*	.882	6	.279
MatLVAL	.349	6	.021	.783	6	.041
NovLVAL	.163	6	.200*	.944	6	.693
ExpEco	.194	6	.200*	.892	6	.329
MatEco	.285	6	.139	.822	6	.092
NovEco	.272	6	.186	.836	6	.120

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

P.2 System Use

P.2.1 Total Ecological Observed Clear Time Adjustments Per Cycle

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpEco	.358	6	.016	.719	6	.010
MatEco	.262	6	.200*	.922	6	.523
NovEco	.275	6	.176	.777	6	.036

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

P.2.2 Total Ecological STOC Adjustments Per Cycle

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpEco	.323	6	.050	.806	6	.067
MatEco	.179	6	.200*	.972	6	.905
NovEco	.149	6	.200*	.967	6	.875

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

P.2.3 Estimated STOC Error

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.230	6	.200*	.900	6	.372
MatLVAL	.202	6	.200*	.918	6	.492
NovLVAL	.211	6	.200*	.958	6	.808

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

P.2.4 Mean STOC Adjustment

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.277	6	.166	.864	6	.205
MatLVAL	.236	6	.200*	.877	6	.257
NovLVAL	.178	6	.200*	.905	6	.402
ExpEco	.326	6	.045	.748	6	.019
MatEco	.291	6	.123	.906	6	.413
NovEco	.201	6	.200*	.947	6	.717

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

P.3 Workload

P.3.1 Overall Workload

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.338	6	.031	.811	6	.073
MatLVAL	.254	6	.200*	.840	6	.131
NovLVAL	.237	6	.200*	.874	6	.244
ExpEco	.214	6	.200*	.965	6	.854
MatEco	.261	6	.200*	.860	6	.191
NovEco	.217	6	.200*	.907	6	.417

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

P.3.2 Mental Demand

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.241	6	.200*	.902	6	.387
MatLVAL	.241	6	.200*	.841	6	.134
NovLVAL	.229	6	.200*	.817	6	.083
ExpEco	.146	6	.200*	.988	6	.985
MatEco	.198	6	.200*	.967	6	.875
NovEco	.234	6	.200*	.879	6	.266

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

P.3.3 Physical Demand

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.254	6	.200*	.872	6	.234
MatLVAL	.333	6	.036	.814	6	.078
NovLVAL	.285	6	.138	.831	6	.110
ExpEco	.241	6	.200*	.871	6	.230
MatEco	.204	6	.200*	.902	6	.389
NovEco	.492	6	.000	.496	6	.000

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

P.3.4 Temporal Demand

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.295	6	.113	.821	6	.089
MatLVAL	.372	6	.010	.654	6	.002
NovLVAL	.167	6	.200*	.960	6	.817
ExpEco	.217	6	.200*	.889	6	.315
MatEco	.209	6	.200*	.907	6	.415
NovEco	.254	6	.200*	.866	6	.212

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

P.3.5 Performance

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.183	6	.200*	.890	6	.320
MatLVAL	.189	6	.200*	.932	6	.596
NovLVAL	.196	6	.200*	.942	6	.673
ExpEco	.232	6	.200*	.907	6	.417
MatEco	.319	6	.055	.780	6	.039
NovEco	.254	6	.200*	.907	6	.415

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

P.3.6 Effort

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.167	6	.200*	.957	6	.800
MatLVAL	.210	6	.200*	.877	6	.256
NovLVAL	.215	6	.200*	.850	6	.158
ExpEco	.220	6	.200*	.955	6	.781
MatEco	.238	6	.200*	.950	6	.737
NovEco	.249	6	.200*	.892	6	.331

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

P.3.7 Frustration

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.265	6	.200*	.799	6	.058
MatLVAL	.167	6	.200*	.934	6	.614
NovLVAL	.201	6	.200*	.896	6	.353
ExpEco	.234	6	.200*	.942	6	.674
MatEco	.333	6	.036	.721	6	.010
NovEco	.246	6	.200*	.834	6	.117

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

P.4 Usability

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExpLVAL	.214	6	.200*	.891	6	.324
MatLVAL	.220	6	.200*	.897	6	.356
NovLVAL	.256	6	.200*	.811	6	.074
ExpEco	.239	6	.200*	.888	6	.307
MatEco	.249	6	.200*	.830	6	.107
NovEco	.186	6	.200*	.914	6	.460

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

Appendix Q: Test Statistics for Performance Measures (Chapter 8)

Q.1 Final Validation Error

Q.1.1 Paired Within

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	.4517	6	.31971	.13052
	ExpertEco	.4900	6	.18569	.07581
Pair 2	MatchedLVAL	.3983	6	.20817	.08499
	MatchedEco	.6017	6	.31984	.13057
Pair 3	NoviceLVAL	.6387	30	.42089	.07684
	NoviceEco	.4650	30	.25080	.04579

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & ExpertEco	6	-.569	.238
Pair 2	MatchedLVAL & MatchedEco	6	-.579	.229
Pair 3	NoviceLVAL & NoviceEco	30	-.232	.218

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	ExpertLVAL - ExpertEco	-.03833	.45199	.18452	-.51267	.43600	-.208	5	.844
Pair 2	MatchedLVAL - MatchedEco	-.20333	.47192	.19266	-.69858	.29191	-1.055	5	.340
Pair 3	NoviceLVAL - NoviceEco	.17367	.53759	.09815	-.02707	.37441	1.769	29	.087

Q.1.2 Paired Between

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	.4517	6	.31971	.13052
	MatchedLVAL	.3983	6	.20817	.08499
Pair 2	ExpertEco	.4900	6	.18569	.07581
	MatchedEco	.6017	6	.31984	.13057

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & MatchedLVAL	6	.255	.626
Pair 2	ExpertEco & MatchedEco	6	-.012	.982

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	ExpertLVAL - MatchedLVAL	.05333	.33417	.13642	-.29735	.40402	.391	5	.712
Pair 2	ExpertEco - MatchedEco	-.11167	.37172	.15175	-.50176	.27843	-.736	5	.495

Q.1.3 Independent Between

<u>Expert – Novice (LVAL)</u>

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	.4517	.31971	.13052
	2	30	.6387	.42089	.07684

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Response	Equal variances assumed	.996	.325	-1.026	34	.312	-.18700	.18228	-.55744	.18344
	Equal variances not assumed			-1.235	8.883	.249	-.18700	.15146	-.53032	.15632

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	.4900	.18569	.07581
	2	30	.4650	.25080	.04579

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.440	.511	.231	34	.819	.02500	.10837	-.19524	.24524
	Equal variances not assumed			.282	9.105	.784	.02500	.08856	-.17499	.22499

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	.3983	.20817	.08499
	2	30	.6387	.42089	.07684

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	3.213	.082	-1.354	34	.185	-.24033	.17747	-.60099	.12032
	Equal variances not assumed			-2.098	14.811	.054	-.24033	.11458	-.48482	.00415

Matched – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	.6017	.31984	.13057
	2	30	.4650	.25080	.04579

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.251	.620	1.166	34	.252	.13667	.11721	-.10154	.37487
	Equal variances not assumed			.988	6.289	.360	.13667	.13837	-.19818	.47151

Q.2 Cycle Validation Error

Q.2.1 Paired Within

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	1.3750	6	.64021	.26137
	ExpertEco	.9350	6	.49302	.20128
Pair 2	MatchedLVAL	1.1650	6	.54695	.22329
	MatchedEco	.8583	6	.39128	.15974
Pair 3	NoviceLVAL	1.1760	30	.47692	.08707
	NoviceEco	.7910	30	.22926	.04186

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & ExpertEco	6	-.684	.134
Pair 2	MatchedLVAL & MatchedEco	6	-.249	.634
Pair 3	NoviceLVAL & NoviceEco	30	-.222	.239

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	ExpertLVAL - ExpertEco	.44000	1.04144	.42517	-.65293	1.53293	1.035	5	.348
Pair 2	MatchedLVAL - MatchedEco	.30667	.74763	.30522	-.47792	1.09125	1.005	5	.361
Pair 3	NoviceLVAL - NoviceEco	.38500	.57315	.10464	.17098	.59902	3.679	29	.001

Q.2.2 Paired Between

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	1.3750	6	.64021	.26137
	MatchedLVAL	1.1650	6	.54695	.22329
Pair 2	ExpertEco	.9350	6	.49302	.20128
	MatchedEco	.8583	6	.39128	.15974

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & MatchedLVAL	6	-.185	.726
Pair 2	ExpertEco & MatchedEco	6	.784	.065

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	ExpertLVAL - MatchedLVAL	.21000	.91571	.37384	-.75098	1.17098	.562	5	.599
Pair 2	ExpertEco - MatchedEco	.07667	.30598	.12492	-.24444	.39778	.614	5	.566

Q.2.3 Independent Between

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	1.3750	.64021	.26137
	2	30	1.1760	.47692	.08707

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.744	.195	.882	34	.384	.19900	.22551	-.25930	.65730
	Equal variances not assumed			.722	6.158	.497	.19900	.27549	-.47091	.86891

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	.9350	.49302	.20128
	2	30	.7910	.22926	.04186

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	9.928	.003	1.134	34	.265	.14400	.12695	-.11399	.40199
	Equal variances not assumed			.700	5.440	.512	.14400	.20558	-.37186	.65986

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	1.1650	.54695	.22329
	2	30	1.1760	.47692	.08707

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.055	.816	-.050	34	.960	-.01100	.21817	-.45438	.43238
	Equal variances not assumed			-.046	6.610	.965	-.01100	.23967	-.58457	.56257

Matched – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	.8583	.39128	.15974
	2	30	.7910	.22926	.04186

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.613	.213	.580	34	.566	.06733	.11606	-.16852	.30319
	Equal variances not assumed			.408	5.706	.698	.06733	.16513	-.34184	.47650

Q.3 Cycles Required

Q.3.1 Paired Within

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	11.7217	6	4.87077	1.98848
	ExpertEco	6.0550	6	.80079	.32692
Pair 2	MatchedLVAL	9.7233	6	2.68770	1.09725
	MatchedEco	5.3883	6	1.28994	.52661
Pair 3	NoviceLVAL	13.5450	30	4.67877	.85422
	NoviceEco	6.4000	30	2.37527	.43366

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & ExpertEco	6	.431	.394
Pair 2	MatchedLVAL & MatchedEco	6	.615	.194
Pair 3	NoviceLVAL & NoviceEco	30	.429	.018

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	ExpertLVAL - ExpertEco	5.66667	4.58311	1.87105	.85699	10.47635	3.029	5	.029
Pair 2	MatchedLVAL - MatchedEco	4.33500	2.14983	.87767	2.07889	6.59111	4.939	5	.004
Pair 3	NoviceLVAL - NoviceEco	7.14500	4.24338	.77473	5.56049	8.72951	9.223	29	.000

Q.3.2 Paired Between

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	11.7217	6	4.87077	1.98848
	MatchedLVAL	9.7233	6	2.68770	1.09725
Pair 2	ExpertEco	6.0550	6	.80079	.32692
	MatchedEco	5.3883	6	1.28994	.52661

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & MatchedLVAL	6	.591	.217
Pair 2	ExpertEco & MatchedEco	6	.492	.321

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	ExpertLVAL - MatchedLVAL	1.99833	3.93362	1.60589	-2.12974	6.12641	1.244	5	.269
Pair 2	ExpertEco - MatchedEco	.66667	1.13511	.46341	-.52455	1.85789	1.439	5	.210

Q.3.3 Independent Between

<u>Expert – Novice (LVAL)</u>

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	11.7217	4.87077	1.98848
	2	30	13.5450	4.67877	.85422

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.284	.598	-.866	34	.393	-1.82333	2.10526	-6.10173	2.45506
	Equal variances not assumed			-.842	6.975	.427	-1.82333	2.16420	-6.94461	3.29794

<u>Expert – Novice (Ecological)</u>

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	6.0550	.80079	.32692
	2	30	6.4000	2.37527	.43366

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	3.461	.072	-.348	34	.730	-.34500	.99061	-2.35816	1.66816
	Equal variances not assumed			-.635	24.825	.531	-.34500	.54309	-1.46391	.77391

<u>Matched Novice – Novice (LVAL)</u>

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	9.7233	2.68770	1.09725
	2	30	13.5450	4.67877	.85422

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.068	.309	-1.924	34	.063	-3.82167	1.98665	-7.85903	.21570
	Equal variances not assumed			-2.748	12.129	.018	-3.82167	1.39056	-6.84785	-.79548

<u>Matched – Novice (Ecological)</u>

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	5.3883	1.28994	.52661
	2	30	6.4000	2.37527	.43366

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.320	.259	-1.006	34	.322	-1.01167	1.00568	-3.05545	1.03211
	Equal variances not assumed			-1.483	13.046	.162	-1.01167	.68219	-2.48492	.46159

Q.4 Time Spent

Q.4.1 Paired Within

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	10.33	6	2.805	1.145
	ExpertEco	35.17	6	4.875	1.990
Pair 2	MatchedLVAL	9.00	6	3.033	1.238
	MatchedEco	30.00	6	3.578	1.461
Pair 3	NoviceLVAL	9.93	30	3.393	.619
	NoviceEco	31.20	30	6.359	1.161

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & ExpertEco	6	.946	.004
Pair 2	MatchedLVAL & MatchedEco	6	.313	.545
Pair 3	NoviceLVAL & NoviceEco	30	.464	.010

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	ExpertLVAL - ExpertEco	-24.833	2.401	.980	-27.353	-22.313	-25.331	5	.000
Pair 2	MatchedLVAL - MatchedEco	-21.000	3.899	1.592	-25.091	-16.909	-13.194	5	.000
Pair 3	NoviceLVAL - NoviceEco	-21.267	5.650	1.032	-23.377	-19.157	-20.615	29	.000

Q.4.2 Paired Between

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	9.5000	6	2.94958	1.20416
	MatchedLVAL	9.1667	6	3.48807	1.42400
Pair 2	ExpertEco	18.0000	6	10.05542	4.10511
	MatchedEco	16.7767	6	9.72377	3.96971

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & MatchedLVAL	6	.418	.410
Pair 2	ExpertEco & MatchedEco	6	.963	.002

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	ExpertLVAL - MatchedLVAL	.33333	3.50238	1.42984	-3.34219	4.00886	.233	5	.825
Pair 2	ExpertEco - MatchedEco	1.22333	2.71353	1.10780	-1.62435	4.07101	1.104	5	.320

Q.4.3 Independent Between

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	10.33	2.805	1.145
	2	30	9.93	3.393	.619

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Response	Equal variances assumed	.916	.345	.270	34	.789	.400	1.482	-2.611	3.411
	Equal variances not assumed			.307	8.234	.766	.400	1.302	-2.587	3.387

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	29.33	8.618	3.518
	2	30	24.03	5.436	.992

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	2.682	.111	1.972	34	.057	5.300	2.688	-.163	10.763
	Equal variances not assumed			1.450	5.821	.199	5.300	3.656	-3.712	14.312

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	9.00	3.033	1.238
	2	30	9.93	3.393	.619

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.109	.300	-.624	34	.537	-.933	1.495	-3.971	2.105
	Equal variances not assumed			-.674	7.732	.520	-.933	1.385	-4.146	2.279

Matched – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	25.33	4.967	2.028
	2	30	24.03	5.436	.992

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.386	.538	.541	34	.592	1.300	2.401	-3.580	6.180
	Equal variances not assumed			.576	7.608	.581	1.300	2.257	-3.953	6.553

Appendix R: Test Statistics for System Use Measures (Chapter 8)

R.1 Ecological Observed Clear Time Adjustments

R.1.1 Paired Between

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertEco	1.8367	6	.37718	.15398
	MatchedEco	2.0483	6	.49224	.20095

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertEco & MatchedEco	6	-.168	.750

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	ExpertEco - MatchedEco	-.21167	.66859	.27295	-.91331	.48998	-.775	5	.473

R.1.2 Independent Between

<u>Expert – Novice</u>

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	1.8367	.37718	.15398
	2	30	3.1053	3.94526	.72030

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Response	Equal variances assumed	4.308	.046	-.778	34	.442	-1.26867	1.63077	-4.58279	2.04546
	Equal variances not assumed			-1.722	31.332	.095	-1.26867	.73658	-2.77028	.23295

<u>Matched Novice - Novice</u>

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	2.0483	.49224	.20095
	2	30	3.1053	3.94526	.72030

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Response	Equal variances assumed	4.082	.051	-.648	34	.521	-1.05700	1.63167	-4.37295	2.25895
	Equal variances not assumed			-1.413	32.546	.167	-1.05700	.74781	-2.57924	.46524

R.2 Ecological STOC Adjustments

R.2.1 Paired Between

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertEco	10.3733	6	6.78910	2.77164
	MatchedEco	10.7233	6	4.64225	1.89519

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertEco & MatchedEco	6	.063	.905

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	ExpertEco - MatchedEco	-.35000	7.97822	3.25709	-8.72263	8.02263	-.107	5	.919

R.2.1 Independent Between

<u>Expert – Novice</u>

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	10.3733	6.78910	2.77164
	2	30	10.0840	4.54470	.82974

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Response	Equal variances assumed	1.879	.179	.131	34	.897	.28933	2.20885	-4.19959	4.77826
	Equal variances not assumed			.100	5.928	.924	.28933	2.89318	-6.81086	7.38952

<u>Matched Novice - Novice</u>

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	10.7233	4.64225	1.89519
	2	30	10.0840	4.54470	.82974

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Response	Equal variances assumed	.107	.746	.314	34	.756	.63933	2.03893	-3.50426	4.78293
	Equal variances not assumed			.309	7.056	.766	.63933	2.06887	-4.24493	5.52360

R.3 LVAL Estimated STOC Error

R.3.1 Paired Between

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	2.4150	6	.66223	.27035
	MatchedLVAL	1.6583	6	.75117	.30666

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & MatchedLVAL	6	.387	.448

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	ExpertLVAL - MatchedLVAL	.75667	.78574	.32078	-.06792	1.58125	2.359	5	.065

R.3.2 Independent Between

Expert – Novice

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	2.4150	.66223	.27035
	2	30	1.6810	.55954	.10216

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.818	.372	2.850	34	.007	.73400	.25750	.21069	1.25731
	Equal variances not assumed			2.540	6.507	.041	.73400	.28901	.03996	1.42804

Matched Novice - Novice

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	1.6583	.75117	.30666
	2	30	1.6810	.55954	.10216

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.740	.196	-.086	34	.932	-.02267	.26458	-.56037	.51503
	Equal variances not assumed			-.070	6.158	.946	-.02267	.32323	-.80869	.76335

R.4 Average STOC Change

R.4.1 Paired Within

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	.4233	6	.26143	.10673
	ExpertEco	1.0450	6	1.03357	.42195
Pair 2	MatchedLVAL	.8617	6	.62185	.25387
	MatchedEco	.8217	6	.41600	.16983
Pair 3	NoviceLVAL	.8960	30	.42214	.07707
	NoviceEco	.7203	30	.33525	.06121

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & ExpertEco	6	.571	.236
Pair 2	MatchedLVAL & MatchedEco	6	.326	.529
Pair 3	NoviceLVAL & NoviceEco	30	.019	.923

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	ExpertLVAL - ExpertEco	-.62167	.90989	.37146	-1.57654	.33320	-1.674	5	.155
Pair 2	MatchedLVAL - MatchedEco	.04000	.62546	.25534	-.61638	.69638	.157	5	.882
Pair 3	NoviceLVAL - NoviceEco	.17567	.53419	.09753	-.02380	.37514	1.801	29	.082

R.4.2 Paired Between

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	.4233	6	.26143	.10673
	MatchedLVAL	.8617	6	.62185	.25387
Pair 2	ExpertEco	1.0450	6	1.03357	.42195
	MatchedEco	.8217	6	.41600	.16983

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & MatchedLVAL	6	-.050	.926
Pair 2	ExpertEco & MatchedEco	6	.865	.026

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	ExpertLVAL - MatchedLVAL	-.43833	.68642	.28023	-1.15869	.28202	-1.564	5	.179
Pair 2	ExpertEco - MatchedEco	.22333	.70557	.28805	-.51712	.96378	.775	5	.473

R.4.3 Independent Between

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	.4233	.26143	.10673
	2	30	.8960	.42214	.07707

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.477	.233	-2.626	34	.013	-.47267	.18003	-.83853	-.10681
	Equal variances not assumed			-3.590	11.056	.004	-.47267	.13165	-.76224	-.18309

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	1.0450	1.03357	.42195
	2	30	.7203	.33525	.06121

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	13.745	.001	1.443	34	.158	.32467	.22493	-.13244	.78177
	Equal variances not assumed			.761	5.212	.479	.32467	.42637	-.75806	1.40740

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	.8617	.62185	.25387
	2	30	.8960	.42214	.07707

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.347	.254	-.168	34	.868	-.03433	.20438	-.44969	.38103
	Equal variances not assumed			-.129	5.955	.901	-.03433	.26531	-.68470	.61604

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	.8217	.41600	.16983
	2	30	.7203	.33525	.06121

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.573	.454	.651	34	.520	.10133	.15576	-.21522	.41788
	Equal variances not assumed			.561	6.365	.594	.10133	.18052	-.33433	.53700

Appendix S: Test Statistics for Workload Measures (Chapter 8)

S.1 Overall Workload

S.1.1 Paired Within

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	30.83	6	8.658	3.535
	ExpertEco	35.33	6	12.987	5.302
Pair 2	MatchedLVAL	37.00	6	13.115	5.354
	MatchedEco	18.00	6	8.438	3.445
Pair 3	NoviceLVAL	37.80	30	12.061	2.202
	NoviceEco	24.50	30	12.275	2.241

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & ExpertEco	6	.675	.142
Pair 2	MatchedLVAL & MatchedEco	6	-.239	.649
Pair 3	NoviceLVAL & NoviceEco	30	.285	.127

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	ExpertLVAL - ExpertEco	-4.500	9.586	3.914	-14.560	5.560	-1.150	5	.302
Pair 2	MatchedLVAL - MatchedEco	19.000	17.205	7.024	.945	37.055	2.705	5	.043
Pair 3	NoviceLVAL - NoviceEco	13.300	14.553	2.657	7.866	18.734	5.005	29	.000

S.1.2 Paired Between

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	30.83	6	8.658	3.535
	MatchedLVAL	37.00	6	13.115	5.354
Pair 2	ExpertEco	35.33	6	12.987	5.302
	MatchedEco	18.00	6	8.438	3.445

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & MatchedLVAL	6	-.035	.947
Pair 2	ExpertEco & MatchedEco	6	-.454	.365

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	ExpertLVAL - MatchedLVAL	-6.167	15.968	6.519	-22.924	10.590	-.946	5	.388
Pair 2	ExpertEco - MatchedEco	17.333	18.425	7.522	-2.002	36.669	2.304	5	.069

S.1.3 Independent Between

<u>Expert – Novice (LVAL)</u>

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	30.83	8.658	3.535
	2	30	37.80	12.061	2.202

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.624	.211	-1.340	34	.189	-6.967	5.198	-17.531	3.597
	Equal variances not assumed			-1.673	9.390	.127	-6.967	4.165	-16.328	2.395

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	35.33	12.987	5.302
	2	30	24.50	12.275	2.241

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.012	.913	1.956	34	.059	10.833	5.537	-.420	22.087
	Equal variances not assumed			1.882	6.908	.102	10.833	5.756	-2.815	24.481

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	37.00	13.115	5.354
	2	30	37.80	12.061	2.202

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.285	.597	-.146	34	.884	-.800	5.466	-11.908	10.308
	Equal variances not assumed			-.138	6.801	.894	-.800	5.789	-14.571	12.971

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	18.00	8.438	3.445
	2	30	24.50	12.275	2.241

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.862	.360	-1.233	34	.226	-6.500	5.272	-17.215	4.215
	Equal variances not assumed			-1.582	9.825	.145	-6.500	4.110	-15.679	2.679

S.2 Mental Demand

S.2.1 Paired Within

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	43.33	6	17.795	7.265
	ExpertEco	48.33	6	13.663	5.578
Pair 2	MatchedLVAL	53.33	6	20.656	8.433
	MatchedEco	24.17	6	10.685	4.362
Pair 3	NoviceLVAL	50.83	30	21.217	3.874
	NoviceEco	33.00	30	18.551	3.387

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & ExpertEco	6	.706	.117
Pair 2	MatchedLVAL & MatchedEco	6	-.393	.441
Pair 3	NoviceLVAL & NoviceEco	30	.164	.386

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	ExpertLVAL - ExpertEco	-5.000	12.649	5.164	-18.274	8.274	-.968	5	.377
Pair 2	MatchedLVAL - MatchedEco	29.167	26.724	10.910	1.122	57.212	2.673	5	.044
Pair 3	NoviceLVAL - NoviceEco	17.833	25.787	4.708	8.204	27.462	3.788	29	.001

S.2.2 Paired Between

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	43.33	6	17.795	7.265
	MatchedLVAL	53.33	6	20.656	8.433
Pair 2	ExpertEco	48.33	6	13.663	5.578
	MatchedEco	24.17	6	10.685	4.362

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & MatchedLVAL	6	-.023	.966
Pair 2	ExpertEco & MatchedEco	6	-.491	.323

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	ExpertLVAL - MatchedLVAL	-10.000	27.568	11.255	-38.931	18.931	-.889	5	.415
Pair 2	ExpertEco - MatchedEco	24.167	21.075	8.604	2.050	46.284	2.809	5	.038

S.2.3 Independent Between

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	43.33	17.795	7.265
	2	30	50.83	21.217	3.874

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.816	.373	-.808	34	.425	-7.500	9.279	-26.358	11.358
	Equal variances not assumed			-.911	8.134	.389	-7.500	8.233	-26.431	11.431

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	48.33	13.663	5.578
	2	30	33.00	18.551	3.387

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.850	.183	1.914	34	.064	15.333	8.012	-.950	31.616
	Equal variances not assumed			2.350	9.152	.043	15.333	6.526	.609	30.058

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	53.33	20.656	8.433
	2	30	50.83	21.217	3.874

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.000	.990	.264	34	.793	2.500	9.452	-16.709	21.709
	Equal variances not assumed			.269	7.277	.795	2.500	9.280	-19.275	24.275

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	24.17	10.685	4.362
	2	30	33.00	18.551	3.387

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	3.746	.061	-1.121	34	.270	-8.833	7.878	-24.843	7.177
	Equal variances not assumed			-1.599	12.088	.136	-8.833	5.523	-20.856	3.190

S.3 Physical Demand

S.3.1 Paired Within

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	23.33	6	19.408	7.923
	ExpertEco	21.67	6	18.074	7.379
Pair 2	MatchedLVAL	15.00	6	5.477	2.236
	MatchedEco	12.50	6	7.583	3.096
Pair 3	NoviceLVAL	13.83	30	11.794	2.153
	NoviceEco	13.67	30	12.658	2.311

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & ExpertEco	6	.979	.001
Pair 2	MatchedLVAL & MatchedEco	6	.120	.820
Pair 3	NoviceLVAL & NoviceEco	30	.272	.146

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	ExpertLVAL - ExpertEco	1.667	4.082	1.667	-2.618	5.951	1.000	5	.363
Pair 2	MatchedLVAL - MatchedEco	2.500	8.803	3.594	-6.739	11.739	.696	5	.518
Pair 3	NoviceLVAL - NoviceEco	.167	14.767	2.696	-5.348	5.681	.062	29	.951

S.3.2 Paired Between

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	23.33	6	19.408	7.923
	MatchedLVAL	15.00	6	5.477	2.236
Pair 2	ExpertEco	21.67	6	18.074	7.379
	MatchedEco	12.50	6	7.583	3.096

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & MatchedLVAL	6	-.800	.056
Pair 2	ExpertEco & MatchedEco	6	-.328	.525

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	ExpertLVAL - MatchedLVAL	8.333	24.014	9.804	-16.868	33.534	.850	5	.434
Pair 2	ExpertEco - MatchedEco	9.167	21.775	8.890	-13.685	32.019	1.031	5	.350

S.3.3 Independent Between

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	23.33	19.408	7.923
	2	30	13.83	11.794	2.153

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	5.488	.025	1.610	34	.117	9.500	5.900	-2.490	21.490
	Equal variances not assumed			1.157	5.760	.293	9.500	8.211	-10.795	29.795

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	21.67	18.074	7.379
	2	30	13.67	12.658	2.311

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	2.362	.134	1.316	34	.197	8.000	6.078	-4.352	20.352
	Equal variances not assumed			1.035	6.019	.341	8.000	7.732	-10.905	26.905

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	15.00	5.477	2.236
	2	30	13.83	11.794	2.153

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.614	.213	.235	34	.815	1.167	4.961	-8.916	11.249
	Equal variances not assumed			.376	16.176	.712	1.167	3.104	-5.408	7.742

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	12.50	7.583	3.096
	2	30	13.67	12.658	2.311

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.966	.333	-.217	34	.830	-1.167	5.387	-12.115	9.782
	Equal variances not assumed			-.302	11.510	.768	-1.167	3.863	-9.624	7.290

S.4 Temporal Demand

S.4.1 Paired Within

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	40.83	6	11.143	4.549
	ExpertEco	35.83	6	15.943	6.509
Pair 2	MatchedLVAL	25.83	6	20.104	8.207
	MatchedEco	13.33	6	6.055	2.472
Pair 3	NoviceLVAL	28.17	30	15.170	2.770
	NoviceEco	18.50	30	11.829	2.160

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & ExpertEco	6	.980	.001
Pair 2	MatchedLVAL & MatchedEco	6	.055	.918
Pair 3	NoviceLVAL & NoviceEco	30	.138	.467

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	ExpertLVAL - ExpertEco	5.000	5.477	2.236	-.748	10.748	2.236	5	.076
Pair 2	MatchedLVAL - MatchedEco	12.500	20.676	8.441	-9.198	34.198	1.481	5	.199
Pair 3	NoviceLVAL - NoviceEco	9.667	17.905	3.269	2.981	16.352	2.957	29	.006

S.4.2 Paired Between

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	40.83	6	11.143	4.549
	MatchedLVAL	25.83	6	20.104	8.207
Pair 2	ExpertEco	35.83	6	15.943	6.509
	MatchedEco	13.33	6	6.055	2.472

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & MatchedLVAL	6	.264	.613
Pair 2	ExpertEco & MatchedEco	6	-.552	.256

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	ExpertLVAL - MatchedLVAL	15.000	20.248	8.266	-6.249	36.249	1.815	5	.129
Pair 2	ExpertEco - MatchedEco	22.500	19.937	8.139	1.577	43.423	2.764	5	.040

S.4.3 Independent Between

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	40.83	11.143	4.549
	2	30	28.17	15.170	2.770

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Response	Equal variances assumed	.651	.425	1.934	34	.062	12.667	6.551	-.646	25.979
	Equal variances not assumed			2.378	9.177	.041	12.667	5.326	.654	24.680

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	35.83	15.943	6.509
	2	30	18.50	11.829	2.160

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.041	.315	3.096	34	.004	17.333	5.598	5.956	28.711
	Equal variances not assumed			2.528	6.149	.044	17.333	6.857	.652	34.015

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	25.83	20.104	8.207
	2	30	28.17	15.170	2.770

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.294	.591	-.326	34	.746	-2.333	7.152	-16.867	12.201
	Equal variances not assumed			-.269	6.190	.796	-2.333	8.662	-23.372	18.706

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	13.33	6.055	2.472
	2	30	18.50	11.829	2.160

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.730	.197	-1.034	34	.308	-5.167	4.995	-15.317	4.984
	Equal variances not assumed			-1.574	14.125	.138	-5.167	3.283	-12.201	1.868

S.5 Perceived Performance

S.5.1 Paired Within

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	20.00	6	10.488	4.282
	ExpertEco	29.17	6	22.675	9.257
Pair 2	MatchedLVAL	39.17	6	18.552	7.574
	MatchedEco	29.17	6	23.962	9.782
Pair 3	NoviceLVAL	49.83	30	19.409	3.544
	NoviceEco	30.33	30	16.291	2.974

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & ExpertEco	6	.820	.046
Pair 2	MatchedLVAL & MatchedEco	6	.819	.046
Pair 3	NoviceLVAL & NoviceEco	30	.502	.005

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	ExpertLVAL - ExpertEco	-9.167	15.303	6.247	-25.226	6.892	-1.467	5	.202
Pair 2	MatchedLVAL - MatchedEco	10.000	13.784	5.627	-4.465	24.465	1.777	5	.136
Pair 3	NoviceLVAL - NoviceEco	19.500	18.021	3.290	12.771	26.229	5.927	29	.000

S.5.2 Paired Between

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	20.00	6	10.488	4.282
	MatchedLVAL	39.17	6	18.552	7.574
Pair 2	ExpertEco	29.17	6	22.675	9.257
	MatchedEco	29.17	6	23.962	9.782

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & MatchedLVAL	6	-.128	.808
Pair 2	ExpertEco & MatchedEco	6	-.241	.646

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	ExpertLVAL - MatchedLVAL	-19.167	22.454	9.167	-42.730	4.397	-2.091	5	.091
Pair 2	ExpertEco - MatchedEco	.000	36.742	15.000	-38.559	38.559	.000	5	1.000

S.5.3 Independent Between

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	20.00	10.488	4.282
	2	30	49.83	19.409	3.544

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Response	Equal variances assumed	4.001	.054	-3.631	34	.001	-29.833	8.216	-46.529	-13.137
	Equal variances not assumed			-5.368	13.132	.000	-29.833	5.558	-41.828	-17.839

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	29.17	22.675	9.257
	2	30	30.33	16.291	2.974

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Response	Equal variances assumed	.349	.558	-.150	34	.882	-1.167	7.772	-16.960	14.627
	Equal variances not assumed			-.120	6.074	.908	-1.167	9.723	-24.888	22.555

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	39.17	18.552	7.574
	2	30	49.83	19.409	3.544

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Response	Equal variances assumed	.294	.591	-1.237	34	.225	-10.667	8.625	-28.194	6.860
	Equal variances not assumed			-1.276	7.368	.241	-10.667	8.362	-30.241	8.907

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	29.17	23.962	9.782
	2	30	30.33	16.291	2.974

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.323	.574	-.148	34	.883	-1.167	7.884	-17.189	14.856
	Equal variances not assumed			-.114	5.958	.913	-1.167	10.225	-26.228	23.894

S.6 Perceived Effort

S.6.1 Paired Within

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	40.00	6	16.432	6.708
	ExpertEco	38.33	6	23.166	9.458
Pair 2	MatchedLVAL	53.33	6	21.134	8.628
	MatchedEco	18.33	6	9.309	3.801
Pair 3	NoviceLVAL	44.33	30	18.742	3.422
	NoviceEco	30.83	30	18.712	3.416

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & ExpertEco	6	.762	.078
Pair 2	MatchedLVAL & MatchedEco	6	.008	.987
Pair 3	NoviceLVAL & NoviceEco	30	.390	.033

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	ExpertLVAL - ExpertEco	1.667	15.055	6.146	-14.133	17.466	.271	5	.797
Pair 2	MatchedLVAL - MatchedEco	35.000	23.022	9.399	10.840	59.160	3.724	5	.014
Pair 3	NoviceLVAL - NoviceEco	13.500	20.684	3.776	5.776	21.224	3.575	29	.001

S.6.2 Paired Between

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	40.00	6	16.432	6.708
	MatchedLVAL	53.33	6	21.134	8.628
Pair 2	ExpertEco	38.33	6	23.166	9.458
	MatchedEco	18.33	6	9.309	3.801

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & MatchedLVAL	6	.288	.580
Pair 2	ExpertEco & MatchedEco	6	.193	.714

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	ExpertLVAL - MatchedLVAL	-13.333	22.730	9.280	-37.187	10.521	-1.437	5	.210
Pair 2	ExpertEco - MatchedEco	20.000	23.238	9.487	-4.387	44.387	2.108	5	.089

S.6.3 Independent Between

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	40.00	16.432	6.708
	2	30	44.33	18.742	3.422

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	1.050	.313	-.526	34	.602	-4.333	8.238	-21.075	12.408
	Equal variances not assumed			-.575	7.849	.581	-4.333	7.531	-21.757	13.090

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	38.33	23.166	9.458
	2	30	30.83	18.712	3.416

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.001	.974	.863	34	.394	7.500	8.690	-10.160	25.160
	Equal variances not assumed			.746	6.371	.482	7.500	10.056	-16.762	31.762

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	53.33	21.134	8.628
	2	30	44.33	18.742	3.422

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.086	.771	1.053	34	.300	9.000	8.547	-8.370	26.370
	Equal variances not assumed			.970	6.668	.366	9.000	9.282	-13.172	31.172

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	18.33	9.309	3.801
	2	30	30.83	18.712	3.416

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	3.577	.067	-1.584	34	.122	-12.500	7.892	-28.538	3.538
	Equal variances not assumed			-2.446	14.691	.028	-12.500	5.110	-23.412	-1.588

S.7 Perceived Frustration

S.7.1 Paired Within

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	17.50	6	10.368	4.233
	ExpertEco	39.17	6	22.675	9.257
Pair 2	MatchedLVAL	35.00	6	24.290	9.916
	MatchedEco	10.00	6	7.746	3.162
Pair 3	NoviceLVAL	39.17	30	23.675	4.322
	NoviceEco	20.50	30	18.862	3.444

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & ExpertEco	6	-.032	.952
Pair 2	MatchedLVAL & MatchedEco	6	-.638	.173
Pair 3	NoviceLVAL & NoviceEco	30	.117	.539

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	ExpertLVAL - ExpertEco	-21.667	25.232	10.301	-48.146	4.813	-2.103	5	.089
Pair 2	MatchedLVAL - MatchedEco	25.000	29.833	12.179	-6.308	56.308	2.053	5	.095
Pair 3	NoviceLVAL - NoviceEco	18.667	28.495	5.202	8.027	29.307	3.588	29	.001

S.7.2 Paired Between

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	17.50	6	10.368	4.233
	MatchedLVAL	35.00	6	24.290	9.916
Pair 2	ExpertEco	39.17	6	22.675	9.257
	MatchedEco	10.00	6	7.746	3.162

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & MatchedLVAL	6	-.258	.621
Pair 2	ExpertEco & MatchedEco	6	.085	.872

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	ExpertLVAL - MatchedLVAL	-17.500	28.766	11.744	-47.688	12.688	-1.490	5	.196
Pair 2	ExpertEco - MatchedEco	29.167	23.327	9.523	4.686	53.647	3.063	5	.028

S.7.3 Independent Between

Expert – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	17.50	10.368	4.233
	2	30	39.17	23.675	4.322

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Response	Equal variances assumed	9.542	.004	-2.180	34	.036	-21.667	9.939	-41.864	-1.469
	Equal variances not assumed			-3.581	17.570	.002	-21.667	6.050	-34.399	-8.934

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	39.17	22.675	9.257
	2	30	20.50	18.862	3.444

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.992	.326	2.144	34	.039	18.667	8.707	.972	36.362
	Equal variances not assumed			1.890	6.458	.104	18.667	9.877	-5.092	42.425

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	35.00	24.290	9.916
	2	30	39.17	23.675	4.322

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.364	.550	-.392	34	.697	-4.167	10.629	-25.766	17.433
	Equal variances not assumed			-.385	7.037	.711	-4.167	10.817	-29.719	21.385

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	10.00	7.746	3.162
	2	30	20.50	18.862	3.444

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	2.732	.108	-1.329	34	.193	-10.500	7.903	-26.561	5.561
	Equal variances not assumed			-2.246	19.229	.037	-10.500	4.675	-20.278	-.722

Appendix T: Test Statistics for System Usability Measures (Chapter 8)

T.1 Overall System Usability

T.1.1 Paired Within

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	74.5833	6	6.00347	2.45091
	ExpertEco	57.9167	6	16.07923	6.56432
Pair 2	MatchedLVAL	56.6667	6	24.98333	10.19940
	MatchedEco	85.0000	6	14.91643	6.08961
Pair 3	NoviceLVAL	54.3333	30	17.57905	3.20948
	NoviceEco	77.5833	30	15.79070	2.88297

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & ExpertEco	6	.196	.709
Pair 2	MatchedLVAL & MatchedEco	6	-.728	.101
Pair 3	NoviceLVAL & NoviceEco	30	-.208	.270

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	ExpertLVAL - ExpertEco	16.66667	16.02082	6.54047	-.14615	33.47949	2.548	5	.051
Pair 2	MatchedLVAL - MatchedEco	-28.33333	37.27153	15.21604	-67.44740	10.78073	-1.862	5	.122
Pair 3	NoviceLVAL - NoviceEco	-23.25000	25.95711	4.73910	-32.94254	-13.55746	-4.906	29	.000

T.1.2 Paired Between

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpertLVAL	74.5833	6	6.00347	2.45091
	MatchedLVAL	56.6667	6	24.98333	10.19940
Pair 2	ExpertEco	57.9167	6	16.07923	6.56432
	MatchedEco	85.0000	6	14.91643	6.08961

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpertLVAL & MatchedLVAL	6	-.386	.450
Pair 2	ExpertEco & MatchedEco	6	.261	.618

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	ExpertLVAL - MatchedLVAL	17.91667	27.85752	11.37279	-11.31801	47.15135	1.575	5	.176
Pair 2	ExpertEco - MatchedEco	-27.08333	18.86907	7.70326	-46.88520	-7.28146	-3.516	5	.017

T.1.3 Independent Between

<u>Expert – Novice (LVAL)</u>

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	74.5833	6.00347	2.45091
	2	30	54.3333	17.57905	3.20948

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Response	Equal variances assumed	7.747	.009	2.761	34	.009	20.25000	7.33319	5.34716	35.15284
	Equal variances not assumed			5.015	24.453	.000	20.25000	4.03828	11.92357	28.57643

Expert – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	57.9167	16.07923	6.56432
	2	30	77.5833	15.79070	2.88297

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.088	.768	-2.777	34	.009	-19.66667	7.08094	-34.05687	-5.27647
	Equal variances not assumed			-2.743	7.070	.029	-19.66667	7.16951	-36.58611	-2.74723

Matched Novice – Novice (LVAL)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	56.6667	24.98333	10.19940
	2	30	54.3333	17.57905	3.20948

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.690	.412	.277	34	.784	2.33333	8.43051	-14.79953	19.46619
	Equal variances not assumed			.218	6.029	.834	2.33333	10.69245	-23.79965	28.46632

Matched Novice – Novice (Ecological)

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
Response	1	6	85.0000	14.91643	6.08961
	2	30	77.5833	15.79070	2.88297

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Response	Equal variances assumed	.138	.712	1.059	34	.297	7.41667	7.00569	-6.82060	21.65394
	Equal variances not assumed			1.101	7.428	.305	7.41667	6.73757	-8.33088	23.16421

T.2 SUS Question 1 Responses

T.2.1 Within-Subjects

Expert

Condition * Response Crosstabulation

			Response				Total
			2	3	4	5	
Condition	Ecological	Count	2	1	3	0	6
		% within Condition	33.3%	16.7%	50.0%	0.0%	100.0%
		% within Response	100.0%	50.0%	42.9%	0.0%	50.0%
		% of Total	16.7%	8.3%	25.0%	0.0%	50.0%
	LVAL	Count	0	1	4	1	6
		% within Condition	0.0%	16.7%	66.7%	16.7%	100.0%
		% within Response	0.0%	50.0%	57.1%	100.0%	50.0%
		% of Total	0.0%	8.3%	33.3%	8.3%	50.0%
Total		Count	2	2	7	1	12
		% within Condition	16.7%	16.7%	58.3%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	16.7%	16.7%	58.3%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.143[a]	3	.370
Likelihood Ratio	4.302	3	.231
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Matched Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	5	Total
Condition	Ecological	Count	0	1	2	1	2	6
		% within Condition	0.0%	16.7%	33.3%	16.7%	33.3%	100.0%
		% within Response	0.0%	33.3%	50.0%	50.0%	100.0%	50.0%
		% of Total	0.0%	8.3%	16.7%	8.3%	16.7%	50.0%
	LVAL	Count	1	2	2	1	0	6
		% within Condition	16.7%	33.3%	33.3%	16.7%	0.0%	100.0%
		% within Response	100.0%	66.7%	50.0%	50.0%	0.0%	50.0%
		% of Total	8.3%	16.7%	16.7%	8.3%	0.0%	50.0%
Total		Count	1	3	4	2	2	12
		% within Condition	8.3%	25.0%	33.3%	16.7%	16.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	8.3%	25.0%	33.3%	16.7%	16.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.333[a]	4	.504
Likelihood Ratio	4.499	4	.343
N of Valid Cases	12		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	5	Total
Condition	Ecological	Count	1	6	3	15	5	30
		% within Condition	3.3%	20.0%	10.0%	50.0%	16.7%	100.0%
		% within Response	33.3%	26.1%	42.9%	68.2%	100.0%	50.0%
		% of Total	1.7%	10.0%	5.0%	25.0%	8.3%	50.0%
	LVAL	Count	2	17	4	7	0	30
		% within Condition	6.7%	56.7%	13.3%	23.3%	0.0%	100.0%
		% within Response	66.7%	73.9%	57.1%	31.8%	0.0%	50.0%
		% of Total	3.3%	28.3%	6.7%	11.7%	0.0%	50.0%
Total		Count	3	23	7	22	5	60
		% within Condition	5.0%	38.3%	11.7%	36.7%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	5.0%	38.3%	11.7%	36.7%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.646[a]	4	.009
Likelihood Ratio	15.874	4	.003
N of Valid Cases	60		

a. 6 cells (60.0%) have expected count less than 5. The minimum expected count is 1.50.

T.2.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	5	Total
Condition	Expert	Count	0	0	1	4	1	6
		% within Condition	0.0%	0.0%	16.7%	66.7%	16.7%	100.0%
		% within Response	0.0%	0.0%	33.3%	80.0%	100.0%	50.0%
		% of Total	0.0%	0.0%	8.3%	33.3%	8.3%	50.0%
	Matched	Count	1	2	2	1	0	6
		% within Condition	16.7%	33.3%	33.3%	16.7%	0.0%	100.0%
		% within Response	100.0%	100.0%	66.7%	20.0%	0.0%	50.0%
		% of Total	8.3%	16.7%	16.7%	8.3%	0.0%	50.0%
Total		Count	1	2	3	5	1	12
		% within Condition	8.3%	16.7%	25.0%	41.7%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	8.3%	16.7%	25.0%	41.7%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.133[a]	4	.189
Likelihood Ratio	7.812	4	.099
N of Valid Cases	12		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Expert	Count	0	0	1	4	1	6
		% within Condition	0.0%	0.0%	16.7%	66.7%	16.7%	100.0%
		% within Response	0.0%	0.0%	20.0%	36.4%	100.0%	16.7%
		% of Total	0.0%	0.0%	2.8%	11.1%	2.8%	16.7%
	Novice	Count	2	17	4	7	0	30
		% within Condition	6.7%	56.7%	13.3%	23.3%	0.0%	100.0%
		% within Response	100.0%	100.0%	80.0%	63.6%	0.0%	83.3%
		% of Total	5.6%	47.2%	11.1%	19.4%	0.0%	83.3%
Total		Count	2	17	5	11	1	36
		% within Condition	5.6%	47.2%	13.9%	30.6%	2.8%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	5.6%	47.2%	13.9%	30.6%	2.8%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.913[a]	4	.018
Likelihood Ratio	13.016	4	.011
N of Valid Cases	36		

a. 8 cells (80.0%) have expected count less than 5. The minimum expected count is .17.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Matched	Count	1	2	2	1	6
		% within Condition	16.7%	33.3%	33.3%	16.7%	100.0%
		% within Response	33.3%	10.5%	33.3%	12.5%	16.7%
		% of Total	2.8%	5.6%	5.6%	2.8%	16.7%
	Novice	Count	2	17	4	7	30
		% within Condition	6.7%	56.7%	13.3%	23.3%	100.0%
		% within Response	66.7%	89.5%	66.7%	87.5%	83.3%
		% of Total	5.6%	47.2%	11.1%	19.4%	83.3%
Total		Count	3	19	6	8	36
		% within Condition	8.3%	52.8%	16.7%	22.2%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	8.3%	52.8%	16.7%	22.2%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.416[a]	3	.491
Likelihood Ratio	2.168	3	.538
N of Valid Cases	36		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .50.

T.2.3 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response				Total
			2	3	4	5	
Condition	Expert	Count	2	1	3	0	6
		% within Condition	33.3%	16.7%	50.0%	0.0%	100.0%
		% within Response	66.7%	33.3%	75.0%	0.0%	50.0%
		% of Total	16.7%	8.3%	25.0%	0.0%	50.0%
	Matched	Count	1	2	1	2	6
		% within Condition	16.7%	33.3%	16.7%	33.3%	100.0%
		% within Response	33.3%	66.7%	25.0%	100.0%	50.0%
		% of Total	8.3%	16.7%	8.3%	16.7%	50.0%
Total		Count	3	3	4	2	12
		% within Condition	25.0%	25.0%	33.3%	16.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	25.0%	25.0%	33.3%	16.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.667[a]	3	.300
Likelihood Ratio	4.499	3	.212
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

Expert – Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Expert	Count	0	2	1	3	0	6
		% within Condition	0.0%	33.3%	16.7%	50.0%	0.0%	100.0%
		% within Response	0.0%	25.0%	25.0%	16.7%	0.0%	16.7%
		% of Total	0.0%	5.6%	2.8%	8.3%	0.0%	16.7%
	Novice	Count	1	6	3	15	5	30
		% within Condition	3.3%	20.0%	10.0%	50.0%	16.7%	100.0%
		% within Response	100.0%	75.0%	75.0%	83.3%	100.0%	83.3%
		% of Total	2.8%	16.7%	8.3%	41.7%	13.9%	83.3%
Total		Count	1	8	4	18	5	36
		% within Condition	2.8%	22.2%	11.1%	50.0%	13.9%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	2.8%	22.2%	11.1%	50.0%	13.9%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.800[a]	4	.772
Likelihood Ratio	2.724	4	.605
N of Valid Cases	36		

a. 8 cells (80.0%) have expected count less than 5. The minimum expected count is .17.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Matched	Count	0	1	2	1	2	6
		% within Condition	0.0%	16.7%	33.3%	16.7%	33.3%	100.0%
		% within Response	0.0%	14.3%	40.0%	6.3%	28.6%	16.7%
		% of Total	0.0%	2.8%	5.6%	2.8%	5.6%	16.7%
	Novice	Count	1	6	3	15	5	30
		% within Condition	3.3%	20.0%	10.0%	50.0%	16.7%	100.0%
		% within Response	100.0%	85.7%	60.0%	93.8%	71.4%	83.3%
		% of Total	2.8%	16.7%	8.3%	41.7%	13.9%	83.3%
Total		Count	1	7	5	16	7	36
		% within Condition	2.8%	19.4%	13.9%	44.4%	19.4%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	2.8%	19.4%	13.9%	44.4%	19.4%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.153[a]	4	.386
Likelihood Ratio	4.112	4	.391
N of Valid Cases	36		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .17.

T.3 SUS Question 2 Responses

T.3.1 Within-Subjects

Expert

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Ecological	Count	0	2	2	2	6
		% within Condition	0.0%	33.3%	33.3%	33.3%	100.0%
		% within Response	0.0%	40.0%	100.0%	66.7%	50.0%
		% of Total	0.0%	16.7%	16.7%	16.7%	50.0%
	LVAL	Count	2	3	0	1	6
		% within Condition	33.3%	50.0%	0.0%	16.7%	100.0%
		% within Response	100.0%	60.0%	0.0%	33.3%	50.0%
		% of Total	16.7%	25.0%	0.0%	8.3%	50.0%
Total		Count	2	5	2	3	12
		% within Condition	16.7%	41.7%	16.7%	25.0%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	16.7%	41.7%	16.7%	25.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.533[a]	3	.209
Likelihood Ratio	6.086	3	.107
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

Matched Novice

Condition * Response Crosstabulation

			Response			Total
			1	2	4	
Condition	Ecological	Count	3	3	0	6
		% within Condition	50.0%	50.0%	0.0%	100.0%
		% within Response	100.0%	42.9%	0.0%	50.0%
		% of Total	25.0%	25.0%	0.0%	50.0%
	LVAL	Count	0	4	2	6
		% within Condition	0.0%	66.7%	33.3%	100.0%
		% within Response	0.0%	57.1%	100.0%	50.0%
		% of Total	0.0%	33.3%	16.7%	50.0%
Total		Count	3	7	2	12
		% within Condition	25.0%	58.3%	16.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%
		% of Total	25.0%	58.3%	16.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.143[a]	2	.076
Likelihood Ratio	7.075	2	.029
N of Valid Cases	12		

a. 6 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

Novice

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Ecological	Count	11	13	2	4	30
		% within Condition	36.7%	43.3%	6.7%	13.3%	100.0%
		% within Response	73.3%	59.1%	16.7%	36.4%	50.0%
		% of Total	18.3%	21.7%	3.3%	6.7%	50.0%
	LVAL	Count	4	9	10	7	30
		% within Condition	13.3%	30.0%	33.3%	23.3%	100.0%
		% within Response	26.7%	40.9%	83.3%	63.6%	50.0%
		% of Total	6.7%	15.0%	16.7%	11.7%	50.0%
Total		Count	15	22	12	11	60
		% within Condition	25.0%	36.7%	20.0%	18.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	25.0%	36.7%	20.0%	18.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	10.145[a]	3	.017
Likelihood Ratio	10.779	3	.013
N of Valid Cases	60		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 5.50.

T.3.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response			Total
			1	2	4	
Condition	Expert	Count	2	3	1	6
		% within Condition	33.3%	50.0%	16.7%	100.0%
		% within Response	100.0%	42.9%	33.3%	50.0%
		% of Total	16.7%	25.0%	8.3%	50.0%
	Matched	Count	0	4	2	6
		% within Condition	0.0%	66.7%	33.3%	100.0%
		% within Response	0.0%	57.1%	66.7%	50.0%
		% of Total	0.0%	33.3%	16.7%	50.0%
Total		Count	2	7	3	12
		% within Condition	16.7%	58.3%	25.0%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%
		% of Total	16.7%	58.3%	25.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.476[a]	2	.290
Likelihood Ratio	3.256	2	.196
N of Valid Cases	12		

a. 6 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

Expert – Novice

Condition * Response Crosstabulation

			Response 1	Response 2	Response 3	Response 4	Total
Condition	Expert	Count	2	3	0	1	6
		% within Condition	33.3%	50.0%	0.0%	16.7%	100.0%
		% within Response	33.3%	25.0%	0.0%	12.5%	16.7%
		% of Total	5.6%	8.3%	0.0%	2.8%	16.7%
	Novice	Count	4	9	10	7	30
		% within Condition	13.3%	30.0%	33.3%	23.3%	100.0%
		% within Response	66.7%	75.0%	100.0%	87.5%	83.3%
		% of Total	11.1%	25.0%	27.8%	19.4%	83.3%
Total		Count	6	12	10	8	36
		% within Condition	16.7%	33.3%	27.8%	22.2%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	16.7%	33.3%	27.8%	22.2%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.900[a]	3	.272
Likelihood Ratio	5.278	3	.153
N of Valid Cases	36		

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is 1.00.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response 1	Response 2	Response 3	Response 4	Total
Condition	Matched	Count	0	4	0	2	6
		% within Condition	0.0%	66.7%	0.0%	33.3%	100.0%
		% within Response	0.0%	30.8%	0.0%	22.2%	16.7%
		% of Total	0.0%	11.1%	0.0%	5.6%	16.7%
	Novice	Count	4	9	10	7	30
		% within Condition	13.3%	30.0%	33.3%	23.3%	100.0%
		% within Response	100.0%	69.2%	100.0%	77.8%	83.3%
		% of Total	11.1%	25.0%	27.8%	19.4%	83.3%
Total		Count	4	13	10	9	36
		% within Condition	11.1%	36.1%	27.8%	25.0%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	11.1%	36.1%	27.8%	25.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.862[a]	3	.182
Likelihood Ratio	6.857	3	.077
N of Valid Cases	36		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .67.

T.3.3 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response 1	Response 2	Response 3	Response 4	Total
Condition	Expert	Count	0	2	2	2	6
		% within Condition	0.0%	33.3%	33.3%	33.3%	100.0%
		% within Response	0.0%	40.0%	100.0%	100.0%	50.0%
		% of Total	0.0%	16.7%	16.7%	16.7%	50.0%
	Matched	Count	3	3	0	0	6
		% within Condition	50.0%	50.0%	0.0%	0.0%	100.0%
		% within Response	100.0%	60.0%	0.0%	0.0%	50.0%
		% of Total	25.0%	25.0%	0.0%	0.0%	50.0%
Total		Count	3	5	2	2	12
		% within Condition	25.0%	41.7%	16.7%	16.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	25.0%	41.7%	16.7%	16.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.200[a]	3	.066
Likelihood Ratio	9.905	3	.019
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

Expert – Novice

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Expert	Count	0	2	2	2	6
		% within Condition	0.0%	33.3%	33.3%	33.3%	100.0%
		% within Response	0.0%	13.3%	50.0%	33.3%	16.7%
		% of Total	0.0%	5.6%	5.6%	5.6%	16.7%
	Novice	Count	11	13	2	4	30
		% within Condition	36.7%	43.3%	6.7%	13.3%	100.0%
		% within Response	100.0%	86.7%	50.0%	66.7%	83.3%
		% of Total	30.6%	36.1%	5.6%	11.1%	83.3%
Total		Count	11	15	4	6	36
		% within Condition	30.6%	41.7%	11.1%	16.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	30.6%	41.7%	11.1%	16.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.720[a]	3	.081
Likelihood Ratio	7.477	3	.058
N of Valid Cases	36		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .67.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Matched	Count	3	3	0	0	6
		% within Condition	50.0%	50.0%	0.0%	0.0%	100.0%
		% within Response	21.4%	18.8%	0.0%	0.0%	16.7%
		% of Total	8.3%	8.3%	0.0%	0.0%	16.7%
	Novice	Count	11	13	2	4	30
		% within Condition	36.7%	43.3%	6.7%	13.3%	100.0%
		% within Response	78.6%	81.3%	100.0%	100.0%	83.3%
		% of Total	30.6%	36.1%	5.6%	11.1%	83.3%
Total		Count	14	16	2	4	36
		% within Condition	38.9%	44.4%	5.6%	11.1%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	38.9%	44.4%	5.6%	11.1%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.479[a]	3	.687
Likelihood Ratio	2.450	3	.484
N of Valid Cases	36		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is .33.

T.4 SUS Question 3 Responses

T.4.1 Within-Subjects

Expert

Condition * Response Crosstabulation

			Response			Total
			1	2	4	
Condition	Ecological	Count	1	2	3	6
		% within Condition	16.7%	33.3%	50.0%	100.0%
		% within Response	100.0%	100.0%	33.3%	50.0%
		% of Total	8.3%	16.7%	25.0%	50.0%
	LVAL	Count	0	0	6	6
		% within Condition	0.0%	0.0%	100.0%	100.0%
		% within Response	0.0%	0.0%	66.7%	50.0%
		% of Total	0.0%	0.0%	50.0%	50.0%
Total		Count	1	2	9	12
		% within Condition	8.3%	16.7%	75.0%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%
		% of Total	8.3%	16.7%	75.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.000[a]	2	.135
Likelihood Ratio	5.178	2	.075
N of Valid Cases	12		

a. 6 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Matched Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Ecological	Count	0	0	0	3	3	6
		% within Condition	0.0%	0.0%	0.0%	50.0%	50.0%	100.0%
		% within Response	0.0%	0.0%	0.0%	75.0%	75.0%	50.0%
		% of Total	0.0%	0.0%	0.0%	25.0%	25.0%	50.0%
	LVAL	Count	1	1	2	1	1	6
		% within Condition	16.7%	16.7%	33.3%	16.7%	16.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	25.0%	25.0%	50.0%
		% of Total	8.3%	8.3%	16.7%	8.3%	8.3%	50.0%
Total		Count	1	1	2	4	4	12
		% within Condition	8.3%	8.3%	16.7%	33.3%	33.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	8.3%	8.3%	16.7%	33.3%	33.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.000[a]	4	.199
Likelihood Ratio	7.638	4	.106
N of Valid Cases	12		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Ecological	Count	0	2	2	11	15	30
		% within Condition	0.0%	6.7%	6.7%	36.7%	50.0%	100.0%
		% within Response	0.0%	15.4%	28.6%	55.0%	78.9%	50.0%
		% of Total	0.0%	3.3%	3.3%	18.3%	25.0%	50.0%
	LVAL	Count	1	11	5	9	4	30
		% within Condition	3.3%	36.7%	16.7%	30.0%	13.3%	100.0%
		% within Response	100.0%	84.6%	71.4%	45.0%	21.1%	50.0%
		% of Total	1.7%	18.3%	8.3%	15.0%	6.7%	50.0%
Total		Count	1	13	7	20	19	60
		% within Condition	1.7%	21.7%	11.7%	33.3%	31.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	1.7%	21.7%	11.7%	33.3%	31.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	15.085[a]	4	.005
Likelihood Ratio	16.557	4	.002
N of Valid Cases	60		

a. 4 cells (40.0%) have expected count less than 5. The minimum expected count is .50.

T.4.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Expert	Count	0	0	0	6	0	6
		% within Condition	0.0%	0.0%	0.0%	100.0%	0.0%	100.0%
		% within Response	0.0%	0.0%	0.0%	85.7%	0.0%	50.0%
		% of Total	0.0%	0.0%	0.0%	50.0%	0.0%	50.0%
	Matched	Count	1	1	2	1	1	6
		% within Condition	16.7%	16.7%	33.3%	16.7%	16.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	14.3%	100.0%	50.0%
		% of Total	8.3%	8.3%	16.7%	8.3%	8.3%	50.0%
Total		Count	1	1	2	7	1	12
		% within Condition	8.3%	8.3%	16.7%	58.3%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	8.3%	8.3%	16.7%	58.3%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.571[a]	4	.073
Likelihood Ratio	10.894	4	.028
N of Valid Cases	12		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Expert	Count	0	0	0	6	0	6
		% within Condition	0.0%	0.0%	0.0%	100.0%	0.0%	100.0%
		% within Response	0.0%	0.0%	0.0%	40.0%	0.0%	16.7%
		% of Total	0.0%	0.0%	0.0%	16.7%	0.0%	16.7%
	Novice	Count	1	11	5	9	4	30
		% within Condition	3.3%	36.7%	16.7%	30.0%	13.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	60.0%	100.0%	83.3%
		% of Total	2.8%	30.6%	13.9%	25.0%	11.1%	83.3%
Total		Count	1	11	5	15	4	36
		% within Condition	2.8%	30.6%	13.9%	41.7%	11.1%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	2.8%	30.6%	13.9%	41.7%	11.1%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	10.080[a]	4	.039
Likelihood Ratio	12.250	4	.016
N of Valid Cases	36		

a. 8 cells (80.0%) have expected count less than 5. The minimum expected count is .17.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Matched	Count	1	1	2	1	1	6
		% within Condition	16.7%	16.7%	33.3%	16.7%	16.7%	100.0%
		% within Response	50.0%	8.3%	28.6%	10.0%	20.0%	16.7%
		% of Total	2.8%	2.8%	5.6%	2.8%	2.8%	16.7%
	Novice	Count	1	11	5	9	4	30
		% within Condition	3.3%	36.7%	16.7%	30.0%	13.3%	100.0%
		% within Response	50.0%	91.7%	71.4%	90.0%	80.0%	83.3%
		% of Total	2.8%	30.6%	13.9%	25.0%	11.1%	83.3%
Total		Count	2	12	7	10	5	36
		% within Condition	5.6%	33.3%	19.4%	27.8%	13.9%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	5.6%	33.3%	19.4%	27.8%	13.9%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.274[a]	4	.513
Likelihood Ratio	2.902	4	.574
N of Valid Cases	36		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .33.

T.4.3 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response				Total
			1	2	4	5	
Condition	Expert	Count	1	2	3	0	6
		% within Condition	16.7%	33.3%	50.0%	0.0%	100.0%
		% within Response	100.0%	100.0%	50.0%	0.0%	50.0%
		% of Total	8.3%	16.7%	25.0%	0.0%	50.0%
	Matched	Count	0	0	3	3	6
		% within Condition	0.0%	0.0%	50.0%	50.0%	100.0%
		% within Response	0.0%	0.0%	50.0%	100.0%	50.0%
		% of Total	0.0%	0.0%	25.0%	25.0%	50.0%
Total		Count	1	2	6	3	12
		% within Condition	8.3%	16.7%	50.0%	25.0%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	8.3%	16.7%	50.0%	25.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.000[a]	3	.112
Likelihood Ratio	8.318	3	.040
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Expert	Count	1	2	0	3	0	6
		% within Condition	16.7%	33.3%	0.0%	50.0%	0.0%	100.0%
		% within Response	100.0%	50.0%	0.0%	21.4%	0.0%	16.7%
		% of Total	2.8%	5.6%	0.0%	8.3%	0.0%	16.7%
	Novice	Count	0	2	2	11	15	30
		% within Condition	0.0%	6.7%	6.7%	36.7%	50.0%	100.0%
		% within Response	0.0%	50.0%	100.0%	78.6%	100.0%	83.3%
		% of Total	0.0%	5.6%	5.6%	30.6%	41.7%	83.3%
Total		Count	1	4	2	14	15	36
		% within Condition	2.8%	11.1%	5.6%	38.9%	41.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	2.8%	11.1%	5.6%	38.9%	41.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.829[a]	4	.019
Likelihood Ratio	12.347	4	.015
N of Valid Cases	36		

a. 8 cells (80.0%) have expected count less than 5. The minimum expected count is .17.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response				Total
			2	3	4	5	
Condition	Matched	Count	0	0	3	3	6
		% within Condition	0.0%	0.0%	50.0%	50.0%	100.0%
		% within Response	0.0%	0.0%	21.4%	16.7%	16.7%
		% of Total	0.0%	0.0%	8.3%	8.3%	16.7%
	Novice	Count	2	2	11	15	30
		% within Condition	6.7%	6.7%	36.7%	50.0%	100.0%
		% within Response	100.0%	100.0%	78.6%	83.3%	83.3%
		% of Total	5.6%	5.6%	30.6%	41.7%	83.3%
Total		Count	2	2	14	18	36
		% within Condition	5.6%	5.6%	38.9%	50.0%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	5.6%	5.6%	38.9%	50.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.029[a]	3	.794
Likelihood Ratio	1.672	3	.643
N of Valid Cases	36		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is .33.

T.5 SUS Question 4 Responses

T.5.1 Within-Subjects

Expert

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Ecological	Count	2	2	1	1	6
		% within Condition	33.3%	33.3%	16.7%	16.7%	100.0%
		% within Response	40.0%	40.0%	100.0%	100.0%	50.0%
		% of Total	16.7%	16.7%	8.3%	8.3%	50.0%
	LVAL	Count	3	3	0	0	6
		% within Condition	50.0%	50.0%	0.0%	0.0%	100.0%
		% within Response	60.0%	60.0%	0.0%	0.0%	50.0%
		% of Total	25.0%	25.0%	0.0%	0.0%	50.0%
Total		Count	5	5	1	1	12
		% within Condition	41.7%	41.7%	8.3%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	41.7%	41.7%	8.3%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.400[a]	3	.494
Likelihood Ratio	3.175	3	.365
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Matched Novice

Condition * Response Crosstabulation

			Response			Total
			1	2	5	
Condition	Ecological	Count	5	1	0	6
		% within Condition	83.3%	16.7%	0.0%	100.0%
		% within Response	71.4%	25.0%	0.0%	50.0%
		% of Total	41.7%	8.3%	0.0%	50.0%
	LVAL	Count	2	3	1	6
		% within Condition	33.3%	50.0%	16.7%	100.0%
		% within Response	28.6%	75.0%	100.0%	50.0%
		% of Total	16.7%	25.0%	8.3%	50.0%
Total		Count	7	4	1	12
		% within Condition	58.3%	33.3%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%
		% of Total	58.3%	33.3%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.286[a]	2	.193
Likelihood Ratio	3.761	2	.153
N of Valid Cases	12		

a. 6 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Novice

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Ecological	Count	11	13	5	1	30
		% within Condition	36.7%	43.3%	16.7%	3.3%	100.0%
		% within Response	68.8%	59.1%	33.3%	14.3%	50.0%
		% of Total	18.3%	21.7%	8.3%	1.7%	50.0%
	LVAL	Count	5	9	10	6	30
		% within Condition	16.7%	30.0%	33.3%	20.0%	100.0%
		% within Response	31.3%	40.9%	66.7%	85.7%	50.0%
		% of Total	8.3%	15.0%	16.7%	10.0%	50.0%
Total		Count	16	22	15	7	60
		% within Condition	26.7%	36.7%	25.0%	11.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	26.7%	36.7%	25.0%	11.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.215[a]	3	.042
Likelihood Ratio	8.699	3	.034
N of Valid Cases	60		

a. 2 cells (25.0%) have expected count less than 5. The minimum expected count is 3.50.

T.5.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response			Total
			1	2	5	
Condition	Expert	Count	3	3	0	6
		% within Condition	50.0%	50.0%	0.0%	100.0%
		% within Response	60.0%	50.0%	0.0%	50.0%
		% of Total	25.0%	25.0%	0.0%	50.0%
	Matched	Count	2	3	1	6
		% within Condition	33.3%	50.0%	16.7%	100.0%
		% within Response	40.0%	50.0%	100.0%	50.0%
		% of Total	16.7%	25.0%	8.3%	50.0%
Total		Count	5	6	1	12
		% within Condition	41.7%	50.0%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%
		% of Total	41.7%	50.0%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.200[a]	2	.549
Likelihood Ratio	1.588	2	.452
N of Valid Cases	12		

a. 6 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	Total
Condition	Expert	Count	3	3	0	0	6
		% within Condition	50.0%	50.0%	0.0%	0.0%	100.0%
		% within Response	37.5%	25.0%	0.0%	0.0%	16.7%
		% of Total	8.3%	8.3%	0.0%	0.0%	16.7%
	Novice	Count	5	9	10	6	30
		% within Condition	16.7%	30.0%	33.3%	20.0%	100.0%
		% within Response	62.5%	75.0%	100.0%	100.0%	83.3%
		% of Total	13.9%	25.0%	27.8%	16.7%	83.3%
Total		Count	8	12	10	6	36
		% within Condition	22.2%	33.3%	27.8%	16.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	22.2%	33.3%	27.8%	16.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.300[a]	3	.098
Likelihood Ratio	8.359	3	.039
N of Valid Cases	36		

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is 1.00.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	5	Total
Condition	Matched	Count	2	3	0	0	1	6
		% within Condition	33.3%	50.0%	0.0%	0.0%	16.7%	100.0%
		% within Response	28.6%	25.0%	0.0%	0.0%	100.0%	16.7%
		% of Total	5.6%	8.3%	0.0%	0.0%	2.8%	16.7%
	Novice	Count	5	9	10	6	0	30
		% within Condition	16.7%	30.0%	33.3%	20.0%	0.0%	100.0%
		% within Response	71.4%	75.0%	100.0%	100.0%	0.0%	83.3%
		% of Total	13.9%	25.0%	27.8%	16.7%	0.0%	83.3%
Total		Count	7	12	10	6	1	36
		% within Condition	19.4%	33.3%	27.8%	16.7%	2.8%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	19.4%	33.3%	27.8%	16.7%	2.8%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	9.514[a]	4	.049
Likelihood Ratio	10.569	4	.032
N of Valid Cases	36		

a. 6 cells (60.0%) have expected count less than 5. The minimum expected count is .17.

T.5.3 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	Total
Condition	Expert	Count	2	2	1	1	6
		% within Condition	33.3%	33.3%	16.7%	16.7%	100.0%
		% within Response	28.6%	66.7%	100.0%	100.0%	50.0%
		% of Total	16.7%	16.7%	8.3%	8.3%	50.0%
	Matched	Count	5	1	0	0	6
		% within Condition	83.3%	16.7%	0.0%	0.0%	100.0%
		% within Response	71.4%	33.3%	0.0%	0.0%	50.0%
		% of Total	41.7%	8.3%	0.0%	0.0%	50.0%
Total		Count	7	3	1	1	12
		% within Condition	58.3%	25.0%	8.3%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	58.3%	25.0%	8.3%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.619[a]	3	.306
Likelihood Ratio	4.441	3	.218
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Expert	Count	2	2	1	1	6
		% within Condition	33.3%	33.3%	16.7%	16.7%	100.0%
		% within Response	15.4%	13.3%	16.7%	50.0%	16.7%
		% of Total	5.6%	5.6%	2.8%	2.8%	16.7%
	Novice	Count	11	13	5	1	30
		% within Condition	36.7%	43.3%	16.7%	3.3%	100.0%
		% within Response	84.6%	86.7%	83.3%	50.0%	83.3%
		% of Total	30.6%	36.1%	13.9%	2.8%	83.3%
Total		Count	13	15	6	2	36
		% within Condition	36.1%	41.7%	16.7%	5.6%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	36.1%	41.7%	16.7%	5.6%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.735[a]	3	.629
Likelihood Ratio	1.318	3	.725
N of Valid Cases	36		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .33.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Matched	Count	5	1	0	0	6
		% within Condition	83.3%	16.7%	0.0%	0.0%	100.0%
		% within Response	31.3%	7.1%	0.0%	0.0%	16.7%
		% of Total	13.9%	2.8%	0.0%	0.0%	16.7%
	Novice	Count	11	13	5	1	30
		% within Condition	36.7%	43.3%	16.7%	3.3%	100.0%
		% within Response	68.8%	92.9%	100.0%	100.0%	83.3%
		% of Total	30.6%	36.1%	13.9%	2.8%	83.3%
Total		Count	16	14	5	1	36
		% within Condition	44.4%	38.9%	13.9%	2.8%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	44.4%	38.9%	13.9%	2.8%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.564[a]	3	.207
Likelihood Ratio	5.361	3	.147
N of Valid Cases	36		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is .17.

T.6 SUS Question 5 Responses

T.6.1 Within-Subjects

Expert

Condition * Response Crosstabulation

			Response			Total
			2	3	4	
Condition	Ecological	Count	2	2	2	6
		% within Condition	33.3%	33.3%	33.3%	100.0%
		% within Response	50.0%	40.0%	66.7%	50.0%
		% of Total	16.7%	16.7%	16.7%	50.0%
	LVAL	Count	2	3	1	6
		% within Condition	33.3%	50.0%	16.7%	100.0%
		% within Response	50.0%	60.0%	33.3%	50.0%
		% of Total	16.7%	25.0%	8.3%	50.0%
Total		Count	4	5	3	12
		% within Condition	33.3%	41.7%	25.0%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%
		% of Total	33.3%	41.7%	25.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.533[a]	2	.766
Likelihood Ratio	.541	2	.763
N of Valid Cases	12		

a. 6 cells (100.0%) have expected count less than 5. The minimum expected count is 1.50.

Matched Novice

Condition * Response Crosstabulation

			Response 2	3	4	5	Total
Condition	Ecological	Count	0	1	2	3	6
		% within Condition	0.0%	16.7%	33.3%	50.0%	100.0%
		% within Response	0.0%	50.0%	50.0%	75.0%	50.0%
		% of Total	0.0%	8.3%	16.7%	25.0%	50.0%
	LVAL	Count	2	1	2	1	6
		% within Condition	33.3%	16.7%	33.3%	16.7%	100.0%
		% within Response	100.0%	50.0%	50.0%	25.0%	50.0%
		% of Total	16.7%	8.3%	16.7%	8.3%	50.0%
Total		Count	2	2	4	4	12
		% within Condition	16.7%	16.7%	33.3%	33.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	16.7%	16.7%	33.3%	33.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.000[a]	3	.392
Likelihood Ratio	3.819	3	.282
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

Novice

Condition * Response Crosstabulation

			Response 2	3	4	5	Total
Condition	Ecological	Count	1	6	14	9	30
		% within Condition	3.3%	20.0%	46.7%	30.0%	100.0%
		% within Response	12.5%	28.6%	70.0%	81.8%	50.0%
		% of Total	1.7%	10.0%	23.3%	15.0%	50.0%
	LVAL	Count	7	15	6	2	30
		% within Condition	23.3%	50.0%	20.0%	6.7%	100.0%
		% within Response	87.5%	71.4%	30.0%	18.2%	50.0%
		% of Total	11.7%	25.0%	10.0%	3.3%	50.0%
Total		Count	8	21	20	11	60
		% within Condition	13.3%	35.0%	33.3%	18.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	13.3%	35.0%	33.3%	18.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	16.012[a]	3	.001
Likelihood Ratio	17.156	3	.001
N of Valid Cases	60		

a. 2 cells (25.0%) have expected count less than 5. The minimum expected count is 4.00.

T.6.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response 2	3	4	Total
Condition	Expert	Count	2	3	1	6
		% within Condition	33.3%	50.0%	16.7%	100.0%
		% within Response	50.0%	60.0%	33.3%	50.0%
		% of Total	16.7%	25.0%	8.3%	50.0%
	Matched	Count	2	2	2	6
		% within Condition	33.3%	33.3%	33.3%	100.0%
		% within Response	50.0%	40.0%	66.7%	50.0%
		% of Total	16.7%	16.7%	16.7%	50.0%
Total		Count	4	5	3	12
		% within Condition	33.3%	41.7%	25.0%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%
		% of Total	33.3%	41.7%	25.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.533[a]	2	.766
Likelihood Ratio	.541	2	.763
N of Valid Cases	12		

a. 6 cells (100.0%) have expected count less than 5. The minimum expected count is 1.50.

Expert – Novice

Condition * Response Crosstabulation

			Response				Total
			2	3	4	5	
Condition	Expert	Count	2	3	1	0	6
		% within Condition	33.3%	50.0%	16.7%	0.0%	100.0%
		% within Response	22.2%	16.7%	14.3%	0.0%	16.7%
		% of Total	5.6%	8.3%	2.8%	0.0%	16.7%
	Novice	Count	7	15	6	2	30
		% within Condition	23.3%	50.0%	20.0%	6.7%	100.0%
		% within Response	77.8%	83.3%	85.7%	100.0%	83.3%
		% of Total	19.4%	41.7%	16.7%	5.6%	83.3%
Total		Count	9	18	7	2	36
		% within Condition	25.0%	50.0%	19.4%	5.6%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	25.0%	50.0%	19.4%	5.6%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.629[a]	3	.890
Likelihood Ratio	.944	3	.815
N of Valid Cases	36		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .33.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response				Total
			2	3	4	5	
Condition	Matched	Count	2	1	2	1	6
		% within Condition	33.3%	16.7%	33.3%	16.7%	100.0%
		% within Response	22.2%	6.3%	25.0%	33.3%	16.7%
		% of Total	5.6%	2.8%	5.6%	2.8%	16.7%
	Novice	Count	7	15	6	2	30
		% within Condition	23.3%	50.0%	20.0%	6.7%	100.0%
		% within Response	77.8%	93.8%	75.0%	66.7%	83.3%
		% of Total	19.4%	41.7%	16.7%	5.6%	83.3%
Total		Count	9	16	8	3	36
		% within Condition	25.0%	44.4%	22.2%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	25.0%	44.4%	22.2%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.450[a]	3	.484
Likelihood Ratio	2.608	3	.456
N of Valid Cases	36		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .50.

T.6.3 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response				Total
			2	3	4	5	
Condition	Expert	Count	2	2	2	0	6
		% within Condition	33.3%	33.3%	33.3%	0.0%	100.0%
		% within Response	100.0%	66.7%	50.0%	0.0%	50.0%
		% of Total	16.7%	16.7%	16.7%	0.0%	50.0%
	Matched	Count	0	1	2	3	6
		% within Condition	0.0%	16.7%	33.3%	50.0%	100.0%
		% within Response	0.0%	33.3%	50.0%	100.0%	50.0%
		% of Total	0.0%	8.3%	16.7%	25.0%	50.0%
Total		Count	2	3	4	3	12
		% within Condition	16.7%	25.0%	33.3%	25.0%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	16.7%	25.0%	33.3%	25.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.333[a]	3	.149
Likelihood Ratio	7.271	3	.064
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

Expert – Novice

Condition * Response Crosstabulation

			Response				Total
			2	3	4	5	
Condition	Expert	Count	2	2	2	0	6
		% within Condition	33.3%	33.3%	33.3%	0.0%	100.0%
		% within Response	66.7%	25.0%	12.5%	0.0%	16.7%
		% of Total	5.6%	5.6%	5.6%	0.0%	16.7%
	Novice	Count	1	6	14	9	30
		% within Condition	3.3%	20.0%	46.7%	30.0%	100.0%
		% within Response	33.3%	75.0%	87.5%	100.0%	83.3%
		% of Total	2.8%	16.7%	38.9%	25.0%	83.3%
Total		Count	3	8	16	9	36
		% within Condition	8.3%	22.2%	44.4%	25.0%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	8.3%	22.2%	44.4%	25.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.800[a]	3	.050
Likelihood Ratio	7.567	3	.056
N of Valid Cases	36		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .50.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response				Total
			2	3	4	5	
Condition	Matched	Count	0	1	2	3	6
		% within Condition	0.0%	16.7%	33.3%	50.0%	100.0%
		% within Response	0.0%	14.3%	12.5%	25.0%	16.7%
		% of Total	0.0%	2.8%	5.6%	8.3%	16.7%
	Novice	Count	1	6	14	9	30
		% within Condition	3.3%	20.0%	46.7%	30.0%	100.0%
		% within Response	100.0%	85.7%	87.5%	75.0%	83.3%
		% of Total	2.8%	16.7%	38.9%	25.0%	83.3%
Total		Count	1	7	16	12	36
		% within Condition	2.8%	19.4%	44.4%	33.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	2.8%	19.4%	44.4%	33.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.029[a]	3	.794
Likelihood Ratio	1.146	3	.766
N of Valid Cases	36		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .17.

T.7 SUS Question 6 Responses

T.7.1 Within-Subjects

Expert

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Ecological	Count	1	2	2	0	1	6
		% within Condition	16.7%	33.3%	33.3%	0.0%	16.7%	100.0%
		% within Response	50.0%	40.0%	66.7%	0.0%	100.0%	50.0%
		% of Total	8.3%	16.7%	16.7%	0.0%	8.3%	50.0%
	LVAL	Count	1	3	1	1	0	6
		% within Condition	16.7%	50.0%	16.7%	16.7%	0.0%	100.0%
		% within Response	50.0%	60.0%	33.3%	100.0%	0.0%	50.0%
		% of Total	8.3%	25.0%	8.3%	8.3%	0.0%	50.0%
Total		Count	2	5	3	1	1	12
		% within Condition	16.7%	41.7%	25.0%	8.3%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	16.7%	41.7%	25.0%	8.3%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.533[a]	4	.639
Likelihood Ratio	3.314	4	.507
N of Valid Cases	12		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Matched Novice

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Ecological	Count	3	3	0	0	6
		% within Condition	50.0%	50.0%	0.0%	0.0%	100.0%
		% within Response	60.0%	75.0%	0.0%	0.0%	50.0%
		% of Total	25.0%	25.0%	0.0%	0.0%	50.0%
	LVAL	Count	2	1	2	1	6
		% within Condition	33.3%	16.7%	33.3%	16.7%	100.0%
		% within Response	40.0%	25.0%	100.0%	100.0%	50.0%
		% of Total	16.7%	8.3%	16.7%	8.3%	50.0%
Total		Count	5	4	2	1	12
		% within Condition	41.7%	33.3%	16.7%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	41.7%	33.3%	16.7%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.200[a]	3	.241
Likelihood Ratio	5.407	3	.144
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Ecological	Count	12	12	4	2	0	30
		% within Condition	40.0%	40.0%	13.3%	6.7%	0.0%	100.0%
		% within Response	80.0%	60.0%	28.6%	25.0%	0.0%	50.0%
		% of Total	20.0%	20.0%	6.7%	3.3%	0.0%	50.0%
	LVAL	Count	3	8	10	6	3	30
		% within Condition	10.0%	26.7%	33.3%	20.0%	10.0%	100.0%
		% within Response	20.0%	40.0%	71.4%	75.0%	100.0%	50.0%
		% of Total	5.0%	13.3%	16.7%	10.0%	5.0%	50.0%
Total		Count	15	20	14	8	3	60
		% within Condition	25.0%	33.3%	23.3%	13.3%	5.0%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	25.0%	33.3%	23.3%	13.3%	5.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.771[a]	4	.008
Likelihood Ratio	15.496	4	.004
N of Valid Cases	60		

a. 4 cells (40.0%) have expected count less than 5. The minimum expected count is 1.50.

T.7.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Expert	Count	1	3	1	1	6
		% within Condition	16.7%	50.0%	16.7%	16.7%	100.0%
		% within Response	33.3%	75.0%	33.3%	50.0%	50.0%
		% of Total	8.3%	25.0%	8.3%	8.3%	50.0%
	Matched	Count	2	1	2	1	6
		% within Condition	33.3%	16.7%	33.3%	16.7%	100.0%
		% within Response	66.7%	25.0%	66.7%	50.0%	50.0%
		% of Total	16.7%	8.3%	16.7%	8.3%	50.0%
Total		Count	3	4	3	2	12
		% within Condition	25.0%	33.3%	25.0%	16.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	25.0%	33.3%	25.0%	16.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.667[a]	3	.644
Likelihood Ratio	1.726	3	.631
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

Expert – Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Expert	Count	1	3	1	1	0	6
		% within Condition	16.7%	50.0%	16.7%	16.7%	0.0%	100.0%
		% within Response	25.0%	27.3%	9.1%	14.3%	0.0%	16.7%
		% of Total	2.8%	8.3%	2.8%	2.8%	0.0%	16.7%
	Novice	Count	3	8	10	6	3	30
		% within Condition	10.0%	26.7%	33.3%	20.0%	10.0%	100.0%
		% within Response	75.0%	72.7%	90.9%	85.7%	100.0%	83.3%
		% of Total	8.3%	22.2%	27.8%	16.7%	8.3%	83.3%
Total		Count	4	11	11	7	3	36
		% within Condition	11.1%	30.6%	30.6%	19.4%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	11.1%	30.6%	30.6%	19.4%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.174[a]	4	.704
Likelihood Ratio	2.607	4	.626
N of Valid Cases	36		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .50.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Matched	Count	2	1	2	1	0	6
		% within Condition	33.3%	16.7%	33.3%	16.7%	0.0%	100.0%
		% within Response	40.0%	11.1%	16.7%	14.3%	0.0%	16.7%
		% of Total	5.6%	2.8%	5.6%	2.8%	0.0%	16.7%
	Novice	Count	3	8	10	6	3	30
		% within Condition	10.0%	26.7%	33.3%	20.0%	10.0%	100.0%
		% within Response	60.0%	88.9%	83.3%	85.7%	100.0%	83.3%
		% of Total	8.3%	22.2%	27.8%	16.7%	8.3%	83.3%
Total		Count	5	9	12	7	3	36
		% within Condition	13.9%	25.0%	33.3%	19.4%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	13.9%	25.0%	33.3%	19.4%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.789[a]	4	.594
Likelihood Ratio	2.876	4	.579
N of Valid Cases	36		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .50.

T.7.3 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response				Total
			1	2	3	5	
Condition	Expert	Count	1	2	2	1	6
		% within Condition	16.7%	33.3%	33.3%	16.7%	100.0%
		% within Response	25.0%	40.0%	100.0%	100.0%	50.0%
		% of Total	8.3%	16.7%	16.7%	8.3%	50.0%
	Matched	Count	3	3	0	0	6
		% within Condition	50.0%	50.0%	0.0%	0.0%	100.0%
		% within Response	75.0%	60.0%	0.0%	0.0%	50.0%
		% of Total	25.0%	25.0%	0.0%	0.0%	50.0%
Total		Count	4	5	2	1	12
		% within Condition	33.3%	41.7%	16.7%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	33.3%	41.7%	16.7%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.200[a]	3	.241
Likelihood Ratio	5.407	3	.144
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	5	Total
Condition	Expert	Count	1	2	2	0	1	6
		% within Condition	16.7%	33.3%	33.3%	0.0%	16.7%	100.0%
		% within Response	7.7%	14.3%	33.3%	0.0%	100.0%	16.7%
		% of Total	2.8%	5.6%	5.6%	0.0%	2.8%	16.7%
	Novice	Count	12	12	4	2	0	30
		% within Condition	40.0%	40.0%	13.3%	6.7%	0.0%	100.0%
		% within Response	92.3%	85.7%	66.7%	100.0%	0.0%	83.3%
		% of Total	33.3%	33.3%	11.1%	5.6%	0.0%	83.3%
Total		Count	13	14	6	2	1	36
		% within Condition	36.1%	38.9%	16.7%	5.6%	2.8%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	36.1%	38.9%	16.7%	5.6%	2.8%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.411[a]	4	.116
Likelihood Ratio	6.268	4	.180
N of Valid Cases	36		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .17.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	Total
Condition	Matched	Count	3	3	0	0	6
		% within Condition	50.0%	50.0%	0.0%	0.0%	100.0%
		% within Response	20.0%	20.0%	0.0%	0.0%	16.7%
		% of Total	8.3%	8.3%	0.0%	0.0%	16.7%
	Novice	Count	12	12	4	2	30
		% within Condition	40.0%	40.0%	13.3%	6.7%	100.0%
		% within Response	80.0%	80.0%	100.0%	100.0%	83.3%
		% of Total	33.3%	33.3%	11.1%	5.6%	83.3%
Total		Count	15	15	4	2	36
		% within Condition	41.7%	41.7%	11.1%	5.6%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	41.7%	41.7%	11.1%	5.6%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.440[a]	3	.696
Likelihood Ratio	2.416	3	.491
N of Valid Cases	36		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is .33.

T.8 SUS Question 7 Responses

T.8.1 Within-Subjects

Expert

Condition * Response Crosstabulation

			Response 1	2	3	4	5	Total
Condition	Ecological	Count	1	1	1	2	1	6
		% within Condition	16.7%	16.7%	16.7%	33.3%	16.7%	100.0%
		% within Response	100.0%	100.0%	33.3%	40.0%	50.0%	50.0%
		% of Total	8.3%	8.3%	8.3%	16.7%	8.3%	50.0%
	LVAL	Count	0	0	2	3	1	6
		% within Condition	0.0%	0.0%	33.3%	50.0%	16.7%	100.0%
		% within Response	0.0%	0.0%	66.7%	60.0%	50.0%	50.0%
		% of Total	0.0%	0.0%	16.7%	25.0%	8.3%	50.0%
Total		Count	1	1	3	5	2	12
		% within Condition	8.3%	8.3%	25.0%	41.7%	16.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	8.3%	8.3%	25.0%	41.7%	16.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.533[a]	4	.639
Likelihood Ratio	3.314	4	.507
N of Valid Cases	12		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Matched Novice

Condition * Response Crosstabulation

			Response				Total
			2	3	4	5	
Condition	Ecological	Count	0	0	3	3	6
		% within Condition	0.0%	0.0%	50.0%	50.0%	100.0%
		% within Response	0.0%	0.0%	50.0%	75.0%	50.0%
		% of Total	0.0%	0.0%	25.0%	25.0%	50.0%
	LVAL	Count	1	1	3	1	6
		% within Condition	16.7%	16.7%	50.0%	16.7%	100.0%
		% within Response	100.0%	100.0%	50.0%	25.0%	50.0%
		% of Total	8.3%	8.3%	25.0%	8.3%	50.0%
Total		Count	1	1	6	4	12
		% within Condition	8.3%	8.3%	50.0%	33.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	8.3%	8.3%	50.0%	33.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.000[a]	3	.392
Likelihood Ratio	3.819	3	.282
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Ecological	Count	0	0	2	8	20	30
		% within Condition	0.0%	0.0%	6.7%	26.7%	66.7%	100.0%
		% within Response	0.0%	0.0%	22.2%	47.1%	69.0%	50.0%
		% of Total	0.0%	0.0%	3.3%	13.3%	33.3%	50.0%
	LVAL	Count	1	4	7	9	9	30
		% within Condition	3.3%	13.3%	23.3%	30.0%	30.0%	100.0%
		% within Response	100.0%	100.0%	77.8%	52.9%	31.0%	50.0%
		% of Total	1.7%	6.7%	11.7%	15.0%	15.0%	50.0%
Total		Count	1	4	9	17	29	60
		% within Condition	1.7%	6.7%	15.0%	28.3%	48.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	1.7%	6.7%	15.0%	28.3%	48.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	12.009[a]	4	.017
Likelihood Ratio	14.211	4	.007
N of Valid Cases	60		

a. 6 cells (60.0%) have expected count less than 5. The minimum expected count is .50.

T.8.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response				Total
			2	3	4	5	
Condition	Expert	Count	0	2	3	1	6
		% within Condition	0.0%	33.3%	50.0%	16.7%	100.0%
		% within Response	0.0%	66.7%	50.0%	50.0%	50.0%
		% of Total	0.0%	16.7%	25.0%	8.3%	50.0%
	Matched	Count	1	1	3	1	6
		% within Condition	16.7%	16.7%	50.0%	16.7%	100.0%
		% within Response	100.0%	33.3%	50.0%	50.0%	50.0%
		% of Total	8.3%	8.3%	25.0%	8.3%	50.0%
Total		Count	1	3	6	2	12
		% within Condition	8.3%	25.0%	50.0%	16.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	8.3%	25.0%	50.0%	16.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.333[a]	3	.721
Likelihood Ratio	1.726	3	.631
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	5	Total
Condition	Expert	Count	0	0	2	3	1	6
		% within Condition	0.0%	0.0%	33.3%	50.0%	16.7%	100.0%
		% within Response	0.0%	0.0%	22.2%	25.0%	10.0%	16.7%
		% of Total	0.0%	0.0%	5.6%	8.3%	2.8%	16.7%
	Novice	Count	1	4	7	9	9	30
		% within Condition	3.3%	13.3%	23.3%	30.0%	30.0%	100.0%
		% within Response	100.0%	100.0%	77.8%	75.0%	90.0%	83.3%
		% of Total	2.8%	11.1%	19.4%	25.0%	25.0%	83.3%
Total		Count	1	4	9	12	10	36
		% within Condition	2.8%	11.1%	25.0%	33.3%	27.8%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	2.8%	11.1%	25.0%	33.3%	27.8%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.120[a]	4	.714
Likelihood Ratio	2.908	4	.573
N of Valid Cases	36		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .17.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	5	Total
Condition	Matched	Count	0	1	1	3	1	6
		% within Condition	0.0%	16.7%	16.7%	50.0%	16.7%	100.0%
		% within Response	0.0%	20.0%	12.5%	25.0%	10.0%	16.7%
		% of Total	0.0%	2.8%	2.8%	8.3%	2.8%	16.7%
	Novice	Count	1	4	7	9	9	30
		% within Condition	3.3%	13.3%	23.3%	30.0%	30.0%	100.0%
		% within Response	100.0%	80.0%	87.5%	75.0%	90.0%	83.3%
		% of Total	2.8%	11.1%	19.4%	25.0%	25.0%	83.3%
Total		Count	1	5	8	12	10	36
		% within Condition	2.8%	13.9%	22.2%	33.3%	27.8%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	2.8%	13.9%	22.2%	33.3%	27.8%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.260[a]	4	.868
Likelihood Ratio	1.410	4	.842
N of Valid Cases	36		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .17.

T.8.3 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	5	Total
Condition	Expert	Count	1	1	1	2	1	6
		% within Condition	16.7%	16.7%	16.7%	33.3%	16.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	40.0%	25.0%	50.0%
		% of Total	8.3%	8.3%	8.3%	16.7%	8.3%	50.0%
	Matched	Count	0	0	0	3	3	6
		% within Condition	0.0%	0.0%	0.0%	50.0%	50.0%	100.0%
		% within Response	0.0%	0.0%	0.0%	60.0%	75.0%	50.0%
		% of Total	0.0%	0.0%	0.0%	25.0%	25.0%	50.0%
Total		Count	1	1	1	5	4	12
		% within Condition	8.3%	8.3%	8.3%	41.7%	33.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	8.3%	8.3%	8.3%	41.7%	33.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.200[a]	4	.380
Likelihood Ratio	5.407	4	.248
N of Valid Cases	12		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	5	Total
Condition	Expert	Count	1	1	1	2	1	6
		% within Condition	16.7%	16.7%	16.7%	33.3%	16.7%	100.0%
		% within Response	100.0%	100.0%	33.3%	20.0%	4.8%	16.7%
		% of Total	2.8%	2.8%	2.8%	5.6%	2.8%	16.7%
	Novice	Count	0	0	2	8	20	30
		% within Condition	0.0%	0.0%	6.7%	26.7%	66.7%	100.0%
		% within Response	0.0%	0.0%	66.7%	80.0%	95.2%	83.3%
		% of Total	0.0%	0.0%	5.6%	22.2%	55.6%	83.3%
Total		Count	1	1	3	10	21	36
		% within Condition	2.8%	2.8%	8.3%	27.8%	58.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	2.8%	2.8%	8.3%	27.8%	58.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	12.823[a]	4	.012
Likelihood Ratio	10.573	4	.032
N of Valid Cases	36		

a. 8 cells (80.0%) have expected count less than 5. The minimum expected count is .17.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response 3	4	5	Total
Condition	Matched	Count	0	3	3	6
		% within Condition	0.0%	50.0%	50.0%	100.0%
		% within Response	0.0%	27.3%	13.0%	16.7%
		% of Total	0.0%	8.3%	8.3%	16.7%
	Novice	Count	2	8	20	30
		% within Condition	6.7%	26.7%	66.7%	100.0%
		% within Response	100.0%	72.7%	87.0%	83.3%
		% of Total	5.6%	22.2%	55.6%	83.3%
Total		Count	2	11	23	36
		% within Condition	5.6%	30.6%	63.9%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%
		% of Total	5.6%	30.6%	63.9%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.508[a]	2	.470
Likelihood Ratio	1.738	2	.419
N of Valid Cases	36		

a. 4 cells (66.7%) have expected count less than 5. The minimum expected count is .33.

T.9 SUS Question 8 Responses

T.9.1 Within-Subjects

Expert

Condition * Response Crosstabulation

			Response 1	2	3	4	Total
Condition	Ecological	Count	0	1	4	1	6
		% within Condition	0.0%	16.7%	66.7%	16.7%	100.0%
		% within Response	0.0%	20.0%	80.0%	100.0%	50.0%
		% of Total	0.0%	8.3%	33.3%	8.3%	50.0%
	LVAL	Count	1	4	1	0	6
		% within Condition	16.7%	66.7%	16.7%	0.0%	100.0%
		% within Response	100.0%	80.0%	20.0%	0.0%	50.0%
		% of Total	8.3%	33.3%	8.3%	0.0%	50.0%
Total		Count	1	5	5	1	12
		% within Condition	8.3%	41.7%	41.7%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	8.3%	41.7%	41.7%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.600[a]	3	.133
Likelihood Ratio	6.627	3	.085
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Matched Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	Total
Condition	Ecological	Count	3	3	0	0	6
		% within Condition	50.0%	50.0%	0.0%	0.0%	100.0%
		% within Response	75.0%	75.0%	0.0%	0.0%	50.0%
		% of Total	25.0%	25.0%	0.0%	0.0%	50.0%
	LVAL	Count	1	1	1	3	6
		% within Condition	16.7%	16.7%	16.7%	50.0%	100.0%
		% within Response	25.0%	25.0%	100.0%	100.0%	50.0%
		% of Total	8.3%	8.3%	8.3%	25.0%	50.0%
Total		Count	4	4	1	3	12
		% within Condition	33.3%	33.3%	8.3%	25.0%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	33.3%	33.3%	8.3%	25.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.000[a]	3	.112
Likelihood Ratio	7.638	3	.054
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	5	Total
Condition	Ecological	Count	13	12	2	3	0	30
		% within Condition	43.3%	40.0%	6.7%	10.0%	0.0%	100.0%
		% within Response	76.5%	54.5%	40.0%	21.4%	0.0%	50.0%
		% of Total	21.7%	20.0%	3.3%	5.0%	0.0%	50.0%
	LVAL	Count	4	10	3	11	2	30
		% within Condition	13.3%	33.3%	10.0%	36.7%	6.7%	100.0%
		% within Response	23.5%	45.5%	60.0%	78.6%	100.0%	50.0%
		% of Total	6.7%	16.7%	5.0%	18.3%	3.3%	50.0%
Total		Count	17	22	5	14	2	60
		% within Condition	28.3%	36.7%	8.3%	23.3%	3.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	28.3%	36.7%	8.3%	23.3%	3.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.718[a]	4	.020
Likelihood Ratio	13.033	4	.011
N of Valid Cases	60		

a. 4 cells (40.0%) have expected count less than 5. The minimum expected count is 1.00.

T.9.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	Total
Condition	Expert	Count	1	4	1	0	6
		% within Condition	16.7%	66.7%	16.7%	0.0%	100.0%
		% within Response	50.0%	80.0%	50.0%	0.0%	50.0%
		% of Total	8.3%	33.3%	8.3%	0.0%	50.0%
	Matched	Count	1	1	1	3	6
		% within Condition	16.7%	16.7%	16.7%	50.0%	100.0%
		% within Response	50.0%	20.0%	50.0%	100.0%	50.0%
		% of Total	8.3%	8.3%	8.3%	25.0%	50.0%
Total		Count	2	5	2	3	12
		% within Condition	16.7%	41.7%	16.7%	25.0%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	16.7%	41.7%	16.7%	25.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.800[a]	3	.187
Likelihood Ratio	6.086	3	.107
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

Expert – Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Expert	Count	1	4	1	0	0	6
		% within Condition	16.7%	66.7%	16.7%	0.0%	0.0%	100.0%
		% within Response	20.0%	28.6%	25.0%	0.0%	0.0%	16.7%
		% of Total	2.8%	11.1%	2.8%	0.0%	0.0%	16.7%
	Novice	Count	4	10	3	11	2	30
		% within Condition	13.3%	33.3%	10.0%	36.7%	6.7%	100.0%
		% within Response	80.0%	71.4%	75.0%	100.0%	100.0%	83.3%
		% of Total	11.1%	27.8%	8.3%	30.6%	5.6%	83.3%
Total		Count	5	14	4	11	2	36
		% within Condition	13.9%	38.9%	11.1%	30.6%	5.6%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	13.9%	38.9%	11.1%	30.6%	5.6%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.269[a]	4	.371
Likelihood Ratio	6.186	4	.186
N of Valid Cases	36		

a. 8 cells (80.0%) have expected count less than 5. The minimum expected count is .33.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Matched	Count	0	1	4	1	0	6
		% within Condition	0.0%	16.7%	66.7%	16.7%	0.0%	100.0%
		% within Response	0.0%	9.1%	57.1%	8.3%	0.0%	16.7%
		% of Total	0.0%	2.8%	11.1%	2.8%	0.0%	16.7%
	Novice	Count	4	10	3	11	2	30
		% within Condition	13.3%	33.3%	10.0%	36.7%	6.7%	100.0%
		% within Response	100.0%	90.9%	42.9%	91.7%	100.0%	83.3%
		% of Total	11.1%	27.8%	8.3%	30.6%	5.6%	83.3%
Total		Count	4	11	7	12	2	36
		% within Condition	11.1%	30.6%	19.4%	33.3%	5.6%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	11.1%	30.6%	19.4%	33.3%	5.6%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	10.512[a]	4	.033
Likelihood Ratio	9.294	4	.054
N of Valid Cases	36		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .33.

T.9.3 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Expert	Count	0	1	4	1	6
		% within Condition	0.0%	16.7%	66.7%	16.7%	100.0%
		% within Response	0.0%	25.0%	100.0%	100.0%	50.0%
		% of Total	0.0%	8.3%	33.3%	8.3%	50.0%
	Matched	Count	3	3	0	0	6
		% within Condition	50.0%	50.0%	0.0%	0.0%	100.0%
		% within Response	100.0%	75.0%	0.0%	0.0%	50.0%
		% of Total	25.0%	25.0%	0.0%	0.0%	50.0%
Total		Count	3	4	4	1	12
		% within Condition	25.0%	33.3%	33.3%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	25.0%	33.3%	33.3%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	9.000[a]	3	.029
Likelihood Ratio	12.137	3	.007
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Expert	Count	0	1	4	1	6
		% within Condition	0.0%	16.7%	66.7%	16.7%	100.0%
		% within Response	0.0%	7.7%	66.7%	25.0%	16.7%
		% of Total	0.0%	2.8%	11.1%	2.8%	16.7%
	Novice	Count	13	12	2	3	30
		% within Condition	43.3%	40.0%	6.7%	10.0%	100.0%
		% within Response	100.0%	92.3%	33.3%	75.0%	83.3%
		% of Total	36.1%	33.3%	5.6%	8.3%	83.3%
Total		Count	13	13	6	4	36
		% within Condition	36.1%	36.1%	16.7%	11.1%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	36.1%	36.1%	16.7%	11.1%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	14.354[a]	3	.002
Likelihood Ratio	13.253	3	.004
N of Valid Cases	36		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .67.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Matched	Count	3	3	0	0	6
		% within Condition	50.0%	50.0%	0.0%	0.0%	100.0%
		% within Response	18.8%	20.0%	0.0%	0.0%	16.7%
		% of Total	8.3%	8.3%	0.0%	0.0%	16.7%
	Novice	Count	13	12	2	3	30
		% within Condition	43.3%	40.0%	6.7%	10.0%	100.0%
		% within Response	81.3%	80.0%	100.0%	100.0%	83.3%
		% of Total	36.1%	33.3%	5.6%	8.3%	83.3%
Total		Count	16	15	2	3	36
		% within Condition	44.4%	41.7%	5.6%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	44.4%	41.7%	5.6%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.170[a]	3	.760
Likelihood Ratio	1.986	3	.575
N of Valid Cases	36		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is .33.

T.10 SUS Question 9 Responses

T.10.1 Within-Subjects

Expert

Condition * Response Crosstabulation

			Response			Total
			3	4	5	
Condition	Ecological	Count	3	3	0	6
		% within Condition	50.0%	50.0%	0.0%	100.0%
		% within Response	100.0%	42.9%	0.0%	50.0%
		% of Total	25.0%	25.0%	0.0%	50.0%
	LVAL	Count	0	4	2	6
		% within Condition	0.0%	66.7%	33.3%	100.0%
		% within Response	0.0%	57.1%	100.0%	50.0%
		% of Total	0.0%	33.3%	16.7%	50.0%
Total		Count	3	7	2	12
		% within Condition	25.0%	58.3%	16.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%
		% of Total	25.0%	58.3%	16.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.143[a]	2	.076
Likelihood Ratio	7.075	2	.029
N of Valid Cases	12		

a. 6 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

Matched Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Ecological	Count	0	0	2	1	3	6
		% within Condition	0.0%	0.0%	33.3%	16.7%	50.0%	100.0%
		% within Response	0.0%	0.0%	33.3%	100.0%	100.0%	50.0%
		% of Total	0.0%	0.0%	16.7%	8.3%	25.0%	50.0%
	LVAL	Count	1	1	4	0	0	6
		% within Condition	16.7%	16.7%	66.7%	0.0%	0.0%	100.0%
		% within Response	100.0%	100.0%	66.7%	0.0%	0.0%	50.0%
		% of Total	8.3%	8.3%	33.3%	0.0%	0.0%	50.0%
Total		Count	1	1	6	1	3	12
		% within Condition	8.3%	8.3%	50.0%	8.3%	25.0%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	8.3%	8.3%	50.0%	8.3%	25.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.667[a]	4	.155
Likelihood Ratio	8.997	4	.061
N of Valid Cases	12		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Ecological	Count	0	2	8	12	8	30
		% within Condition	0.0%	6.7%	26.7%	40.0%	26.7%	100.0%
		% within Response	0.0%	15.4%	44.4%	66.7%	80.0%	50.0%
		% of Total	0.0%	3.3%	13.3%	20.0%	13.3%	50.0%
	LVAL	Count	1	11	10	6	2	30
		% within Condition	3.3%	36.7%	33.3%	20.0%	6.7%	100.0%
		% within Response	100.0%	84.6%	55.6%	33.3%	20.0%	50.0%
		% of Total	1.7%	18.3%	16.7%	10.0%	3.3%	50.0%
Total		Count	1	13	18	18	10	60
		% within Condition	1.7%	21.7%	30.0%	30.0%	16.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	1.7%	21.7%	30.0%	30.0%	16.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.053[a]	4	.011
Likelihood Ratio	14.362	4	.006
N of Valid Cases	60		

a. 2 cells (20.0%) have expected count less than 5. The minimum expected count is .50.

T.10.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response			Total
			3	4	5	
Condition	Expert	Count	0	4	2	6
		% within Condition	0.0%	66.7%	33.3%	100.0%
		% within Response	0.0%	57.1%	100.0%	50.0%
		% of Total	0.0%	33.3%	16.7%	50.0%
	Matched	Count	3	3	0	6
		% within Condition	50.0%	50.0%	0.0%	100.0%
		% within Response	100.0%	42.9%	0.0%	50.0%
		% of Total	25.0%	25.0%	0.0%	50.0%
Total		Count	3	7	2	12
		% within Condition	25.0%	58.3%	16.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%
		% of Total	25.0%	58.3%	16.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.143[a]	2	.076
Likelihood Ratio	7.075	2	.029
N of Valid Cases	12		

a. 6 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

Expert – Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Expert	Count	0	0	0	4	2	6
		% within Condition	0.0%	0.0%	0.0%	66.7%	33.3%	100.0%
		% within Response	0.0%	0.0%	0.0%	40.0%	50.0%	16.7%
		% of Total	0.0%	0.0%	0.0%	11.1%	5.6%	16.7%
	Novice	Count	1	11	10	6	2	30
		% within Condition	3.3%	36.7%	33.3%	20.0%	6.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	60.0%	50.0%	83.3%
		% of Total	2.8%	30.6%	27.8%	16.7%	5.6%	83.3%
Total		Count	1	11	10	10	4	36
		% within Condition	2.8%	30.6%	27.8%	27.8%	11.1%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	2.8%	30.6%	27.8%	27.8%	11.1%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.520[a]	4	.021
Likelihood Ratio	13.435	4	.009
N of Valid Cases	36		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .17.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Matched	Count	1	1	4	0	0	6
		% within Condition	16.7%	16.7%	66.7%	0.0%	0.0%	100.0%
		% within Response	50.0%	8.3%	28.6%	0.0%	0.0%	16.7%
		% of Total	2.8%	2.8%	11.1%	0.0%	0.0%	16.7%
	Novice	Count	1	11	10	6	2	30
		% within Condition	3.3%	36.7%	33.3%	20.0%	6.7%	100.0%
		% within Response	50.0%	91.7%	71.4%	100.0%	100.0%	83.3%
		% of Total	2.8%	30.6%	27.8%	16.7%	5.6%	83.3%
Total		Count	2	12	14	6	2	36
		% within Condition	5.6%	33.3%	38.9%	16.7%	5.6%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	5.6%	33.3%	38.9%	16.7%	5.6%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.229[a]	4	.265
Likelihood Ratio	6.032	4	.197
N of Valid Cases	36		

a. 7 cells (70.0%) have expected count less than 5. The minimum expected count is .33.

T.10.3 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response			Total
			3	4	5	
Condition	Expert	Count	3	3	0	6
		% within Condition	50.0%	50.0%	0.0%	100.0%
		% within Response	60.0%	75.0%	0.0%	50.0%
		% of Total	25.0%	25.0%	0.0%	50.0%
	Matched	Count	2	1	3	6
		% within Condition	33.3%	16.7%	50.0%	100.0%
		% within Response	40.0%	25.0%	100.0%	50.0%
		% of Total	16.7%	8.3%	25.0%	50.0%
Total		Count	5	4	3	12
		% within Condition	41.7%	33.3%	25.0%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%
		% of Total	41.7%	33.3%	25.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.200[a]	2	.122
Likelihood Ratio	5.407	2	.067
N of Valid Cases	12		

a. 6 cells (100.0%) have expected count less than 5. The minimum expected count is 1.50.

Expert – Novice

Condition * Response Crosstabulation

			Response				Total
			2	3	4	5	
Condition	Expert	Count	0	3	3	0	6
		% within Condition	0.0%	50.0%	50.0%	0.0%	100.0%
		% within Response	0.0%	27.3%	20.0%	0.0%	16.7%
		% of Total	0.0%	8.3%	8.3%	0.0%	16.7%
	Novice	Count	2	8	12	8	30
		% within Condition	6.7%	26.7%	40.0%	26.7%	100.0%
		% within Response	100.0%	72.7%	80.0%	100.0%	83.3%
		% of Total	5.6%	22.2%	33.3%	22.2%	83.3%
Total		Count	2	11	15	8	36
		% within Condition	5.6%	30.6%	41.7%	22.2%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	5.6%	30.6%	41.7%	22.2%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.011[a]	3	.390
Likelihood Ratio	4.537	3	.209
N of Valid Cases	36		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .33.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response				Total
			2	3	4	5	
Condition	Matched	Count	0	2	1	3	6
		% within Condition	0.0%	33.3%	16.7%	50.0%	100.0%
		% within Response	0.0%	20.0%	7.7%	27.3%	16.7%
		% of Total	0.0%	5.6%	2.8%	8.3%	16.7%
	Novice	Count	2	8	12	8	30
		% within Condition	6.7%	26.7%	40.0%	26.7%	100.0%
		% within Response	100.0%	80.0%	92.3%	72.7%	83.3%
		% of Total	5.6%	22.2%	33.3%	22.2%	83.3%
Total		Count	2	10	13	11	36
		% within Condition	5.6%	27.8%	36.1%	30.6%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	5.6%	27.8%	36.1%	30.6%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.125[a]	3	.547
Likelihood Ratio	2.490	3	.477
N of Valid Cases	36		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .33.

T.11 SUS Question 10 Responses

T.11.1 Within-Subjects

Expert

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Ecological	Count	2	1	2	1	6
		% within Condition	33.3%	16.7%	33.3%	16.7%	100.0%
		% within Response	50.0%	25.0%	100.0%	50.0%	50.0%
		% of Total	16.7%	8.3%	16.7%	8.3%	50.0%
	LVAL	Count	2	3	0	1	6
		% within Condition	33.3%	50.0%	0.0%	16.7%	100.0%
		% within Response	50.0%	75.0%	0.0%	50.0%	50.0%
		% of Total	16.7%	25.0%	0.0%	8.3%	50.0%
Total		Count	4	4	2	2	12
		% within Condition	33.3%	33.3%	16.7%	16.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	33.3%	33.3%	16.7%	16.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.000[a]	3	.392
Likelihood Ratio	3.819	3	.282
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

Matched Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Ecological	Count	2	2	1	1	0	6
		% within Condition	33.3%	33.3%	16.7%	16.7%	0.0%	100.0%
		% within Response	40.0%	66.7%	50.0%	100.0%	0.0%	50.0%
		% of Total	16.7%	16.7%	8.3%	8.3%	0.0%	50.0%
	LVAL	Count	3	1	1	0	1	6
		% within Condition	50.0%	16.7%	16.7%	0.0%	16.7%	100.0%
		% within Response	60.0%	33.3%	50.0%	0.0%	100.0%	50.0%
		% of Total	25.0%	8.3%	8.3%	0.0%	8.3%	50.0%
Total		Count	5	3	2	1	1	12
		% within Condition	41.7%	25.0%	16.7%	8.3%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	41.7%	25.0%	16.7%	8.3%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.533[a]	4	.639
Likelihood Ratio	3.314	4	.507
N of Valid Cases	12		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Novice

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Ecological	Count	10	16	4	0	30
		% within Condition	33.3%	53.3%	13.3%	0.0%	100.0%
		% within Response	71.4%	59.3%	30.8%	0.0%	50.0%
		% of Total	16.7%	26.7%	6.7%	0.0%	50.0%
	LVAL	Count	4	11	9	6	30
		% within Condition	13.3%	36.7%	30.0%	20.0%	100.0%
		% within Response	28.6%	40.7%	69.2%	100.0%	50.0%
		% of Total	6.7%	18.3%	15.0%	10.0%	50.0%
Total		Count	14	27	13	6	60
		% within Condition	23.3%	45.0%	21.7%	10.0%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	23.3%	45.0%	21.7%	10.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.420[a]	3	.010
Likelihood Ratio	13.879	3	.003
N of Valid Cases	60		

a. 2 cells (25.0%) have expected count less than 5. The minimum expected count is 3.00.

T.11.2 Between-Subjects (LVAL)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response					Total
			1	2	3	4	5	
Condition	Expert	Count	2	3	0	1	0	6
		% within Condition	33.3%	50.0%	0.0%	16.7%	0.0%	100.0%
		% within Response	40.0%	75.0%	0.0%	100.0%	0.0%	50.0%
		% of Total	16.7%	25.0%	0.0%	8.3%	0.0%	50.0%
	Matched	Count	3	1	1	0	1	6
		% within Condition	50.0%	16.7%	16.7%	0.0%	16.7%	100.0%
		% within Response	60.0%	25.0%	100.0%	0.0%	100.0%	50.0%
		% of Total	25.0%	8.3%	8.3%	0.0%	8.3%	50.0%
Total		Count	5	4	1	1	1	12
		% within Condition	41.7%	33.3%	8.3%	8.3%	8.3%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	41.7%	33.3%	8.3%	8.3%	8.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.200[a]	4	.380
Likelihood Ratio	5.407	4	.248
N of Valid Cases	12		

a. 10 cells (100.0%) have expected count less than 5. The minimum expected count is .50.

Expert – Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	Total
Condition	Expert	Count	2	3	0	1	6
		% within Condition	33.3%	50.0%	0.0%	16.7%	100.0%
		% within Response	33.3%	21.4%	0.0%	14.3%	16.7%
		% of Total	5.6%	8.3%	0.0%	2.8%	16.7%
	Novice	Count	4	11	9	6	30
		% within Condition	13.3%	36.7%	30.0%	20.0%	100.0%
		% within Response	66.7%	78.6%	100.0%	85.7%	83.3%
		% of Total	11.1%	30.6%	25.0%	16.7%	83.3%
Total		Count	6	14	9	7	36
		% within Condition	16.7%	38.9%	25.0%	19.4%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	16.7%	38.9%	25.0%	19.4%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.257[a]	3	.354
Likelihood Ratio	4.512	3	.211
N of Valid Cases	36		

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is 1.00.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	5	Total
Condition	Matched	Count	3	1	1	0	1	6
		% within Condition	50.0%	16.7%	16.7%	0.0%	16.7%	100.0%
		% within Response	42.9%	8.3%	10.0%	0.0%	100.0%	16.7%
		% of Total	8.3%	2.8%	2.8%	0.0%	2.8%	16.7%
	Novice	Count	4	11	9	6	0	30
		% within Condition	13.3%	36.7%	30.0%	20.0%	0.0%	100.0%
		% within Response	57.1%	91.7%	90.0%	100.0%	0.0%	83.3%
		% of Total	11.1%	30.6%	25.0%	16.7%	0.0%	83.3%
Total		Count	7	12	10	6	1	36
		% within Condition	19.4%	33.3%	27.8%	16.7%	2.8%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	19.4%	33.3%	27.8%	16.7%	2.8%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	10.577[a]	4	.032
Likelihood Ratio	9.494	4	.050
N of Valid Cases	36		

a. 6 cells (60.0%) have expected count less than 5. The minimum expected count is .17.

T.11.3 Between-Subjects (Ecological)

Expert – Matched Novice

Condition * Response Crosstabulation

			Response 1	2	3	4	Total
Condition	Expert	Count	2	1	2	1	6
		% within Condition	33.3%	16.7%	33.3%	16.7%	100.0%
		% within Response	50.0%	33.3%	66.7%	50.0%	50.0%
		% of Total	16.7%	8.3%	16.7%	8.3%	50.0%
	Matched	Count	2	2	1	1	6
		% within Condition	33.3%	33.3%	16.7%	16.7%	100.0%
		% within Response	50.0%	66.7%	33.3%	50.0%	50.0%
		% of Total	16.7%	16.7%	8.3%	8.3%	50.0%
Total		Count	4	3	3	2	12
		% within Condition	33.3%	25.0%	25.0%	16.7%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	33.3%	25.0%	25.0%	16.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.667[a]	3	.881
Likelihood Ratio	.680	3	.878
N of Valid Cases	12		

a. 8 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.

Expert – Novice

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Expert	Count	2	1	2	1	6
		% within Condition	33.3%	16.7%	33.3%	16.7%	100.0%
		% within Response	16.7%	5.9%	33.3%	100.0%	16.7%
		% of Total	5.6%	2.8%	5.6%	2.8%	16.7%
	Novice	Count	10	16	4	0	30
		% within Condition	33.3%	53.3%	13.3%	0.0%	100.0%
		% within Response	83.3%	94.1%	66.7%	0.0%	83.3%
		% of Total	27.8%	44.4%	11.1%	0.0%	83.3%
Total		Count	12	17	6	1	36
		% within Condition	33.3%	47.2%	16.7%	2.8%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	33.3%	47.2%	16.7%	2.8%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.624[a]	3	.054
Likelihood Ratio	6.382	3	.094
N of Valid Cases	36		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .17.

Matched Novice - Novice

Condition * Response Crosstabulation

			Response				Total
			1	2	3	4	
Condition	Matched	Count	2	2	1	1	6
		% within Condition	33.3%	33.3%	16.7%	16.7%	100.0%
		% within Response	16.7%	11.1%	20.0%	100.0%	16.7%
		% of Total	5.6%	5.6%	2.8%	2.8%	16.7%
	Novice	Count	10	16	4	0	30
		% within Condition	33.3%	53.3%	13.3%	0.0%	100.0%
		% within Response	83.3%	88.9%	80.0%	0.0%	83.3%
		% of Total	27.8%	44.4%	11.1%	0.0%	83.3%
Total		Count	12	18	5	1	36
		% within Condition	33.3%	50.0%	13.9%	2.8%	100.0%
		% within Response	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	33.3%	50.0%	13.9%	2.8%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.440[a]	3	.142
Likelihood Ratio	4.065	3	.255
N of Valid Cases	36		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is .17.

References

Ahlstrom, U. (2005). Work domain analysis for air traffic control weather displays. *Journal of Safety Research, 36*(2), 159-169.

Amalberti, R. (2006). Optimum system safety and optimum system resilience: Agonistic or antagonistic concepts? In E. Hollnagel, D. Woods & N. Leveson (Eds.), *Resilience Engineering: Concepts and Precepts*. Aldershot: Ashgate.

Anguera, R. (2006). The Channel Tunnel - an ex post economic evaluation. *Transportation Research Part A - Policy and Practice, 40*(4), 291-315. doi: 10.1016/j.tra.2005.08.009

Annet, J. (2005). Hierarchical task analysis. In N. A. Stanton, A. Hedge, K. Brookhuis & E. Salas (Eds.), *Handbook of human factors and ergonomics methods*. London: CRC.

Association of Chief Police Officers. (2009). *Police Driving 2009*. Paper presented at the National Police Driving Schools Conference:, London.

Baber, C., Stanton, N.A., Atkinson, J., McMaster, R., & Houghton, R.J. (2013). Using social network analysis and agent-based modelling to explore information flow using common operational pictures for maritime search and rescue operations. *Ergonomics, 56*(6), 889-905. doi: 10.1080/00140139.2013.788216

Bangor, A., Kortum, P.T., & Miller, J.T. (2008). An empirical evaluation of the System Usability Scale. *International Journal of Human-Computer Interaction, 24*(6), 574-594.

Barth, M., & Boriboonsomsin, K. (2008). Real-World CO2 Impacts of Traffic Congestion. *Transportation Research Record*(2058), 163-171.

Baskar, L.D., Schutter, B.D., Hellendoorn, J., & Papp, Z. (2011). Traffic control and intelligent vehicle highway systems: A survey. *IET Intelligent Transportation Systems, 5*(1), 38-52.

BBC News. (2010). from http://news.bbc.co.uk/1/hi/wales/south_east/8441918.stm

Beers, T.M., & Folds, D.J. (1996). *An Evaluation of Monitor Viewing Distance for Text and Video Interpretation Tasks*. Paper presented at the The Third World Congress on Intelligent Transport Systems, Orlando, FL.

Bertini, R.L., Monsere, C.M., & Yin, T. (2005). Benefits of Intelligent Transport Systems Technologies in Urban Areas: A Literature Review. Portland, OR: Portland State University.

Bevelas, A. (1948). A mathematical model for group structure. *Applied Anthropology, 7*, 16-30.

Brooke, J. (1996). A "quick and dirty" usability scale. In P. W. Jordan, B. Thomas, B. A. Weerdmeester & I. L. McClelland (Eds.), *Usability evaluation in industry* (pp. 189-194). London: Taylor & Francis.

Brown, S. (1997). ROMANSE Public Transport Information Systems. *Journal of Navigation, 50*(1), 14-26.

Burke, S.C. (2005). Team task analysis. In N. A. Stanton, A. Hedge, K. Brookhuis & E. Salas (Eds.), *Handbook of Human Factors and Ergonomics Methods*. London: CRC.

Burns, C.M., & Hajdukiewicz, J.R. (2004). *Ecological Interface Design*. Boca Raton, FL: CRC Press.

Burns, C.M., Skraning, G., Jamieson, G.A., Lau, N., Kwok, J., Welch, R., & Anderson, G. (2008). Evaluation of ecological interface design for nuclear process control: situation awareness effects. *Human Factors, 50*(4), 663-679.

Chang, Y. C., Williams, G., & Hsu, C. J. (2009). An Ongoing Process: A Review of the Open Skies Agreements between the European Union and the United States. *Transport Reviews, 29*(1), 115-127. doi: 10.1080/01441640802196293

Chorus, C. G., Molin, E. J. E., & Van Wee, B. (2006). Use and effects of Advanced Traveller Information Services (ATIS): A review of the literature. *Transport Reviews, 26*(2), 127-149. doi: 10.1080/01441640500333677

Civil Aviation Authority. (2012). Airspace Structure. Retrieved November 8, 2012, from http://www.caa.co.uk/default.aspx?catid=2392&pagetype=90

Civil Aviation Authority Safety Regulation Group. (2012a). Flight Crew Licensing: Mandatory Requirements, Policy and Guidance. Norwich: Civil Aviation Authority.

Civil Aviation Authority Safety Regulation Group. (2012b). Manual of Air Traffic Services Part 1. Norwich: Civil Aviation Authority.

Cloke, J., & Layfield, R.E. (1996). *The environmental impacts of traffic management schemes*. Paper presented at the Urban Transport and the Environment for the 21st Century II, Barcelona. http://library.witpress.com/pages/PaperInfo.asp?PaperID=9533

Cloud Amber. (2012). Argonaut Product Specification. Bristol.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*. New York, NY: Routledge Academic.

Commission of the European Communities. (2006). Keep Europe Moving - Sustainable mobility for our continent. Brussels: European Commission.

Commission of the European Communities. (2009). Strategic goals and recommendations for the EU's maritime transport policy until 2018. Brussels: European Commission.

Commission of the European Communities. (2011a). Roadmap to a single European transport area - towards a competitive and resource efficient transport system [White Paper]. Brussels: European Commission.

Commission of the European Communities. (2011b). The European Aviation Safety Programme. Brussels: European Commission.

Commission of the European Communities. (2012). Single European Sky. Retrieved December 13, 2012, from http://ec.europa.eu/transport/modes/air/single_european_sky/

Cook, R., & Woods, D. (2006). Distancing through differencing: An obstacle to organisational learning following incidents. In E. Hollnagel, D. Woods & N. Leveson (Eds.), *Resilience Engineering: Concepts and Precepts*. Aldershot: Ashgate.

Coon, V.E., & Folds, D.J. (1996). *A Comparison of Manual, Preset, and Hybrid Remote Camera Control Configurations in a Traffic Management Centre Simulator*. Paper presented at the The Third World Congress on Intelligent Transport Systems, Orlando, FL.

Cooper, T. (2004). *Journey time monitoring by ANPR, and the implications of larger scale systems*. Paper presented at the 12th IEE International Conference on Road Transport Information & Control, London.

Corbet, A.G. (1992). Towards global marine traffic control - The need, the technical feasibility, and the social and political impediments. *Journal of Navigation, 45*(3), 425-439.

Curchod, A., & Genête, M. (2002). *OPTIRAILS: Optimisation of traffic through the European rail traffic management systems*. Paper presented at the Swiss Transport Research Conference, Ascona.

Davey, E. (2012). *Rail Traffic Management Systems (TMS)*. Paper presented at the Railway and Signalling and Control Systems, London.

de Carvalho, P.V.R., Gomes, J.O., Huber, G.J., & Vidal, M.C. (2009). Normal people working in normal organizations with normal equipment: system safety and cognition in a mid-air collision. *Applied Ergonomics, 40*(3), 325-340.

Dennis, C. (2004). *Development and use of the UK railway network's Safety Risk Model*. Godalming: Springer-Verlag.

Department for Transport. (2011). National Travel Survey: Statistical Release. London: DfT.

Department for Transport. (2012a). Driver Certificate of Professional Competence (CPD) for lorry, bus, and coach drivers. Retrieved November 14, 2012, from http://www.gov.uk/driver-certificate-of-professional-competence-cpc/overview

Department for Transport. (2012b). Road Transport Forecasts 2011; Results from the Department for Transport's National Transport Model. London: Department for Transport.

Department for Transport. (2013). Safety at street works and road works: a code of practice 2013.

Desai, P., Loke, S.W., Desai, A., & Singh, J. (2011). *Multi-Agent Based Vehicular Congestion Management.* Paper presented at the IEEE Intelligent Vehicles Symposium (IV), Baden-Baden.

Devoe, D.B., Abernathy, C.N., Royal, J.W., Kearns, K.J., & Rudlich, R.A. (1979). Vessel Traffic Service Watchstander Performance in Routine Operations. Washington D.C.: U.S. Coast Guard, Office of Research and Development.

Driskell, J.E., & Mullen, B. (2005). Social network analysis. In N. A. Stanton, A. Hedge, E. Salas, H. Hendrick & K. Brookhaus (Eds.), *Handbook of Human Factors and Ergonomics Methods*. London: Taylor & Francis.

Drivalou, S. (2005). *Supporting critical operational conditions in an electricity distribution control room through ecological interfaces.* Paper presented at the 2005 annual conference on European association of cognitive ergonomics.

Driver Vehicle Licensing Agency. (2012). Your photocard driving license explained. Retrieved December 10, 2012, from http://www.dft.gov.uk/dvla/forms/~/media/pdf/leaflets/INF45.ashx

Dudek, C.L., Huchingson, R.D., Stockton, W.R., Koppa, R.J., Richards, S.H., & Mast, T.M. (1978). Human Factors Requirements for Real-time Motorist Information Displays. Vol 1 - Design Guide. Washington D.C.: Federal Highway Administration.

Durugbo, C. (2012). Work domain analysis for enhancing collaborative systems: a study of the management of Microsystems design. *Ergonomics, 53*(2), 145-148.

Eddington, R. (2006). The Eddington Transport Study. London: Department for Transport.

Effken, J.A. (2006). Improving clinical decision-making through Ecological Interfaces. *Ecological Psychology, 18*, 283-318.

Elix, B., & Naikar, N. (2008). *Designing safe and efficient future systems: A new approach for modelling decisions in future systems with Cognitive Work Analysis.* Paper presented at the 8th International Symposium of the Australian Aviation Psychology Association Sydney, Australia.

Ellerbroek, J., Brantegem, K.C.R., van Paassen, M.M., & Mulder, M. (2013). Design of a Coplanar Airborne Seperation Display. *IEEE Transactions on Human-Machine Systems, 43*(3).

Endsley, M.R. (1995). Towards a theory of situational awareness in dynamic-systems. *Human Factors, 37*(1), 32-64. doi: 10.1518/001872095779049543

Evans, J.E., Weber, M.E., & Moser, W.R. (2006). Integrating advanced weather forecast technologies into air traffic management decision support. *Lincoln Laboratory Journal, 16*(1), 81-96.

Everall, P.F. (1972). *Urban Freeway Surveillance and Control: The State of the Art*. Washington, D.C.: Federal Highway Administration.

Farrington-Darby, T., Wilson, J.R., Norris, B.J., & Clarke, T. (2006). A naturalistic study of railway controllers. *Ergonomics, 49*(12-13), 1370-1394.

Folds, D.J., Brooks, J., Stocks, D., Fain, W., Courtney, T., & Blankenship, S. (1993). *Functional Definition of an Ideal Traffic Management System*. Atlanta: Georgia Tech Research Institute.

Folds, D.J., & Fain, W.B. (1997). *On whether to allow computers to post traffic advisory messages without operator approval.* Paper presented at the 41st Annual Meeting of the Human Factors and Ergonomics Society, Albuquerque, NM.

Garabet, A., & Burns, C.M. (2004). *Collaboration with ecological interface design.* Paper presented at the 48th Annual Meeting of the Human Factors and Ergonomics Society.

Greenbaum, J., & Kyng, M. (1991). *Design at work: Cooperative design of computer systems*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Griffin, T.G.C., Young, M.S., & Stanton, N.A. (2010). Investigating accident causation through information network modelling. *Ergonomics, 53*(2), 198-210.

Grundmann, K. (1996). *Free flight: Air traffic control evolution or revolution.* Paper presented at the Air Traffic Control Technologies II Conference, Orlando, FL.

Hale, A.R., Guldenmund, F., & Goossens, L. (2006). Auditing resilience in risk control and safety management systems. In E. Hollnagel, D. Woods & N. Leveson (Eds.), *Resilience Engineering: Concepts and Precepts*. Aldershot: Ashgate.

Hale, A.R., Guldenmund, F.W., Goossens, L.H.J., Karczewski, J., Duijm, N.J., Hourtolou, D., . . . Gerbec, M. (2005). *Management influences on major hazard prevention: The ARAMIS audit*. Paper presented at the ESREL conference on safety & reliability, Gdynia.

Hale, A.R., & Heijer, T. (2006). Is resilience really necessary? The case of railways. In E. Hollnagel, D. Woods & N. Leveson (Eds.), *Resilience Engineering: Concepts and Precepts*. Aldershot: Ashgate.

Harris, D. (2004). *Human factors for civil flight deck design*. Burlington, VT: Ashgate.

Harris, D., & Stanton, N.A. (2010). Aviation as a system of systems. *Ergonomics, 53*(6), 603-620.

Hart, S.G., & Staveland, L.E. (1988). Development of NASA-TLX task load index results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human Mental Workload*. Amsterdam, Netherlands: North Holland Press.

Heinrich, H.W. (1931). *Industrial accident prevention*. New York, NY: McGraw-Hill.

Highways Agency. (2009). Highways Agency Network Management Manual: Part 7 - Traffic Incident Management and Contingency Planning. London: Highways Agency.

Highways Agency. (2012). Our Network. Retrieved January 15, 2013, from http://www.highways.gov.uk/our-road-network/our-network/

Hilliard, A., & Jamieson, G.A. (2007). *Ecological interface design for solar car strategy: From state equations to visual relations*. Paper presented at the 2007 IEEE International Conference on Systems, Man and Cybernetics.

Hollnagel, E. (2004). *Barriers and accident prevention*. Aldershot, UK: Ashgate.

Hollnagel, E. (2012). *FRAM: The functional resonance analysis method for modelling complex socio-technical systems*. Farnham, UK: Ashgate.

Hollnagel, E., & Fujita, Y. (2013). The Fukushima Disaster - Systemic failures as a lack of resilience. *Nuclear Engineering and Technology, 45*(1), 13-20.

Hollnagel, E., Paries, J., Woods, D., & Wreathall, J. (2011). *Resilience engineering in practice: A guidebook*. Farnham, UK: Ashgate.

Hollnagel, E., & Woods, D. (2006). Epilogue: Resilience Engineering Concepts and Precepts. In E. Hollnagel, D. Woods & N. Leveson (Eds.), *Resilience Engineering: Concepts and Precepts*. Aldershot: Ashgate.

Hopkin, D.V. (1989). Man-Machine Interface Problems in Designing Air Traffic Control Systems. *Proceedings of the IEEE, 77,* 1634-1642.

Hopkin, D.V. (1995). *Human Factors in Air Traffic Control*. UK: Burgess Science Press.

Houghton, R.J., Baber, C., McMaster, R., Stanton, N.A., Salmon, P.M., Stewart, R., & Walker, G.H. (2006). Command and control in emergency services operations: A social network analysis. *Ergonomics, 49*(12&13), 1204-1225.

House of Commons Transport Committee. (2011). Keeping the UK moving: The impact on transport of the winter weather in December 2010. London: The House of Commons.

Hsieh, M.C., Chiu, M.C., & Hwang, S.L. (2014). An interface redesign for the feed-water system of the advanced boiling water reactor in a nuclear power plan in Taiwan. *Journal of Nuclear Science and Technology, 51*(5), 720-729.

Hunt, P.B., Robertson, D.I., Bretherton, R.D., & Winton, R.I. (1981). SCOOT - a traffic responsive method of coordinating signals: Transport Research Laboratory.

Hutchins, E. (1995). *Cognition in the Wild*. Cambridge, MA: MIT Press.

Inoue, S., Furuta, K., Nakata, K., Kanno, T., Aoyama, H., & Brown, M. (2012). Cognitive process modelling of controllers in en route air traffic control. *Ergonomics, 55*(4), 450-464.

International Maritime Organization. (1974). International Convention for the Safety of Life At Sea.

International Maritime Organization. (2012). Vessel Traffic Services. from http://www.imo.org/ourwork/safety/navigation/pages/vesseltrafficservices.aspx

Ip, W.H., & Wang, D. (2011). Resilience and Friability of Transportation Networks: Evaluation, Analysis and Optimisation. *IEEE Systems Journal, 5*(2), 189-198.

Jamieson, G.A. (2002). *Empirical evaluation of an inductrial application of ecological interface design.* Paper presented at the 46th Annual Meeting of the Human Factors and Ergonomics Society.

Jamieson, G.A. (2007). Ecological interface design for petrochemical process control: an empirical assessment. *Ieee Transactions on Systems, Man and Cybernetics - Part A Systems and Humans, 37*(6), 906-920.

Jamieson, G.A., Reising, D.V.C., & Hajdukiewicz, J.R. (2001). EID design rationale project: Case study report. Toronto, ON.

Jenkins, D.P., Salmon, P.M., Stanton, N.A., Walker, G.H., & Rafferty, L. (2011). What could they have been thinking? How sociotechnical system design influences cognition: a case study of the Stockwell shooting. *Ergonomics, 54*(2), 103-119. doi: 10.1080/00140139.2010.539706

Jenkins, D.P., Stanton, N.A., Salmon, P.M., & Walker, G.H. (2011). A formative approach to developing synthetic environment fidelity requirements for decision-making training. *Applied Ergonomics, 42*(5), 757-769.

Jenkins, D.P., Stanton, N.A., Salmon, P.M., Walker, G.H., & Rafferty, L. (2010). Using the Decision-Ladder to Add a Formative Element to Naturalistic Decision-Making Research. *International Journal of Human-Computer Interaction, 26*(2-3), 132-146.

Jenkins, D.P., Stanton, N.A., Salmon, P.M., Walker, G.H., & Young, M.S. (2008). Using cognitive work analysis to explore activity allocation within military domains. *Ergonomics, 51*(6), 798-815.

Jenkins, D.P., Stanton, N.A., Salmon, P.M., Walker, G.H., Young, M.S., Whitworth, I., . . . Hone, T.G. (2007). The development of a cognitive work analysis tool. In D. Harris (Ed.), *Engineering Psychology and Cognitive Ergonomics* (pp. 504-511). Berlin: Springer.

Jenkins, D.P., Stanton, N.A., Walker, G.H., & Salmon, P.M. (2009). *Cognitive Work Analysis: coping with complexity*. Aldershot: Ashgate.

Jhaveri, C.S., Perrin, J., & Martin, P.T. (2003). *SCOOT Adaptive Signal Control: An Evaluation of its Effectiveness over a Range of Congestion Intensities*. Paper presented at the Transportation Research Board.

Jolliffe, I.T. (1986). *Principle Component Analysis*. New York, NY: Springer-Verlag.

Kelly, M.J. (1995). *Human Factors Handbook for Advanced Traffic Management*. Atlanta, GA: Georgia Tech Research Institute.

Kelly, M.J. (1999). Human Factors Guidelines for Traffic Management Centres. McLean, VA: Federal Highway Administration.

Kelly, M.J., & Folds, D.J. (1998). The Advanced Traffic Management Centre. In W. Barfield & T. A. Dingus (Eds.), *Human factors in intelligent transportation systems* (pp. 165-186). Mahwah, NJ: Erlbaum Lawrence Associates.

Kilgore, R., & St-Cyr, O. (2006). *SRK Inventory: A tool for Structuring and Capturing Worker Competencies Analysis.* Paper presented at the Human Factors and Ergonomics Society 50th Annual Meeting.

Kilgore, R., St-Cyr, O., & Jamieson, G.A. (2009). From work domains to worker competencies: a five-phase CWA. In A. M. Bisantz & C. M. Burns (Eds.), *Applications of Cognitive Work Analysis* (pp. 15-47). Boca Raton, FL: CRC Press.

Kirk, R.E. (1995). *Experimental Design: Procedures for the Behavioural Sciences, 3rd ed.* Pacific Grove, CA: Brooks/Cole.

Klein, G., & Armstrong, A.A. (2005). Critical decision method. In N. A. Stanton, A. Hedge, K. Brookhuis & E. Salas (Eds.), *Handbook of Human factors and ergonomics methods*. London: CRC.

Knapp, Sabine, & Franses, Philip Hans. (2010). Comprehensive Review of the Maritime Safety Regimes: Present Status and Recommendations for Improvements. *Transport Reviews, 30*(2), 241-270. doi: 10.1080/01441640902985934

Knight, P., & Emmerson, P. (2008). PCMOVA, SCOOT and VISSIM. *Traffic Software News, 46*. Retrieved from www.trl.co.uk website: http://www.trl.co.uk/media/55322/TSN46.pdf

Lau, N., & Jamieson, G.A. (2006). *Ecological interface design for the condenser subsystems of a boiling water reactor.* Paper presented at the 27th Annual Conference of the Canadian Nuclear Society.

Lau, N., Jamieson, G.A., Skraaning, Jr, & Burns, C.M. (2008). Ecological interface design in the nuclear domain: An empirical evaluation of ecological displays for the secondary subsystems of a boiling water reactor plant simulator. *IEEE Transactions on Nuclear Science, 55*(6), 3597-3610.

Lau, N., Veland, Ø, Kwok, J, Jamieson, G.A., Burns, C.M., Braseth, A.O., & Welch, R. (2008). Ecological Interface Design in the Nuclear Domain: An application to the Secondary Subsystems of a Boiling Water Reactor Plant Simulator. *IEEE Transactions on Nuclear Science, 55*(6), 3579-3596.

Leavitt, H.J. (1951). Some effects of certain communication patterns on group performance. *Journal of Abnormal and Social Psychology, 46*, 38-50.

Lee, J.D., Hoffman, J.D., Stoner, H.A., Seppelt, B.D., & Brown, M.D. (2006). *Application of ecological interface design to driver support systems.* Paper presented at the IEA 2006: World Congress on Ergonomics.

Lee, J.D., & Moray, N. (1992). Trust, control strategies and allocation of function in human machine systems. *Ergonomics, 35*, 1243-1270.

Lee, S.W., Nam, T.S., & Myung, R. (2008). *Work Domain Analysis (WDA) for Ecological Interface Design (EID) of vehicle control display*. Paper presented at the 9th WSEAS International Conference on AUTOMATION and INFORMATION (ICAI'08).

Leveson, N. (2004). A new accident model for engineering safer systems. *Safety Science, 42*(4), 237-270.

Leveson, N., Dulac, N., Zipkin, D., Cutcher-Gershenfeld, J, Carroll, J.M., & Barrett, B. (2006). Engineering resilience in safety-critical systems. In E. Hollnagel, D. Woods & N. Leveson (Eds.), *Resilience Engineering: Concepts and Precepts*. Aldershot: Ashgate.

Maritime and Coastguard Agency. (2012). MIN 434 (M) Boatmasters' Licence Regulations: General Exemption: Department for Transport.

McDonald, N. (2006). Organisational Resilience and Industrial Risk. In E. Hollnagel, D. Woods & N. Leveson (Eds.), *Resilience Engineering: Concepts and Precepts*. Aldershot, UK: Ashgate.

McIlroy, R.C., & Stanton, N.A. (2011). Getting past first base: Going all the way with Cognitive Work Analysis. *Applied Ergonomics, 42*(2), 358-370.

McIlroy, R.C., & Stanton, N.A. (2015). Ecological Interface Design Two Decades On: Whatever Happened to the SRK Taxonomy *IEEE Transactions on Human-Machine Systems, 45*(2), 145-163.

Mendonca, D. (2008). Measures of Resilient Performance. In E. Hollnagel, C. P. Nemeth & S. Dekker (Eds.), *Resilience Engineering Perspectives: Remaining Sensitive to the Possibility of Failure* (Vol. 1, pp. 29-47). Aldershot, UK: Ashgate.

Mendoza, P., Angelelli, A., & Lindgren, A. (2011). Ecological interface design inspired human machine interface for advanced driver assistance systems. *IET Intelligent Transportation Systems, 5*(1), 53-59.

Mitta, D.A., Folds, D.J., Fain, W.B., & Beers, T.M. (1997). *Traffic Management Centre Operators: A capabilities investigation*. Paper presented at the 41st Annual Meeting of the Human Factors and Ergonomics Society, Albuquerque, NM.

Mitta, D.A., Kelly, M.J., & Folds, D.J. (1996). Design of an ITS-Level Advanced Traffic Management System: A Human Factors Perspective. Atlanta: Georgia Institute of Technology.

Mumaw, R.J., Roth, E.M., Vicente, K.J., & Burns, C.M. (2000). There is more to monitoring a nuclear power plant than meets the eye. *Human Factors, 42*(1), 36-55.

Murray, J., & Liu, Y. (1997). Hortatory Operations in Highway Traffic Management. *IEEE Transactions on Systems, Man and Cybernetics Part A: Systems and Humans, 27*, 340-350.

Naikar, N. (2011). Cognitive Work Analysis: Foundations, Extensions and Challenges. Fishermans Bend, Australia: Defence Science and Technology Organisation.

Naikar, N., Hopcroft, R., & Moylan, A. (2005). *Work domain analysis: theoretical concepts and methodology*. Canberra: Defence Science and Technology Organisation.

Naikar, N., Moylan, A., & Pearce, B. (2006). Analysing activity in complex systems with cognitive work analysis: concepts, guidelines and case study for control task analysis. *Theoretical Issues in Ergonomics Science, 7*(4), 371-394.

NATO. (2006). SAS-050 Exploring new command and control concepts and capabilities: final report.

Norman, D.A. (1990). The 'problem' with automation: inappropriate feedback and interaction, not 'over-automation'. *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences, 327*, 585-593.

Nottingham City Council. (2013). Nottingham Travelwise. Retrieved 02/12/13, 2013, from www.itsnottingham.info/about.aspx

Nottingham Traffic Control Centre. (1997). SCOOT Evaluation - A Comparative Study: Nottingham University Transportation Group.

Nowakowski, C., Green, P., & Kojima, M. (1999). Human Factors in Traffic Management Centres: A Literature Review. Ann Arbor: University of Michigan Transportation Research Institute

Office for National Statistics. (2011). UK population projected to reach 70 million by mid-2027. Newport: ONS.

Office of Rail Regulation. (2008). Promoting safety and value in Britain's railways: Our strategy for 2009-2014. London: ORR.

Office of Rail Regulation. (2010). Train Driving Licenses and Certificates Regulations. London: ORR.

Page, L., Brin, S., Motwani, R., & Winograd, T. (1998). The PageRank Citation Ranking: Bringing Order to the Web. Stanford, CA: Stanford InfoLab.

Parasuraman, R. (1997). Humans and Automation: Use, Misuse, Disuse, Abuse. *Human Factors, 39*, 230-253.

Parasuraman, R., Sheridan, T.B., & Wickens, C.D. (2000). A Model for Types and Levels of Human Interaction with Automation. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans, 30*(3), 286-297.

Pasman, H.J., Knegtering, B., & Rogers, W.J. (2013). A holistic approach to control process safety risks: Possible ways forward. *Reliability Engineering and System Safety, 117*, 21-29.

Payne, V. (1981). Unjamming the jams: Scoot gets on the road. *Computing, 9*(20), 28-29.

Perrow, C. (1984). *Normal Accidents: Living with High-Risk Technologies*. New York: Basic Books.

Prinzo, O.V. (2004). Automatic dependent surveillance - Broadcast/cockpit display of traffic information: Innovations in pilot-managed departures. *International Journal of Aviation Psychology, 14*(2), 171-189. doi: 10.1207/s15327108ijap1402_4

Rasmussen, J. (1974). The Human Data Processor as a System Component: Bits and Pieces of a Model. Roskilde, Denmark: Danish Atomic Energy Commission.

Rasmussen, J. (1983). Skills, Rules, and Knowledge - Signals, Signs, and Symbols, and other distinctions in human-performance models. *IEEE Transactions on Systems, Man and Cybernetics, 13*(3), 257-266.

Rasmussen, J. (1985). The role of hierarchical knowledge representation in decision-making and system management. *IEEE Transactions on Systems, Man and Cybernetics, 15*(2), 234-243.

Rasmussen, J. (1986). *Information Processing and Human-machine Interaction: an Approach to Cognitive Engineering*. New York, NY: North-Holland.

Rasmussen, J., Pejtersen, A., & Goodstein, L.P. (1994). *Cognitive systems engineering*. New York, NY: Wiley.

Rasmussen, J., & Vicente, K.J. (1989). Coping with human errors through system design - Implications for Ecological Interface Design *International Journal of Man-Machine Studies, 31*(5), 517-534. doi: 10.1016/0020-7373(89)90014-x

Reason, J.T. (1990). *Human Error*. Cambridge, UK: Cambridge University Press.

Reising, D. (2000). *The abstraction hierarchy and its extension beyond process control*. Paper presented at the Joint 14th triennial congress of the International Ergonomics Association/44th annual meeting of the Human Factors and Ergonomics Society (IEA 2000/HFES 2000), San Diego, CA.

Reising, D.V.C., & Sanderson, P.M. (2004). Minimal instrumentation may compromise failure diagnosis with an ecological interface. *Human Factors, 46*(1), 316-333.

Robertson, D.I. (1969). TRANSYT: A Traffic Network Study Tool. Wokingham: Transport Research Laboratory.

Rodrigues de Carvalho, P.V. (2011). The use of Functional Resonance Analysis Method (FRAM) in a mid-air collision to understand some characteristics of the air traffic management system resilience. *Reliability Engineering and System Safety, 96*(11), 1482-1498.

Salmon, P.M., Stanton, N.A., Walker, G.H., Jenkins, D., Baber, C., & McMaster, R. (2008). Representing situation awareness in collaborative systems: A case study in the energy distribution domain. *Ergonomics, 51*(3), 367-384.

Sanderson, P.M., Anderson, J., & Watson, M.O. (2000). *Extending Ecological Interface Design to Auditory Displays.* Paper presented at the 2000 Annual Conference of the Computer-Human Interaction Special Interest Group (CHISIG) of the Ergonomics Society of Australia (OzCHI2000).

Schuler, D., & Namioka, A. (1993). *Participatory Design: Principles and Practices*. Hillsday, NJ: Lawrence Erlbaum Associates, Inc.

Seppelt, B.D., & Lee, J.D. (2007). Making adaptive cruise control (ACC) limits visible. *International Journal of Human-Computer Studies, 65*(3), 192-205.

Seppelt, B.D., Lees, M.N., Lee, J.D., Stoner, H., Brown, M., & Hoffman, J.D. (2005). Integrating ecological interface design into the engineering process for vehicles *Nissan Final Report, Year 3*. Iowa City.

Sheridan, T.B., & Verplanck, W.L. (1978). *Human and computer control of undersea teleoperators*. Cambridge, MA: MIT Man-Machine Laboratory.

Shirali, Gh.A., Mohammadfam, I., & Ebrahimipour, V. (2013). A new method for quantitative assessment of resilience engineering by PCA and NT approach: A case study in the process industry. *Reliability Engineering and System Safety, 119*, 88-94.

Siemens. (2011). SCOOT user guide. Poole, UK.

Siemens. (2013). PC SCOOT: Urban traffic control system. Poole, UK.

Siemens. (2015). How SCOOT Works. Retrieved 11/12/2015, 2015, from http://www.scoot-utc.com/DetailedHowSCOOTWorks.php

Siemens Traffic Solutions. (2009). COMET: modular traffic management system. Poole.

Simpson, A., & Kamnitzer, D. (2010, 2010). *Operational challenges of managed motorways.* Paper presented at the IET Road Transport Information and Control Conference, London.

Stanton, N.A. (2014). Representing Distributed Cognition in Complex Systems: How a submarine returns to periscope depth. *Ergonomics, 57*(3), 403-418.

Stanton, N.A., & Baber, C. (2008). Modelling of human alarm handling response times: a case study of the Ladbroke Grove rail accident in the UK. *Ergonomics, 51*(4), 423-440. doi: 10.1080/00140130701695419

Stanton, N.A., Baber, C., & Harris, D. (2008). *Modelling Command and Control: Event Analysis of Systemic Teamwork*. Aldershot, UK: Ashgate.

Stanton, N.A., & Bessell, K. (2014). How a submarine returns to periscope depth: Analysing complex socio-technical systems using Cognitive Work Analysis. *Applied Ergonomics, 45*(1), 110-125.

Stanton, N.A., & McIlroy, R.C. (2012). Designing mission communication planning: the role of Rich Pictures and Cognitive Work Analysis. *Theoretical Issues in Ergonomics Science, 13*(2), 146-168.

Stanton, N.A., McIlroy, R.C., Harvey, C., Blainey, S., Hickford, A., Preston, J.M., & Ryan, B. (2013). Following the cognitive work analysis train of thought: exploring the constraints of modal shift to rail transport. *Ergonomics, 56*(3), 522-540.

Stanton, N.A., & Salmon, P.M. (2011). Planes, trains and automobiles: contemporary ergonomics research in transportation safety. *Applied Ergonomics, 42*(4), 529-532.

Stanton, N.A., Salmon, P.M., Walker, G.H., Baber, C., & Jenkins, D.P. (2005). *Human Factors Methods: A Practical Guide for Engineering and Design*. Aldershot: Ashgate.

Stanton, N.A., Walker, G.H., & Sorensen, L.J. (2012). It's a small world after all: contrasting hierarchical and edge networks in a simulated intelligence analysis task. *Ergonomics, 55*(3), 265-281.

Stanton, N.A., Walker, G.H., Young, M.S., Kazi, T., & Salmon, P.M. (2007). Changing drivers' minds: the evaluation of an advanced driver coaching system. *Ergonomics, 50*(8), 1209-1234. doi: 10.1080/00140130701322592

Stanton, N.A., Young, M.S., & Walker, G.H. (2007). The psychology of driving automation: a discussion with Professor Don Norman. *International Journal of Vehicle Design, 45*(3), 289-306.

Stocks, D.R., Folds, D.J., & Gerth, J.M. (1996). *Lessons Learned During Development of Simulated Support Systems for the TMC Operator*. Paper presented at the The Third World Congress on Intelligent Transport Systems, Orlando, FL.

Strong, Christopher K., Ye, Zhirui, & Shi, Xianming. (2010). Safety Effects of Winter Weather: The State of Knowledge and Remaining Challenges. *Transport Reviews, 30*(6), 677-699. doi: 10.1080/01441640903414470

Sud, V.P., Tanino, M., Wetherly, J. , Brennan, M. , Lehky, M., Howard, K. , & Oiesen, R. (2009). Reducing Flight Delays Through Better Traffic Management. *Interfaces, 39*(1), 35-45.

Technical Committee 16 Network Operations. (2006). ITS Handbook 2nd Edition: Recommendations from the World Road Association. Kent.

Torenvliet, G.L., Jamieson, G.A., & Vicente, K. J. (2000). Making the most of ecological interface design: the role of individual differences. *Applied Ergonomics, 31*(4), 395-408.

Transport Research Knowledge Centre. (2009). Traffic Management for Land Transport. Brussels: Prepared for the Directorate General for Energy and Transport, European Commission

United Nations Regional Commission. (2010). Improving Global Road Safety: Setting Regional and National Road Traffic Casualty Reduction Targets. Geneva: UN.

Van Dam, S.B.J., Mulder, M., & Van Paassen, M.M. (2006). *Ecological Interface Design for Vessel Traffic Management: A Theoretical Overview*. Delft: Delft University of Technology.

Van Dam, S.B.J., Steens, C.I.A., Mulder, M., & Van Paasen, M.M. (2008). *Evaluation of two pilot self-seperation displays using conflict situation measurements*. Paper presented at the IEEE International Conference on Systems, Man and Cybernetics, Singapore.

van Marwijk, B.J.A., Borst, C., Mulder, M., & van Paasen, M.M. (2011). The International Journal of Supporting 4D Trajectory Revisions on the Flight Deck: Design of a Human-Machine Interface. *International Journal of Aviation Psychology, 21*(1), 35-61.

Vicente, K.J. (1996). Improving dynamic decision-making in complex systems through ecological interface design: A research overview. *System Dynamics Review, 12*(4), 251-279.

Vicente, K.J. (1999). *Cognitive Work Analysis: Toward Safe, Productive, and Healthy Computer-Based Work*. Mahwah, NJ: Lawrence Erlbaum Associates.

Vicente, K.J. (2002). Ecological Interface Design: Progress and challenges. *Human Factors, 44*(1), 62-78.

Vicente, K.J., & Rasmussen, J. (1992). Ecological Interface Design - Theoretical Foundations. *IEEE Transactions on Systems, Man and Cybernetics, 22*(4), 589-606. doi: 10.1109/21.156574

Visser, J.P.F., & Klijnhout, J.J. (1998). *Traffic management: State of the art and future trends*. Leiden: A.A. Balkema

VTS Committee. (2008). Vessel Traffic Services Manual, 4th Edition. Saint Germain en Laye: International Association of Marine Aids to Navigation and Lighthouse Authorities.

Walker, G.H., Gibson, H., Stanton, N.A., Baber, C., Salmon, P., & Green, D. (2006). Event analysis of systemic teamwork (EAST): a novel integration of ergonomics methods to analyse C4i activity. *Ergonomics, 49*(12-13), 1345-1369.

Walker, G.H., Stanton, N.A., Baber, C., Wells, L., Gibson, H., Salmon, P.M., & Jenkins, D.P. (2010). From ethnography to the EAST method: A tractable approach for representing distributed cognition in Air Traffic Control. *Ergonomics, 53*(2), 184-197.

Walker, G.H., Stanton, N.A., Salmon, P.M., & Jenkins, D.P. (2008). A review of sociotechnical systems theory: a classic concept for new command and control paradigms. *Theoretical Issues in Ergonomics Science, 9*(6), 479-499.

Walker, G.H., Stanton, N.A., & Young, M.S. (2001). Where is computing driving cars? A technology trajectory of vehicle design. *International Journal of Human-Computer Interaction, 13*(2), 203-229.

Watts, D.J., & Strogatz, S.H. (1998). Collective dynamics of 'small world' networks. *Nature, 393*(4), 440-442.

Watts, L.A., & Monk, A.F. (1998). Reasoning about tasks, activities and technology to support collaboration. *Ergonomics, 41*(11), 1583-1606.

Weick, K.E., & Sutcliffe, K.M. (2001). *Managing the Unexpected*. San Francisco: Jossey Bass.

Weick, K.E., Sutcliffe, K.M., & Obstfeld, D. (1999). Organising for high reliability: Process of collective mindfulness. *Research in organisational behavior, 21*(13-81), 81-123.

Wickens, C.D., & Hollands, J.G. (2000). *Engineering psychology and human performance*. Saddle River (NJ): Prentice-Hall.

Wickens, C.D., Mavor, A.S., & McGee, J.P. (1997). *Flight to the Future, Human Factors in Air Traffic Control*. Washington, D.C.: National Academy Press.

Williams, B.M., & Guin, A. (2007). Traffic management center use of incident detection algorithms: Findings of a nationwide survey. *IEEE Transactions on Intelligent Transportation Systems, 8*(2), 351-358. doi: 10.1109/tits.2007.894193

Woods, D.D. (2006). Essential Characteristics of Resilience. In E. Hollnagel, D. Woods & N. Leveson (Eds.), *Resilience Engineering: Concepts and Precepts*. Aldershot, UK: Ashgate.

Woods, D.D., Johannesen, L.J., Cook, R.J., & N.B., Sarter. (1994). *Behind human error: Cognitive systems, computers, and hindsight*. Wright-Patterson Air Force Base, OH: Crew System Ergonomics Information Analysis Center.

World Health Organisation. (2013). Global Status Report on Road Safety 2013. Geneva: WHO.

Wreathall, J. (2006). Properties of resilient organisations: An initial view. In E. Hollnagel, D. Woods & N. Leveson (Eds.), *Resilience Engineering: Concepts and Precepts*. Aldershot, UK: Ashgate.

Young, M.S., Stanton, N.A., & Harris, D. (2007). Driving automation: learning from aviation about design philosophies. *International Journal of Vehicle Design, 45*, 323-338.