Performance variability: Black and white or shades of grey?

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Abstract. Road transport is a complex sociotechnical system prone to performance variability. Unfortunately, performance variability of road users is not well understood and methods do not provide sufficient means to provide understanding and manage performance variability in complex systems appropriately. This article demonstrates how this gap can be addressed using Cognitive Work Analysis and the recently purposefully developed Strategies Analysis Diagram. It is demonstrated how application in road transport provides understanding of performance variability. It outlines that even if system constraints are similar for all road users, road users can and will engage in different behavior and this is induced by their own characteristics and interaction with infrastructure, environment and other road users. It is further demonstrated how Cognitive Work Analysis and the Strategies Analysis Diagram can be used to evaluate behavior induced by new intersection designs before these are build in the real world. Such understanding can then be used to adequately manage performance variability.

1 INTRODUCTION

Road transport is a complex sociotechnical system (Larsson, Dekker & Tingvall, 2010; Salmon, McClure & Stanton 2012). Many components such as road users, vehicles, infrastructure and environment interact and circumstances and demands vary which makes it prone to performance variability. Performance variability of road users has, however, received limited attention and is not well understood (Larsson et al., 2010).

Unfortunately, few conceptual frameworks or modeling methods exist and complex sociotechnical systems lack the means to understand and manage performance variability. For example, the Functional Resonance Accident Model (FRAM; Hollnagel, 2004) and system dynamics (Kontogiannis, 2010) model the interaction of performance variability in the system. However, a *structured* approach to *identify* a wide range of performance variability *possible* remains absent (Cornelissen, Salmon, Jenkins & Lenné 2012). The Strategies Analysis Diagram (SAD; Cornelissen et al., 2012) has been developed to augment the Cognitive Work Analysis framework (CWA; Rasmussen, Pejtersen & Goodstein, 1994; Vicente, 1999) to model performance variability. This article will describe how CWA and SAD when used to model performance variability, provide an understanding of and support management of performance variability in complex sociotechnical systems such as road transport.

1.1 Cognitive Work Analysis

CWA is used to design and evaluate complex sociotechnical systems and comprises five phases, each modeling a different constraint set (Vicente, 1999). The first three phases will be applied here. First, Work Domain Analysis (WDA) models system constraints from physical objects to the functional purpose of the system. Second, Control Task Analysis (ConTA) models situational constraints and decision making processes. Third, Strategies Analysis (StrA) models potential ways in which activities can be carried out within these constraints.

2 UNDERSTANDING PERFORMANCE VARIABILITY

CWA and SAD can be used to provide understanding of performance variability in road transport. Using these methods the interaction of constraints and behavior will be described outlining how road users, vehicles, infrastructure and environment interact and subsequently road user’s behavior may vary.

2.1 System constraints

System constraints on performance variability can be described conducting a WDA. The functional purpose of a road transport system can for example be defined as supporting negotiation of intersections by road users. Values and priority measures include safety, positive subjective experience, reach desired end point, efficiency, compliance and keeping upright in case of two wheelers and pedestrians. Purpose related functions that have to be executed to achieve the functional purpose include, for example, monitor infrastructure, determine path, establish position at the lights, negotiate stop or go and avoid conflict with other road users. Physical objects in the system include road users, vehicles, road, traffic lights and weather conditions, for example. These afford object related processes such as show behavior, control vehicle, allow movement of traffic and affect vehicle performance. These aspects of the road transport system constrain performance variability possible. For example, road users can only engage with the objects provided and have to execute purpose related functions to achieve the purpose.

2.2 Situational constraints

Situational constraints on performance variability can be described using the ConTA phase of CWA and the Contextual Activity Template (CAT; Naikar, Moylan & Pearce, 2006) in particular. The CAT describes for each situation defined whether purpose related functions can and are likely to be employed. In road transport, situations can be defined as approach, at the intersection and exiting the intersection, for example, (Fastenmeier & Gstalter, 2007).

In road transport systems, and Melbourne intersections in particular, the spatial distribution of function execution is similar across road users. Pedestrians and cyclists using the footpath, however, do not execute functions such as determine and take lane, and the emphasis of function execution is on the approach and at the intersection, rather than upon exiting the intersection.

2.3 Decision making processes

Decision making processes can be analyzed using decision ladders which display information requirements, options for purpose related functions and task execution (Rasmussen, 1974). Here, information requirements and options are of interest.

Road users' information requirements are similar but differences exist. For example, all road users are concerned with the location of other road users and status of the traffic light. Drivers, motorcycle riders and cyclists are concerned with speed control and following lane markings. In addition, vulnerable two wheelers, motorcycle riders and cyclists, for example, enquire about car doors opening and road conditions ahead. Road users using the pedestrian facilities on the other hand are focused on locating pedestrian crossings and assessing the status of the activation light.

Performance variability is also shaped by different options road users have for execution of purpose related functions. These are influenced by the facilities road users use and their vehicle characteristics. For example, to establish a position at the traffic light, road users can position their vehicle at the stop line, traffic light sensor, behind or adjacent to other vehicles. In addition, two wheelers can filter to the front and position themselves in front of other vehicles. Cyclists and pedestrians can position themselves at the pedestrian lights.

2.4 Courses of actions

SAD can be used to define how the above constraints influence variability in road user behavior, see figure 1. SAD provides detailed descriptions of how system constraints can be used to achieve functional purpose, defined in WDA, and describes both information requirements and task execution, defined in the decision ladders. Such descriptions follow a syntax including the different levels of the SAD. For example, road users can 'assess vehicles directional heading' to ensure they are 'travelling in the same direction' or 'assess vehicles speed control' to 'avoid conflict with other road users' when establishing a position at the lights. Each pathway in SAD represents a possible course of action. Road users can employ multiple courses of actions in varying orders across situations and these can be discovered following the links in the diagram.

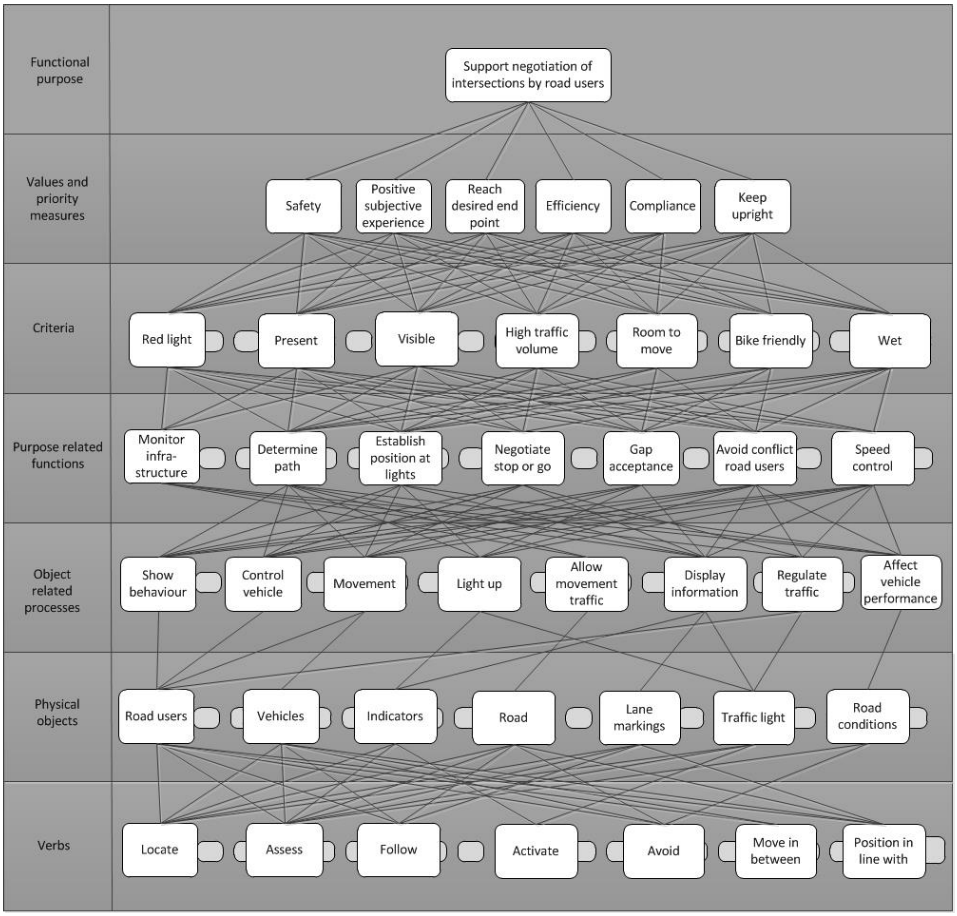

Fig. 1. Strategies Analysis Diagram highlights

Different road users can, for example, engage in different courses of action for the same function. For example, to decide whether to position behind other road users, drivers, motorcycle riders and cyclists may ‘assess road user movement and directional heading’. Motorcycle riders and cyclists, however may consider to position in front of other vehicles and can therefore engage in strategies such as ‘assess whether road users controlling vehicles in front appear friendly’ or are likely to ‘block access’.

The availability of physical objects also influences employment of courses of action. For example, if arrow lane markings are blocked by other traffic, ‘road users may assess indicators, recall information on the directional sign or anticipate information on the traffic light ahead’ to make up for the missing information.

Different courses of action may be employed in different circumstances as represented by criteria in SAD. For example, when motorcycle riders and cyclists assess road users in front to be unfriendly motorcycle riders and cyclists are likely to position their vehicle behind those road users. On the other hand, if road users appear friendly they may move in between and position their vehicle in front.

Different courses of action may also be employed when behavior is driven by different values and priority measures. For example, safety is likely to motivate road users to wait for the green light at pedestrian crossings whereas efficiency values may motivate a pedestrian to jay walk or cross mid block.

Different courses of action may also be the result of complementary or redundant courses of actions. For example, motorcycle riders positioning themselves behind other road users can position themselves in line with wheels or mirrors of the vehicle in front. Positioning in line with wheels prevents tripping over obstacles appearing from underneath but puts them in a blind spot while positioning in line with mirrors increases their visibility.

Therefore, different road users operating within the same system constraints can and will display different behavior based on their characteristics and interaction with other road users, vehicles, infrastructure and the environment. CWA and SAD provide comprehensive insight into constraints shaping variability in behavior of road users.

3 MANAGING PERFORMANCE VARIABILITY

To demonstrate how understanding of performance variability can help manage it, an evaluation of a future intersection design will be discussed next. The cut-through intersection, see figure 2, was designed (Corben et al., 2010) to make intersections safer. Traffic islands are placed in the middle of the intersection to separate turning and straight through traffic meeting at 90^0 angles and allow them to meet under more favorable angles in different parts of the intersection. Changes in road user behavior, induced by this new design, will be discussed next using CWA and SAD.

3.1 System constraints

From a system constraints perspective the cut-through intersection is not that dissimilar from a traditional Melbourne intersection. It aims to achieve the same functional purpose (support negotiation of intersection), is driven by the same values and priority measures (e. g. safety, efficiency, compliance) and the functions that have to be executed are the same (e.g. although gap acceptance has been removed in the middle of the intersection by creation of the cut-through lane the task still has to be executed elsewhere in the intersection). The main difference from a system constraint perspective is that the slip lane as an option to turn left has been removed and lane markings across have been replaced by traffic islands.

3.2 Situational constraints

The physical distribution of constraints through the intersection, situational constraints, do affect road user behavior differently. For example, traffic islands in the middle of the intersection remove the gap acceptance task there but create instances of gap acceptance when entering and exiting the intersection and cut through lane. The traffic island separating traffic entering the cut through lane from other traffic, ensures determining a path and lane occurs earlier on approach as changes cannot be made after the traffic island has been reached.

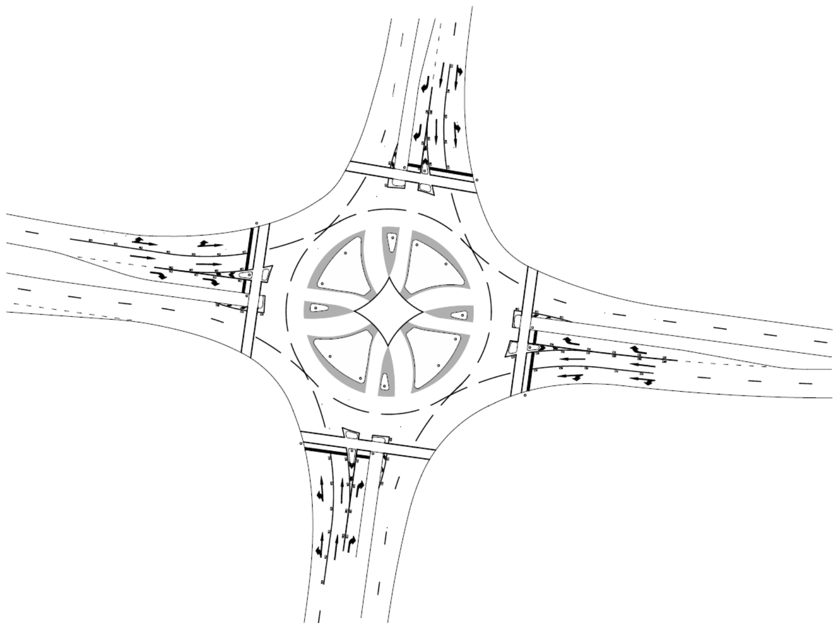

Figure 2. Cut-through intersection

3.3 Decision making processes

The decision to determine a path and lane to negotiate the intersection are positioned earlier on approach. Unfortunately, the information elements required, e.g. arrow lane markings, as determined in the decision ladders are not. Therefore information requirements are not satisfied by the new layout.

The layout creates new options to negotiate the intersection. More specifically, road users can use the intersection in a fashion similar to a roundabout and travel the long way around. Pedestrians and cyclists furthermore can use the traffic islands in the middle to cross the intersection diagonally.

3.4 Courses of actions

Changes in behavior will be induced by the design and were analyzed using SAD. For example, due to the removal of the slip lane, courses of action no longer include 'locate and enter slip lane' while courses of actions such as 'locate and follow lane markings' are replaced by 'locate and follow traffic islands'. Furthermore, traffic islands in the middle of the intersection 'divide and protect road users'. Therefore conflict avoidance and gap acceptance tasks will be easier. These changes will satisfy the values and priority measures of safety and efficiency. Those traffic islands also afford movement. Therefore when 'traffic volumes are low and speeds are low or traffic is stopped' and safety values are satisfied, pedestrians and cyclists may enter and exit the traffic islands in the middle to cross diagonally, motivated by efficiency values.

Road users can negotiate the intersection in a similar fashion to a roundabout and travel the long way around. Drivers' efficiency values will motivate them to use the cut-through lane. However, cyclists may find that this is a valid option depending on the situation. On approach, in addition to weighing of the many other options they have, they will have to decide whether they are going to use the cut through lane or use the intersection in a similar fashion to a roundabout. Therefore they may assess traffic, road and weather conditions to make such decision. This increases cyclists' workload and their unpredictability to other road users.

Altered traffic light positioning will also induce variability in road user behavior. In the cut-through lane, for example, road users will find an arrow light positioned upon exiting. A yellow or red light may cause road users to stop in the lane. However, as all directions of traffic will have to use the space in the middle this will block all traffic. Also, the designers do not intend road users to travel the long way around and therefore road users will not face a traffic light when facing traffic entering the intersection from the opposite direction. Therefore both streams of traffic have a green light and expect to have right of way, which may prove challenging.

Taking such changes in behavior into account is essential to understand how behavior is induced by design and can be managed adequately. For example, based on such evaluation cyclists can be provided with a dedicated facility which removes the many path options and therefore the decision making workload and unpredictability of these road users. Also information elements, such as arrows, used to determine a path and lane can be positioned earlier on approach to accompany the new decision point.

4 DISCUSSION AND CONCLUSIONS

This article aimed to demonstrate the value of CWA and SAD to model performance variability to improve understanding and to better manage performance variability. The application in road transport demonstrated that using such a low cost desktop approach, it can be easily assessed how designs induce different behavior for different road users, whether current systems support all road users and the interaction between them, whether additional support should be provided, reveal whether timely, redundant and complementary information elements are provided, consider road users as part of the design and assess whether performance variability with positive outcomes is encouraged and negative outcomes are discouraged. It provides insight into the interaction of a wide range of variables and provides insight into what, why, when, where, and who will be in conflict in road transport systems. Designing based on such understanding to manage performance variability will deliver holistic solutions. It is therefore argued here that the use of CWA and SAD to model performance variability to understand and manage performance variability should be explored further.

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