UNIVERSITY OF SOUTHAMPTON

MODELLING

INTELLIGENT TRANSPORT SYSTEMS APPLICATIONS

FOR

PUBLIC TRANSPORT

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ABSTRACT

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MODELLING INTELLIGENT TRANSPORT SYSTEM APPLICATIONS FOR PUBLIC TRANSPORT

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The need for enhancing public transportation is widely accepted as a means to alleviate the problems of traffic congestion and pollution associated with growth in transportation. Bus services provide a significant proportion of public transport trips in urban areas however its patronage is declining in may cases due to a perceived poor level of service relative to other modes. This has led to a range of initiatives to enhance bus services. In recent years new technologies in form of Intelligent Transport Systems Applications (ITS) have been increasingly used in public transport with varying degree of success. The techniques generally used to evaluate the impacts of these measures on public transport, such as 'before and after' studies and surveys, are limited in scope for pre-implementation evaluations. To assist the decision-makers, appropriate appraisal methodologies are required to assess the impacts of these measures in bus services for further implementation.

This research has explored the impacts and benefits of selected ITS measures in bus service networks in an urban area. It outlines the probable influencing parameters and critically reviews the evaluation techniques used to assess the impacts of these measures. A state-of-the-art review of modelling has been undertaken to outline the requirements for effective modelling of impacts of selected ITS measures in public transportation. The research has then illustrated the operational impacts of these measures using a modelling framework incorporating two transport modelling packages, TRIPS and SPLIT, which has been used in a series of case studies. Assumptions used in the evaluation framework were based on previous studies and surveys. The survey data was also used to develop a rigorous method of calculating the average waiting time at bus stops.

The literature review has shown that application-specific evaluation techniques are often required due to the variation in impacts and influencing parameter of different ITS measures. Current modelling, whilst useful, has limitations in their structure and functions. Any pre-implementation evaluation framework used needs to be an integrated modelling tool, which can simulate temporal and dynamic behavioural responses of users to these measures and the potential impact these responses can have in demand and supply of both public and private trips.

The results from the illustrative modelling showed worthwhile benefits with individual measures and a high potential to influence perceived changes and influence patronage. The scale of impact of combined measures could be similar to conventional measures but would have lower dis-benefits to other traffic. However its implementation may require significant investments. The level of benefits also showed that these might not be the means for mode shift but needs to be integrated with other conventional and operational measures to provide a better package deal.

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I would like to dedicate this study to my parents who constantly pray for my success.

Abbreviations Used

Throughout this thesis the following Abbreviations have been used

AVL	Automatic Vehicle Location
DRTS	Demand Responsive Transport Systems/Services
ITS	Intelligent Transport Systems
LOS	Level of Service
OD	Origin Destination
PT	Public Transport
TPJtime	Total Passenger Journey time (passenger-minutes)
UTC	Urban Transport Control

1. Introduction

1.1 Background

The problems resulting from exponential growth in transport demand has led policy makers in transportation to focus on development of sustainable transport systems. One of the major solutions put forward is improved public transportation, particularly buses in urban areas. Governments around the globe have been focusing on this aspect for the past decade. The UK white paper (DETR, 1998) outlines 'too often buses have been treated as second-class transport. It doesn't have to be so. They can be modern, comfortable and clean' thereby generating more patronage and modal shift from private transport to alleviate the problems to develop a sustainable transport system.

New technologies are now being applied to transport to improve road conditions, reduce costs and negative environmental impacts and to improve efficiency. These systems are commonly called Intelligent Transport Systems (ITS). ITS can be described as the application of improved technology to conventional transport systems (http://itsdeployment.ed.ornl.gov).

These systems can also be used in bus services to improve the level of service, which is one of the main reasons cited for the increase in use of private transport. The impacts and benefits of ITS on public transportation have generally been evaluated using before and after measurements and surveys. These techniques however are limited in scope and they cannot be used to evaluate a scheme before implementation to aid decision makers. An appropriate appraisal methodology to assess their impact in a transport network for further implementation is essential for this purpose.

The development of appropriate transport systems and services is often assisted by the use of transport planning models. Such models serve to investigate the likely consequences of new policies or developments. This research sets out to explore the impacts and benefits of ITS measures used to enhance public transportation, namely bus service in urban area. It outlines the probable influencing parameters and requirements for effective modelling and critically reviews the existing models within this context. A modelling framework is developed using two transport models, TRIPS public transport model and SPLIT to illustrate the impacts and predict benefits of selected ITS measures in a public transport network.

1.1 Objectives:

To reduce dependency on the private car, public transport needs to be attractive, reliable, affordable and accessible. A number of requirements ranging from policy matters to scheme details can be outlined to pursue this objective. The focus here is on transport network modelling to analyse impacts of some key ITS measures. This research concentrates on the possible and stated evidence of effectiveness of these measures, outlines the modelling requirements and illustrates the impacts using network modelling.

The specific objectives of this research have been to:

1. Review the methods used for enhancing public transport systems and the evidence of the use of Intelligent Transport Systems to enhance these methods.
2. Identify the role of modelling in the evaluation of ITS applications for public transport.
3. Outline the requirements for effective modelling of ITS measures.
4. Illustrate the impacts and benefits of selected ITS measures in a public transport network using appropriate modelling techniques and case studies.

1.2. Organisation of the Thesis:

The chronology of the thesis is given below:

Chapter 1 gives the general overview about the research and states the specific objectives and how the research has evolved to achieve these objectives in a chronological manner.

Chapter 2 starts with a review of the importance of public transportation leading to importance of bus service for a sustainable transport system. It outlines key reasons for the decline in the use of bus services and what methods can be used to rectify this process.

Chapter 3 contains a detailed literature review of how ITS measures can be used to enhance bus services, leading to its impacts, benefits and influencing parameters.

Chapter 4 discusses how these measures can be evaluated and the role of modelling within this context. It gives a model framework of how ITS impacts can be evaluated. It details the requirements for effective modelling of these measures and gives an overview of modelling procedures and available modelling packages. It also contains a critical review of existing transport modelling procedures and modelling packages within the context of requirements for effective modelling of impacts of ITS measures in public transport.

Chapter 5 describes the characteristics of two public transport models, TRIPS and SPLIT, selected for this research and explains how and why these models were used.

Chapter 6 outlines the issues related to the evaluation of impacts of selected ITS measures in public transport and presents the modelling framework used in this research for this objective. It outlines the data requirements and describes the surveys carried out to collect the relevant data. A description of the public transport network developed and the data analysis carried out to derive appropriate relationships for the modelling is presented in this chapter.

Chapter 7 outlines and analyses the results obtained from the illustrative modelling in a transport network for various scenarios.

Chapter 8 concludes the thesis with discussion on findings and recommendation for future research.

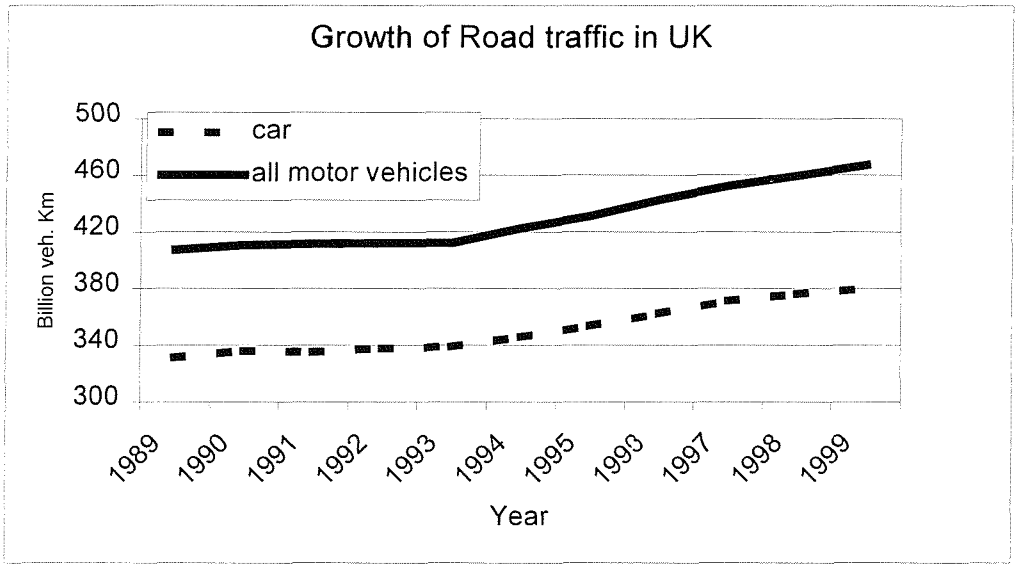
2. Enhancing Public Transport

This chapter reviews the importance of public transportation and why bus services are viewed as a major means for a sustainable transport system. It outlines the reasons for the prevailing trend of decline in bus use and summarises potential measures, which could help to reverse this trend. These relate to organisational, operational and traffic management measures, whilst those related to Intelligent Transport Systems (ITS) are described in Chapter 3.

2.1 Background:

Economic competition in world markets makes it essential to move people and goods quicker and more economically. Road based transportation plays a significant role in stimulating this growth (Vuchic, 1982). People's lifestyle has also changed. There is a craving for more and greater choice in life in terms of goods, leisure, accommodation and work. This has led to further growth in road-based transportation. The trend of this growth is illustrated in figure 2.1 for UK (DETR, 1998), which is mirrored in many developed countries around the world.

Figure 2.1. Growth of Road Traffic in UK



The growth trend shows that the private car is catering mainly for this growth. The 20th century had always attached a high value to private transport. The number of cars per household in a country has been a gauge to its economic position. It determines one's choice for a place to live, work and leisure. Generally it is more reliable, comfortable and economical and its flexibility has revolutionised the way we live by widening horizons.

This unchecked growth has incurred significant negative impacts in terms of congestion and pollution. The very purpose for which the car became popular is being defeated by the increase in its number. Congestion and unreliability of journeys add to the costs of business undermining competitiveness. The Confederation of British Industry (CBI) has put the cost of congestion to the British economy at around £15 billion every year (DETR, 1998). Furthermore cars use 5.5 times more fuel per passenger trip in urban areas than a bus and require 7.5 times more width of infrastructure to cater for the same demand (UITP, 1992).

People having no access to a car have restricted freedom of choice and depend on public transport. This is widening the gulf between the rich and the poor as the latter have limited access to both jobs and education. This not only degrades the social environ but can also have detrimental effect a nation's economy (Laconte, 1996).

Except for SO_2 (Sulphur Dioxide), vehicles are the main source of all other polluting emissions. Land based transport contributes significantly to noise levels. Twenty percent of Western Europe lives at an unacceptable noise level. In the UK, emission of CO_2 (Carbon Dioxide) from road transport is the fastest growing contributor to climate change, which is the greatest global environmental threat facing the international community (DETR, 1998).

Over the past decade, a consensus among decision makers and the public for changes to make transportation more sustainable have been observed. 'We need to improve public transport and reduce dependence on the car. Businesses, unions, environmental organisations and individuals throughout Britain share that analysis' (DETR, 1998). Some 84 % of people interviewed in 13 EU countries believe that priority should be given to public transport over cars in congested areas (UITP, 1992). To achieve such aspirations, transport policies to encourage a demand shift to more efficient modes, namely public transport is vital.

Bus services are recognised as a major contributor of non-car provision in urban areas ('75 to 90% of such journeys is the norm outside London' - Kilvington 1992). Some of the reasons why measures like the introduction of light rail transits or underground metro are not always the best answer (Snoble et. al., 2000, Cracknell et. al., 1992), because:

- Initial capital cost for buses are only 20% of the cost per passenger mile compared to light rail.
- They are feasible only in corridors where demand is high whereas buses can be used more economically in areas with lower demand.
- Their flexibility is also very limited in comparison to buses. Buses are more versatile and flexible in route design.
- Bus services can also be introduced rapidly and incrementally.
- Buses offer users a cheaper way to travel than other modes of transport.
- Buses offer comparable speed and passenger capacity.

It should be noted here that LRT combines the flexibility of buses with speed and capacity of heavy rail and would be effective where such combination is appropriate.

Figure 2.2. Average distance travelled per person per year by mode in UK.

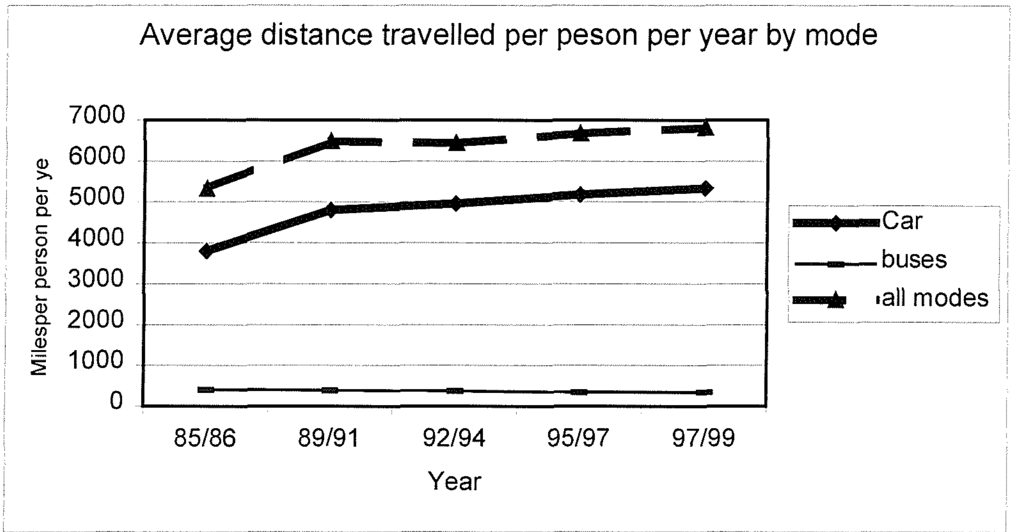


Figure 2.2 (source: http://www.detr.gov.uk/) shows a gradual decrease of bus use over the years (-15% from year 85/86 to the year 97/99) with all the increased distance travelled being taken up by private mode. This decline has been due to a number of factors, including: increased car ownership, changing land uses and a perceived decline in the quality of bus services (Harrison et al, 1995).

Surveys have shown that the (lack of) quality and level of service of buses is a major factor for travellers preferring private transport. For example 50% of travellers surveyed in five cities in UK (Harrison et al, 1995) said that they would use the bus more often if the reliability and regularity improved; similarly 41% of the surveyed bus riders and residents in Greensboro, North Carolina (Morse, 1996) stated quality and level of service to be the reason for not using buses or using them less.

2.2. Requirements to Improve Bus Service Quality

To reverse this trend of falling patronage, it is essential to improve the quality of bus service. Some requirements to improve the quality of bus service are discussed in the following sections.

- *Regular and reliable services:* There is no doubt that passengers regard service reliability (buses arriving and on time), regularity (regular intervals for headway based service) and/or punctuality (buses arriving on time for schedule based service) as being of great importance. Uncertainty about vehicle arrivals can cause considerable anxiety and annoyance to passengers. A decrease in regularity/punctuality would have more effect on trips where time schedule is more important, like journey to work and to school. (TRLL, 1982)
- *Reliable and easily accessible information at all the stages of travel:* Information allows users to have a greater control over their journey by providing them with alternate choices. It will have positive impacts on interchanges, intermodality, trip planning and generate confidence in its use (Atkins et. al., 1994).
- *Smoother and reliable interchanges and connections:* Confusing interchanges present a poor image of public transport. In an integrated network a trip can consist of a series of connections. A missed/unreliable connection would frustrate commuters and put off any potential users (Pullen et. al., 1991)
- *Integrated, simplified and reasonable fares:* A simple reasonable fare structure should be implemented which can be used over different modes, operators and zones to reduce confusion at transfers and decrease boarding times.
- *Easy-access public transport:* Services need to be easily accessible to users. The route and stops should be designed to be compatible with demand and easily accessible. The bus itself should be designed to help disabled and elderly people (Lesauvage et al., 1994).
- *Increase in Speed:* Increase in overall speed to lessen journey time or end-to-end duration of journey would make public transportation more attractive (TRL, 1998).
- *Vehicle Image, comfort, cleanliness and positive staff attitude:* The image of public transport is also important in influencing perception of users about the quality of service (Harrison et al., 1995). There is also a concern that the (poor) drivers behaviour or staff attitude towards users alienate their passengers (Boddy, 1993).

- *Improved personal security when travelling:* Concern for personal well-being or fear of abuse from anti-social behaviour whilst travelling by public transport is not a new phenomenon, but in common with perceptions of fear in society in general is apparently growing. Concerns usually are perception of crime in public transport, unruly behaviour at the stop or in the vehicle (Murray et al., 1994). It is obvious that people would not choose to travel in unsafe buses.
- *Enhanced marketing:* In this modern era of competitiveness no commodity can be sold without proper marketing. Public transport is a commodity, which cannot be stored, and therefore needs a higher level of marketing than prevalent. Public transport systems need to retain current riders and constantly attract new customers. These systems require a continual investment of advertising resources to maintain and expand market share (Bush 1999, Cutler 1987).

2.3. Measures to Enhance Bus Service

Requirements to enhance bus services have been outlined in the above section. These requirements can be achieved using a variety of measures. These can include demand and traffic management policies implemented by planning and regulatory bodies or service enhancements by the operators. Some of the measures are outlined in the following sections.

2.3.1. Integrated Land Use and Transportation

The pattern of land use and activities is the major determinant of traffic demand and structure. Although the relationship between land use and transport is complex, it is well established that the decentralisation of people and jobs to suburbia, and to smaller free-standing towns in non-metropolitan areas, has been possible because of the increase in personal mobility brought about by the private car.

This outward spread of people and jobs has been accompanied by an increasing physical separation of homes, jobs and other facilities. This has been reinforced by the concentration of shops, schools, hospitals and other services into fewer and larger units. The end result is a greater level of car dependency, rendering public transport services less practicable (O'Flaherty, 1997).

Practical land use control measures can be used to create a demand environment, which can be more efficiently served by public transport. Some of the measures are outlined below:

1. Limit the spread of cities so as to keep residential densities.
2. Concentrate higher density residential developments, offices, retail establishment and other trip generating centres near public transport centres or alongside corridors well served by public transport.
3. Promote the juxtaposition of employment and residential uses so that people have increasing opportunities to work at or near their homes.
4. Allocate sites unlikely to be served by public transport solely for uses, which are not employment intensive.

2.3.2. Integrated Transportation Across Services and Mode

All multi-modal journeys with intermediate changing points put up barriers of some kind to the traveller. They are barriers of cost, delay, effort, luggage handling, and uncertainty of timing and reliability. People's choice of mode depends on their perception of the cost and impact of these barriers compared with those of the alternatives. Where door-to-door car travel is available, this is crucial. This will depend on achieving better information and levels of service for public transport, better co-ordination of modes and services, and better interchanges and facilities (DETR, 1998).

For example, a 10 year evaluation in Madrid of monthly pass, a multi trip, multi day, multi mode transport ticket along with a creation of a single authority defining integrated fare structures and a co-ordinated planning and exploitation of the services showed a definite increase in public transport demand of about 12 to 23% (Jadraque et al., 1997).

2.3.3. Constructive Partnerships

In the present trend of privatisation and fragmentation of public transportation very little can be achieved by any single establishment on its own. Constructive partnership can implement programs of co-ordinated measures that attract substantial growth in public transport use. The long term effectiveness of these partnership are dependent upon all partners sharing a common vision of the long term goal, and accepting the concept of shared management responsibility for the public transport as a whole (Southampton City Council, 1999).

2.3.4. Parking Policies

Parking control can be a significant form of traffic demand management. The control of the supply of parking is often proposed as a way of restricting the amount of traffic entering an urban area and encouraging a change of mode to public transport (Combe et al, 1997). For example, parking control measures have been accepted as an essential part of a viable transport policy to restrain traffic in London (Bayliss, 1998). Increase in the number of cars over the last 20 years in London is 24% compared to 64 % nationally. The use in public transport has risen in London over this period compared with a 20% fall nationally.

Most formal parking is already controlled in congested areas and will already be influencing demand. It is probably fair to say that this influence is primarily being felt at a tactical planning level, rather then as a strategic restrain upon traffic demand (Combe et. al., 1997). The problem with trying to use the 'stick approach' to reduce travel demand is that restricting car use in one area often leads to greater growth in another. The growth of developments along the M4 corridor and around the M25 ring is an obvious example of this. The option for reducing car travel by such control is therefore limited unless it could be applied nation-wide. (Foster et al., 1993)

A study of the impact of park and ride in Tyne and Wear showed evidence of people using public transport who otherwise would have used car. However it reinforced previous evidence from the UK, that generally park and ride had little impact on traffic flows into city centres. It further argues that the latent demand for road space is such that any road space made available as a consequence of, park and ride, will be put to use (Pullen et. al, 1991).

2.3.5. Bus Priority Measures:

A powerful tool to enhance bus services is to manage the traffic so that buses are given priority over private modes by using different measures. Bus services can be assisted by measures aimed at reducing congestion and improving the flow of traffic in general along bus routes. For example, on the priority "Red" routes in north and east London, which were subject to special parking controls and other traffic management measures, buses benefited because of general reduction in congestion and more reliable journey time (DETR, 1997). Dedicated bus lanes are considered to be strong bus priority measure. They have been used to increase the speed and improve the reliability of bus services, thereby encouraging the use of scarce urban road space more efficiently (Bus uses less road space and fuel per passenger mile than private car). Some of the methods are outlined in the following paragraphs.

With-flow bus lanes are the original and the most common form of bus priority where buses would otherwise be adversely affected by traffic congestion. A traffic lane, usually the nearside, is reserved for the use of buses and other vehicles that are accorded priority. Where road width allows, double-width bus lanes can assist buses to pass slower or stopped buses. This will often mean a substantial time saving to buses and passengers, possibly offset by some additional delay to vehicles, which have been overtaken.
Some measures are used to minimise the delay to other vehicles. For example bus lanes are normally stopped short of the stop line at traffic signalled junctions to ensure that the full width of the stop line at the junction is available to all traffic during the green period. It also facilitates, and makes left turns safer. The aim is to ensure that buses clear the stop line during the first available green period. As a general guideline a set back, in metres, of twice the green time would normally achieve this. (Oakes et. al, 1994)

With-flow bus lanes may not be fully effective (Cracknell, 1992) for the following reasons:

- Intentional infringement of bus lanes by other vehicles
- Unintentional blocking of the start of bus lanes by vehicles trying to merge into the single, all-vehicle lane and failure to clear on the set back at the main traffic signal due to downstream congestion.

Various measures such as more positive segregation in the form of low kerbs to heavy weight studs, camera enforcement, pre-signals to allow buses to arrive first at the main signal, early start stage and queue relocation to allow buses to overtake the queue at wider part of the road can be used to overcome these problems.

In ***bus advance areas***, the non-priority traffic is stopped at a secondary stop line level with the end of the bus lane. During the red phase at the main signal, buses proceed to main stop line and take up their preferred lane while non-priority traffic is subsequently released by the pre-signal to allow full use to be made of the green phase at the main signal (DETR, 1997). The impact of these measures have been found to be very site specific (Seaman et al, 1999), with bus delay savings typically ranging from an insignificant amount to 50% for a given route (Balcombe et al. 1997)

Contra-flow bus lanes with prohibited entry for other vehicles enable buses to avoid unnecessary diversions, to maintain route patterns when one-way streets are introduced, and to gain better access to business and shopping areas. They also allow buses to be quicker than other modes. The introduction of such measures needs to be carefully assessed to determine any dis-benefits to other modes and safety implications (DETR, 1997).

Bus only streets may be used where appropriate. They allow buses to maintain route patterns, avoid long detours and gain easier access to premises making the service more attractive and convenient. London Transport suggests that the exclusion of buses from the shopping streets was in the interest of neither the passenger nor the public transport itself and could incur losses (Bond, 1982).

Bus priority can provide a range of benefits, as indicated above. In London, for example, benefits with bus lanes and advance areas showed journey time average savings of 14%, more regular/reliable service and a potential frequency reduction from 10 minutes to 8-9 minutes due to saving in travel time (Blitz et al 1997). Attitude surveys showed passengers were 2% more likely to have used the bus more compared to the previous year and 55% less likely to have used the bus less. Six percent of users using buses more said they did it due to improvement in service compared to 3% in other areas. Cost benefit analysis showed that payback period for nearly all schemes were less than two years and less than two months in some cases (Shalaby et al., 1994).

2.3.6. Service Enhancement: The following are indicative of the range of potential service enhancements to illustrate the wide range of possibilities.

Improved waiting conditions, Buses and Access:

One of the major reasons for the reluctance of passengers to change from metro to bus in the Tyne and Wear scheme (Pullen, 1991) was the prevalent poor condition of bus stops. Improving condition of the rolling stock, for example maintaining the appearance of the bus (Lesauvage, 1994) or introducing low floor access (Guster et al., 1994) are also widely appreciated by passengers. Improved standards of bus shelters and access to bus stops are also seen as service enhancements by passengers (Seaman et al. 1999).

A bus stop is considered to be a street space mechanism where buses and passengers merge or diverge. It can be thought of in terms of its constituent parts, a stop area for buses and a compatible platform for passengers. The design principal of bus stops is to provide an interchange mechanism in which service times of passengers and buses are minimised (Fitzpatrick et al, 1997). Another aspect is that the proximity of the bus stop to the demand points should be carefully chosen to minimise walking times (Fernandez, '99).

Increase in service frequency

The effects of changes in frequencies are in general higher for lines with originally a low frequency than for lines with higher frequency. This was found (Beek et al., 1994) in the case of increasing as well as in the case of decreasing frequencies. It would also be different for different user groups. If the bus lines with low occupancy are reduced, a high probability of buying or using a private car are found for small user groups with driving license or with access to car and low probability for large user group without such resources (Beek et al., 1994). 50% of bus users surveyed in five UK cities (Higginson et al., 1995) said they would increase bus use if frequency of the services were higher. Though this figure looks optimistic it nonetheless highlights the potential for improved bus service.

Improved Fares systems:

Offering chained services between different modes, operators and zones using a single card would be more attractive to the traveller. It makes transfers less frustrating and decreases boarding time. It can also be used for data collection and reducing fraud (Blythe et. al., 1997). There is also evidence of increase in patronage with use of such systems (Holoszyc et al, 1981, McKenzie, 1985). It should be noted here that this increase could be a combination of bus users using buses more and/or mode shift.

Fare should also be reasonably priced as it would affect any potential mode change and increase in patronage. For any mode change from private to public transport, the total cost of using public transport should be less than the marginal cost (direct cost like fuel, parking, toll charges etc but excluding costs like taxes and insurance) of motoring (TRL, 1998). Fare elasticity based on empirical evidence of bus patronage in the West Midlands (McKenzie, 1985) for short term was approximately -0.20 (a reduction of 1% in fare would increase 0.2% patronage). A before and after study in Gosport and Fareham area in 1978 (Layfield 1981) also showed fare elasticity of - 0.2 for week day travel.

Staff attitude and management:

Poor driver behaviour/attitude is partly responsible for poor customer care, which can alienate passengers (Boddy, 1993). The study showed that though the majority of drivers appeared to have a good underlying motivation to do their job well, it could be undermined by conditions on and off the buses, poor communication with supervisory management and poor feedback on job performance. The data also indicate that, while most drivers have good commercial awareness, they consider that their desire to give a high quality service is frustrated by the factors above and competition on the road, unrealistic schedules, over-long shifts, poor vehicle ergonomics and stress arising from one or more of the preceding factors. It suggests the possibility of giving the driver greater involvement in improving the quality of service to passengers.

Safety:

In a recent study (Ingalls et al., 1999) nearly 3% of people cited personal safety for not using bus service. Major bus related safety problems identified are disorderly conduct, drunkenness, and panhandling/begging. Image links between bus service and perceived crimes are major deterrents to increased rider-ship. Surveys show that users are not only concerned about personal safety on or near the bus system but also about general safety in the community (Hartgen et al., 1993). There is a need for information on crime levels, and identifying who and where is the risk. A whole spectrum of authority, staff and press has a hand in ameliorating the situation. For example better lighting, paths, monitored CCTV, uniformed staff etc (Murray et al., 1999).

Marketing

Public transport is a commercial product and therefore requires marketing to attract users. The users need to be made aware of the available alternative to private transport. Publicity, one of the main marketing tools, has been limited, as generally the spending in advertising in this field is less than one percent. Studies have shown increase in level of public transport use with marketing which results in increased revenue for operators (King et.al., 1997).

An example is an international project co-ordinated by UITP (Union Internationale des transports Publics) between December 1995 and June 1997 "switching to public transport", in Hampshire (King et. al., 1997). The marketing approach in Hampshire included publicity and home visits by company staff to inform, generate confidence to use the service and provide free tickets as an incentive. The trial did improve people's perception of the bus service, supporting the theory that the quality of service is better than many non-users believe. It was more successful in reducing short urban car trips in the off-peak time (reduction from 71 to 61% in shopping trips and increase of bus use from 3 to 11% by pass users) but could not reduce peak hour traffic congestion.

Research based transit marketing to produce high quality marketing materials that are visibly persuasive and memorable help to improve opinions about public transportation, expand awareness and increase rider-ship (Bush, 1999). Similarly results of a demonstration project in Idaho for small rural and urban area showed an increase of 11 percent rider-ship over a 6 months period (Cutler 1987).

2.4. Conclusion

The private car caters for most of the growth in road-based transportation due to economic growth and change in people's lifestyle. However policy makers and many users now realise that this is not sustainable and public transport should be improved to check the growth in private car. Bus services provide a major portion of public transport trips in urban areas. There is a wide range of issues, which influence bus patronage. The main requirements are that the service should be reliable, regular, easily accessible with appropriate level of information, reasonably priced, with smooth interchanges and securely take the users to their destination in time.

This can be achieved/improved by a variety of measures, ranging from policy matters like land use, parking policies and partnership between the parties involved to traffic demand measures like bus priority measures and enhancing the bus service itself, for example, improved waiting conditions, bus and bus stops, increase in service frequency, improved fare structures, staff attitude and marketing. However, there is an increasing role for measures relating to Intelligent Transport Systems (ITS) to contribute to improved bus operations, which are described in the next chapter.

3. Intelligent Transport Systems for Buses

Intelligent transport systems are being developed for a wide range of transportation applications, including public transport. This chapter starts with a literature review of types of Intelligent Transport Systems (ITS) used in bus services leading on to a discussion on their impacts, benefits and influencing parameters.

3.1. ITS Applications:

New communications and computing technology, usually described by the generic term ITS are a set of key tools, which apply advanced computer and communications technologies to improve the management and operation of the transportation network. ITS systems and products are diverse, serving many users with many goals. Five major goals have been identified for ITS (http://itsdeployment.ed.ornl.gov):

- *Improve safety*: Reduce the number and/or severity of accidents.
- *Improve service level* (efficiency): Improve transportation customer service
- *Reduce energy and environmental impact*: Reduce energy consumption.
- *Enhance productivity*: Improve transportation system management and planning.
- *Improve accessibility*: Ease travelling for all travellers.

To meet these goals, ITS have evolved in response to the particular needs of different groups of users. Users can be *operational managers* (who plan and operate services and provide information to users), *institutional managers* (Authorities managing the transportation systems/assets), *travellers* (The end users of services provided) or *information suppliers* (who integrate spatial data to improve products to their customers). Many user services have been defined to date. They have been bundled into nine major categories and are tabulated in Table 3.1 (Chen et. al., 1997).

3.2. ITS User Services in Bus Services:

A wide range of ITS measures has been used to enhance bus services. For example Automatic Vehicle Location (AVL) technology, which locates vehicles in real time along with improved communications allow operators to improve the management of their services. Once vehicle are fitted with location equipment, facilities may be developed further to enable bus priority to be provided at traffic signals in the network; and real time information can be provided to travellers to keep them informed about arrival times and any delays.

Table 3.1. User Services of ITS in transportation:

User Service Bundle	User Service
Travel and Transportation Management	En-route Driver Information Route guidance Traveller Services Information Traffic Control Incident Management Parking Management Highway-Rail Intersection Emission testing and mitigation
Travel Demand Management	Pre-Trip information Ride Matching and Reservation Demand Management and Operations
Public Transport Operation	Public Transportation Management En-route Transit Information Personalised Public transit Public travel Security
Electronic Payment Services	Electronic Payment Services
Commercial Vehicle Operations	Commercial vehicle Electronic Clearance Automated Roadside Safety Inspection On-Board Safety monitoring Commercial vehicle administrative process Hazardous Material Incident Response Commercial Fleet Management
Emergency Management	Emergency Vehicle Management Emergency notification and personal security
Advanced Vehicle Control & Safety System	Longitudinal Collision Avoidance Lateral Collision Avoidance Intersection collision Avoidance Vision Enhancement for Crash Avoidance Safety Readiness Pre-Crash Restraint deployment Automated Highway Systems
Law Enforcement	Policing/Enforcing Traffic regulations
Vulnerable Traveller Services	Pedestrian Safety and Information System Bicyclist Safety and Information System

Another example concerns contact-less smart card. This technology can be used for integrated ticketing systems and for reducing boarding times. Improvements in telecommunication technologies and computer software are supporting a range of new demand responsive transport services (DRTS).

Major developments around the world involving ITS in Public Transportation (TRL Report 342, 1998, Nickel, 1997) include:

- Information system for trip planning
- Portable information terminals

- Real time passenger Information at bus stops
- Bus priority systems at signal controlled junctions
- Multi-modal ticketing and integrated payment
- Demand responsive transport service
- Enforcement

These ITS applications in bus services are further described in the following sections.

Automatic Vehicle Location:

Automatic vehicle location (AVL) can play an important role in bus service operations, providing support for real-time management, control of bus fleets and the platform for other beneficial functions including passenger information systems and bus priority (Hounsell et al., 1998). AVL systems typically comprise:

- A means of locating the vehicle concerned
- Control/management centres to monitor the progress of vehicles in real time.
- A communication system between the vehicles and the control/management centres and various applications for which the AVL system acts as a platform.

Vehicle location can be established using technologies shown in Table 3.2.

Table 3.2. Vehicle Location technologies (Lobo –1998):

Technology	Advantages	Disadvantages
Dead Reckoning, using odometers, compasses and radio transmissions.	Low cost. Possibly no roadside infrastructure or line-of sight requirements.	Vulnerable to inaccurate instrumentation and initialisation.
Beacon Based / Loops, using tags, transponders and radio transmission.	Exact position of bus known if tag is used, low cost equipment	Roadside infrastructure required. Lack of flexibility in route choice as bus cannot be tracked off route and line of sight requirement for beacons. If beacon fails, all buses affected.
Radio triangulation to calculate distance between receiver on the vehicle and radio transmitters.	No roadside infrastructure. Flexible route choice. No line of sight requirement. No initialisation required.	Subscription charge to network may be high. Vulnerable to interference.
Satellite based GPS/DGPS to determine three dimensional position and velocity anywhere in the world in all condition.	No roadside infrastructure. Flexible route choice. Relatively low cost. No subscription cost. No initialisation required	Line of sight requirement. Inaccuracies introduced near high buildings. System owned by a third party.

There are several technologies currently being used by operators to transfer locational information from a bus to the control centre, which includes private mobile radio, band III, mobile public data networks and cellular phone services (Scorer, 1993, Nelson et al 1997). There is a variety of ways in which the control centre may receive vehicle updates including:

- Sequential polling - enquiry sent to all vehicles but only the vehicle to which the message refers will respond.
- Time slot polling - each bus is given a unique periodic time slot during which it transmits its current status and can achieve regular updates.
- Event driven updates - bus initiates communication with the control centre when a certain condition is met (e.g. when a bus reaches a beacon).

Many of the AVL applications are described in the following sections.

3.2.1. Passenger Information using ITS

ITS offers new routes for the provision of passenger information. The ability of information technology to distribute large volumes of data around a network of terminals in user friendly ways at affordable prices and allied with developments in communications; allows users to be provided with real time information before they begin their trips (pre-trip), at-stop or in-vehicle (en-route) by personal information devices like pagers or mobile phones, Internet, kiosks and information boards.

These systems are sophisticated, rely upon latest technologies to deliver information and are generally termed as Advanced Traveller Information Systems (ATIS). For example, the location of a bus using AVL technology can be relayed to a centre system, which predicts the arrival time at a bus stop using algorithms based on historic data. This real time information can be displayed at bus stops. Telecommunication networks can be used to collect data from multiple sources and disseminated to users using dedicated radio and TV channels, phone lines, Internet, and information boards or kiosks. According to various studies (Stoveken, 1997, Blackledge, 1991) the potential benefits of using ITS for passenger information are:

- Information can be given in real time as well as in static (timetable) time and provided more visibly (LED displays) in different locations.
- Fully computerised systems can respond rapidly to enquiry and change in the network.

- A single database of information can be maintained for a variety of applications. It would be more efficient to maintain and is likely to result in fewer errors than information systems relying on multiple data source or on manual techniques.
- Interactive information terminals can be provided, allowing users or enquiry terminals to have access to information tailored to meet the needs of individuals.
- Algorithms can be used to calculate optimum routes, which can be displayed on screen or printed out.
- Satellite supported AVL with mobile radio network facility can be used cost effectively even in rural areas.
- Operators can disseminate information strategically and manage passenger flow in the network.

3.2.1.1. Information System for Trip Planning

The purpose of providing trip planning information like pre trip information systems (for example telephone enquiry, information kiosks and Internet) and en route information systems (for example in-vehicle displays and mobile phones) is to allow passengers to make informed choices about the public transport services they can take or connect to, for their journey. It is worthwhile noting that the power of information comes not from its compilation but from its application whereby the right information is provided to the right person at the right time (Thompson, 1998).

As noted in various studies (TRL 1998, Blythe et al., 1999, de Saint Laurent et al., 1994, Nickel, 1997, Anderson et al., 1997) the primary impact of pre-trip passenger information is its potential of influencing the behavioural response of the users by allowing them to make informed choices to accrue various benefits. This could subsequently affect both demand and supply. Impacts of pre-trip passenger information include:

- Reduction in waiting time due to use of alternative services or arriving closer to the arrival time of the bus.
- Allowing optimum route selection for convenience (choosing the service that suits ones schedule) and/or to save journey time (choosing a service that saves time either by less waiting time or shorter in-vehicle time).
- Promoting a perception of enhancement in level of service (LOS). It removes the uncertainty of service arrival times and the service itself to reduce stress while waiting

at bus stops.

- Easing service transfers at interchanges by informing users of the available choices.
- Serving as an advertisement (for example Internet sites), which can help in attracting more patronage.
- It can increase patronage and/or influence mode change and improve attitude towards public transport due to real/perceived change in LOS.

These impacts will be affected by:

- The reliability of the system (the more reliable it is, the more it is used by the users and 'incomplete and outdated information may lead to sub-optimal choices being made by the individual' – Lyons et. al. 1998) and the bus service (the less reliable the bus service the more benefit for the users with information)
- The location of the system, which determines the accessibility of the system to users as the impact will be higher with higher proportion of users using the system. In other words the effectiveness will depend on market penetration and extent of use.
- User friendliness, organisation and display of information and usefulness (quality) of information, (Lyons et al., 1999), which will affect the user volume (Kitamura et al, 1991).
- User category (used more by less frequent users and one off long journeys, some users have more confidence in personal contact and less on a machine providing accurate information, Cassidy, 1997).
- Whether the system is stand-alone or as a part of a package. Continuous information at all stages of a trip (pre trip, en route and at stop) helps users to have a seamless journey (Anderson et al., 1997) and also helps to build user confidence in the system.
- Network conditions – information about public transport options available can induce change in mode where road network is congested (Jones et al, 1993) provided that buses are protected from congestion.

In the past, journeys by public transport have generally been planned from information presented in paper timetables published as brochures or booklets, which show routes, stops and times, and can be obtained from PT operators. More recently, telematics systems have been developed to make journey planning more accessible by disseminating ***Pre-trip information*** using dedicated radio and TV channels, enquiry phone lines, pagers, mobile phones with WAP (Wireless Application Protocol), Internet, information boards or kiosks at interchanges. Some examples are given in Table 3.3.

Table 3.3. Examples of pre-trip information services

Description	Type	Services
CENTRO and ORS (Optimum Route Software), Birmingham.	Central database with static information and real time information using AVL, and optimum route software connected to Telephone enquiry, pc based interactive and videotext terminals	Provides best routes, arrivals and departures
TRIP planner, Southampton, Public Access Terminals (PAT) Pireaus and Genoa under Euroscope project (Leach et al 1995)	Central database (Integrated traffic management computer) collects and collates all traffic and travel information and provides on line Internet site and to interactive terminal kiosks	Public and private trip planning service and tourist information including multi modal trip planning and real time information.
SITU, Paris & Autoplus Caen (Blackledge et. al., 1991)	Central server providing information to Interactive passenger terminal	Optimum routes
EBIS (Bus information Systems in Korea, (Kim et al., 1997)	AVL equipped buses and use of GPS to locate buses and communicate with roadside beacons or wireless data modems and a data centre gathering information and data to process and relay it to terminals.	Arrival times, static and dynamic traffic, bus schedules using In vehicle displays, interactive terminal, display board and IT.
JESS – Journey Enquiry Support Systems (Thomas et al., 1998)	Raw data server accumulates data from a number of source and supplies to the active server, which exports required information to telephone service, terminals and Internet.	Best journey times using routeing algorithm via Telephone and direct terminals and Internet
PT information service, Netherlands, (Van Der Loop, 1994)	Phone connected to PC.	Timetables, fares, arrivals and departures.
Ile-de-France multi modal information (Allouche 1994)	Central server transmitting information to Minitel and onboard information system.	Pre trip Best mode choice and real time schedule, park and ride facilities.
Multimodal information agency. (Ampelas, 1999)	Single source of data using travel information and radio positioning serving telephone and Minitel service	Static and dynamic multi-mode information
Rhine-Main-Area, WAP phones (Stoveken, 2001)	Internet access using WAP mobile phones	Static and Dynamic multi modal information

Two approaches (TRL, 1998) have emerged to present information to the users as a single, easy to access source. First is a centralised approach, where information is drawn into one major database. The main drawback is the effort required in consistently updating the huge input required into one system. Collecting and presenting data mainly, though not exclusively, from the largest company can ameliorate the problem to some extent. The second is the distributed approach where information is dispersed by a number of sources. With this approach users can be frustrated by having to deal with a number of sources to get information for their total journey plan when their journey spans more than one mode, company or route.

However, with the advent of IT, the distributed approach is being predominantly used. It forms the basis of travel agencies and, to some extent, enquiry lines. It uses software to identify relevant sources to access and interrogate those sources and to collate and provide the information seamlessly to users to meet their needs. Supply and maintenance of information is dispersed across a large number of suppliers (and therefore the cost) keeping the information management task manageable and thereby ensuring accuracy.

A few years ago the Internet was a computer interconnection network reserved for Universities and researchers. SYTADIN was the first European real time traffic information server open to public since 1996 (Blardone et al., 1997). Since then the proliferation has been dramatic. There are now over 400 web sites in the UK, which provides public transport information (Austin, 1999).

For the second quarter of 2001 the Office of National Statistics estimated that 9.4 million households had access to the Internet and 56 percent of adult males and 47 percent of female adults had in the UK had access (Lyons, 2001) which is substantially higher than predicted (By 2001, the western European domestic market is predicted at 38 million households online, with over a tenth of those in the UK, TRL 1998). A principle impact of the Internet and WWW is the opportunity to deliver comprehensive information into the home and office. This represents a tremendous step forward in the ability to provide pre-trip information (Lyons et. al., 1998).

Examples of Internet Sites: Table 3.4 provides examples of Internet sites with public transport information. A comprehensive list of public transport information Web sites can be found at www.pti.org.uk. One example is the Superroute 66 real time information

Internet Site. This site shows current positions and predicted arrival times for "Superoute 66" buses, operated by eastern counties and Suffolk County Council, covering 50 stops, over approximately 12 km. The buses are fitted with GPS receivers, and broadcast their position, direction and whether the door is open via band 3 radio to a central base station twice a minute.

Two versions of site were developed (Thompson S M, 1997). The first site uses Java to display an interactive "tube" map of the route. Current bus positions are displayed, with arrival times shown on a simulated LED display. A simpler HTML (Hypertext Mark-up Language) version, automatically updated once a minute, provides the same information but in a general-purpose format.

The data for these sites is also the source of travel information delivered by short messaging service (SMS), pager messages (which can be personalised through a WWW interface); voice over the telephone (including text-to-speech and Interactive Voice Response systems) and real time bus stop information systems.

Table 3.4. Examples of Internet sites:

Description	Web Page Address	Service
Brighton & Hove Bus company	www.buses.com	Bus frequency
Nottingham County Council	www.nottscc.gov.uk/city line/index.htm	Bus frequency
South Yorkshire PTE	www.sypte.co.uk	Multimodal timetable
West Midlands Travel	www.travelwm.co.uk	Multimodal timetable
West Highlands	www.gael.net.co.uk/travel/index.html	Multimodal timetable
London Underground	www.londontranport.co.uk	Single mode journey planner
Tyne and wear PTE	www.tag.co.uk/twpta/default.htm	Single mode journey planner
Glasgow Underground	www.metro.jussieu.fr	Single mode journey planner
Lancashire County	www.lancashire.com	Multi-modal planner
Bedfordshire County	www.ukbus.u-net.co.uk/ibcounty.htm	Multi-modal planner
Buckinghamshire county	www.pindar.co.uk	Multi-modal planner
TABASCO, South Yorkshire	www.sypte.co.uk	Multi-modal planner and static information

Portable Information Systems:

The power of information comes not from its compilation but from its application. The challenge is to provide the right information to the right people at the right time to allow them to make informed choice (Thompson, 1998). Portable information systems can be used to provide fast and convenient information to users when they need it irrespective of where they are. Accessing information from the Internet using computers or from information kiosk takes up longer time and the user may have to reach a specific place to access these systems.

Pagers, cellular phones with WAP and Interactive Voice Response Systems (IVR) are playing an increasing role in delivering travel and transport information as they can provide fast and convenient access to information. For example mobile phones with WAP (Wireless Application Protocol) have been used in the Rhine-Main-Area for dynamic passenger information (Stoveken, 2001). This system allows the user to access information from the Internet using WAP mobile phones. This system allows users to have continuous information throughout their journey.

Internet systems can also be used to support messaging systems, which allow request for personalised information to be created for delivery, at a later time, to a pager or cell phone (Minitel system, Ampelas, 1999) or IVR system (Superroute 66) capable of recognising voice commands.

3.2.1.2. Real Time Passenger Information at Bus Stops:

For real time information at bus stops, a form of bus location means (for example one of the AVL systems) is used to convey bus location to a central intelligence, which uses algorithms based on past history to predict arrival times. Recent advances in these systems allow display monitors to receive data from the approaching buses and process it to display information (Bain, 2001). Information, generally bus arrival times is displayed at bus stops using display boards. Some examples of these systems are given in table 3.5.

A study of the effects of the integration of bus and metro service in Tyne and Wear (Pullen, 1991) showed that one key area where the network fails to live up to the expectation concerns interchange facilities. Unlike the transfer from bus to metro there was an understandable reluctance to transfer from metro to bus, which necessitates a waiting period of uncertain duration due to lack of information, in a relatively unpleasant environment of a bus stop. Behavioural change in users responses with provision of real time information at bus stops can enhance bus services by:

- *Reducing actual and perceived waiting time.* In a survey conducted for STOPWATCH, it was found that when bus stop information showed that bus would arrive in 5 minutes and there is no other alternate service 93% of passengers chooses to wait at the stop. However for 10 minute and 20 minute predicted arrival times 24 and 36% of users choose to walk away from the stop and come back later (i.e., make better use of the time available to reduce the actual waiting time).

  This is consistent with study carried out by Backstrom, (1997) where 20% of respondents stated that they would leave the stop and come back later if the waiting time is 10 minutes or more. Information at stops also helps to reduce the perceived waiting time (Atkins et. al., 1994, Nelson et. al., 2001). Mismatch between perceived and actual cost can result in 'sub optimal' choices by users, i.e., it could result in the use of car when public transport would have been cheaper (Lyons, 2001).
- *Optimum route selection*: User may be able to make an informed choice to wait for a convenient (later) bus, take the one predicted to arrive first or already at the stop depending on whichever is more convenient or quicker.
- *Increase in patronage:* Passengers are more likely to wait due to information and as stated in surveys by users (though this might be negated by users leaving the stop when informed that the wait time is long) and even a small increase in patronage of new users in some cases were evidenced (McGarth et al, 1997) which could have resulted due to improvement in level of service with provision of information.
- *Perception of enhancement in LOS* in terms of removing the uncertainty of the service, which helps to reduce stress while waiting for the users (Atkins et al., 1994). It also provides a sense of security. (Wren et al., 1996).

These impacts will be affected by:

- The reliability of the systems. COUNTDOWN users (Atkins et al., 1994) often cite unreliability and breakdowns as a reason for this system being of reduced effectiveness.
- The reliability of the service: The more unreliable the bus service the more the use of the system and greater the benefit (McGarth et al, 1997).
- Frequency of service: Higher frequency services will be less influenced as the waiting time will be usually less; it would be more useful for lower frequency services to support a potential change route or mode.

- Location: Users should have the choice of using their waiting time for other activities; or choose another service.
- User category: Not all users would need to leave the stop to engage in other activities.

Table 3.5. Examples of bus stop information services

Description	Service
COUNTDOWN, Route 18 in London (Atkins et. al., 1994)	Keypad in bus registers the bus trip and information is sent to the central computer using radio. Buses located using beacons at the roadside and radio polling. Central computer using predictive algorithm calculates bus arrivals at stops and displays using LED display at stops.
ELMI (Espoo and Lansivalya Passenger Information system, Finland, Backstrom 1999)	DPGS and radio transmission of information between bus and control centre used for bus location. Centre predicts the arrival using predictive algorithm to relay message to displays at the stops.
Bustime, Strathclyde, McGarth et al, 1997)	Buses are fitted with passive tags, which are read by roadside interrogators. The location and identity of each bus is transmitted to a central control unit, which calculates the arrival time of that bus at all the downstream stops and sends the appropriate message to each stop displayed using LED displays
STOPWATCH (Brown, 1997)	Buses are equipped with onboard computer units, which receive location information from the roadside beacons, which is updated using data transmitted from the bus odometer. This information is transmitted using radio when polled by central control. Current and historical data used to predict arrival times and transmitted to the relevant displays (LED) at bus stops via radio paging
STIB, PHOEBUS, Brussels (Aron et al, 1995)	Dynamic information at bus stops
INFOPLUS, Augouleme (Blackledge et al, 1991)	Passive system at bus stops

3.2.2. Bus Priority at Signal Controlled Junctions.

The traditional bus lane is a widely accepted means of both allowing buses to overtake the existing queues to combat traffic growth and consequent delay over time. However the need for bus priority measures where land and road space is at a premium has led to use of bus priorities at signal controlled junction using a variety of techniques. Furthermore priority at signal-controlled junction can also be used in conjunction with bus lanes to enhance bus priority. Advanced real-time traffic control strategies fall within the scope of ITS and are described below.

Bus Priority at Signal controlled junctions using selective detection

Two types of signal priority have been identified, termed passive and active. Passive priority is obtained by setting the traffic signals to favour links with buses without any selective detection. Active priority gives priority to individual buses detected on their approach to the junction. There is a range of control strategies for active bus priority. The main methods adopted are summarised below (Mcleod, 2001):

- Extensions and Recalls – In this method the green time is extended or recalled depending on the state of the signal stages when a bus is detected, the bus should then be able to pass through the junction without having to stop or with minimum of delay. These methods are commonly used where detection is relatively close to the junctions and can be implemented with constraints (e.g. according to the conditions required for non-priority traffic like target degree of saturation).
- Rolling horizon method – These methods use bus location information further upstream from the junction and use gradual adaptation of the relevant green stage occurrence and duration to match the predicted arrival time of the bus.
- Stage reordering – This is a stronger form of priority often used in tram priority systems where a specific stage is allocated to the vehicle when detected.

Other strategies – A range of other strategies have been used to cater for particular circumstances.

- In *Selective differential priority,* instead of all detected buses getting priority only vehicles over a certain 'threshold' levels receive priority. For headway-based services the priority level can be based on the difference between the field headway and service headway. Similarly for scheduled based services the priority level is based on how late a bus is running from the scheduled departure at each stop. Priority can also be based on other criteria like bus occupancies (Mcleod, 2001) allowing more benefits to be accrued (more passengers saving time) to justify the dis-benefits to non-priority vehicles.

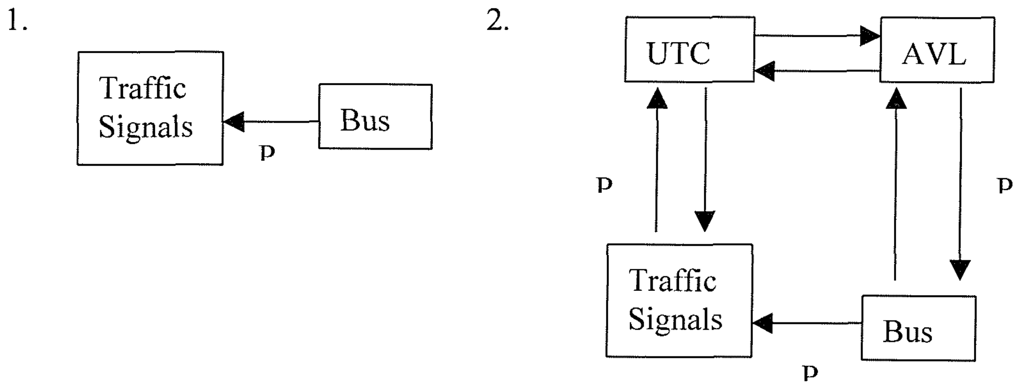
- *Gap generation facilities* help in reducing delays incurred when buses emerge from lay-bys where the section of road on which they are sited is heavily trafficked. This technique often consists of two call cancel detector loops and a linkage to a signal controller(s). It can be used to activate or inhibit stage changes to generate a gap in traffic just sufficiently long for the bus driver to accept the gap and move off into the traffic stream (Oakes et. al, '94).
- *Pre signals* can have particular benefits at junctions where buses are required to change lanes (for example from a near side bus lane) in order to make a turning movement further ahead. Typically, a set of signals would be installed some distance upstream from a junction, with the bus lane extending to the pre-signal stop line, and operated such that the green signal is displayed to buses in the bus lane in advance of green to other traffic in the offside lane (Oakes et. al. 1994).
- *Queue Relocation Strategies* can be used effectively along a corridor, which suffers from over capacity at certain junctions. In situations where the co-ordination of traffic signals on a corridor is performed using UTC system, scope exists for controlling/metering the rate of arrival of traffic to the junctions suffering from over capacity similar to ramp metering in motorways. The space thus created on the congested link(s) can be utilised by buses, which can be allowed to bypass the queue relocation system, for example SCOOT gating (Oakes et. al. 1994).
- *'Stage skipping'* allows one or more stages to be omitted from the normal stage sequence when a bus is detected, so that the bus stage can be easily recalled as quickly as possible.
- *Green Wave:* A special plan is initiated in the UTC system to provide a sequence of green signals for buses (green wave). This is often implemented for emergency vehicles responding to emergency calls.

Some other non-priority vehicles can gain or lose during this process, but the policy is usually to ensure that the network should regain its equilibrium as quickly as possible, in order to minimise the adverse effects on non-priority traffic. Relatively small, but useful, savings in both journey time and variability are made which aggregate over the long term to provide worthwhile benefits (Hounsell, 1995). Some UK examples of bus priority at traffic signals are given in Table 3.7.

Priority Implementation

Bus priority at traffic signals can be achieved with different system architectures. It can range from the simplest form (category 1. in figure 3.6) where local roadside bus detection provides local bus priority through intelligence in the local signal controller(s) to a system where there is full integration with one or two way communication between the bus, AVL centre, UTC centre and the local signal controller as shown in category 2 in figure 3.6.

Figure 3.1. AVL System Architectures:



Note: P – Priority Request.

Category one is generally used for isolated junctions. For larger networks the advantage of moving towards category two would be; a more cost efficient, accurate and flexible system (Laurens 1994).

It is also possible to categorise bus priority systems architecture according to the location of intelligence in the system. In *Fully centralised architecture* traffic control and priority functions are operated and integrated at the central level. *Centralised UTC and decentralised priority* may be preferred where the benefits from the bus priority might be adversely affected by data transmission delays in centralised priority. *Decentralised UTC and centralised priority* may be appropriate where area wide priority requirement takes precedence over local control and *fully decentralised architecture* is used for isolated intersection/s.

The benefits of bus priority vary between sites, type of priority used and traffic control system. The main impacts of this system on buses will be (Hounsell et al 1995, 1996):

- A reduction of journey time due to decrease in junction delays
- A reduction in variability of journey time thus improving regularity and reliability. This can decrease waiting time for users.
- A reduction in bus operating cost for operators as bus journey time decreases.

- A potential mode change or increase in patronage due to decrease in journey times and/or improved reliability/regularity.
- Change in user attitude due to perceived/real change in LOS

Table 3.7. Examples of Bus priorities:

Description/Examples	Method
Isolated Junction: 1. Non UTC controlled: a) Hounslow Selective detection b) b)SELKENT, in Southeast London and Kent in 1987. 2. MOVA signal control strategy. Trails in London and Winchester.	Transponders in the bus and subsurface inductive loops to locate the bus. Transponders in the bus and subsurface inductive loops to locate the bus. Compensation given to non-priority stages with inhibit facilities in peak periods to reduce dis-benefits Transponders in the bus and subsurface inductive loops to locate the bus. It operates within the MOVA system and introduces weights to optimising for the signal approach in question subject to user constraints.
Bus priority in UTC systems: 1. Fixed time UTC a) SPRINT (selective Priority Network Technique). Uxbridge road, 8 junctions 3 km. with 40 buses/hr with 11 stops, London.	Loops and transponders and relayed to central computer. Extensions, recalls and constraints depending on user fed flow and saturation flow.
2.Traffic responsive UTC a) Passive bus priority: Using SCOOTS's "Gating" facility in Twickenham and Edgware road in London and Southampton's Bitterne Corridor	Allocate spare green to roads with high bus flows. Bus lanes on approach road allow bus to bypass the queues where traffic is being held back.
b) Active bus Priority: i) PROMPT developed by TRL in updated version of SCOOT in London	Transponders and loop technology used. Extension and recalls subject to constraints using local controllers to provide more opportunity to award an extension.
ii) Active bus priority in SPOT	SPOT is an intelligent signal control processor developed by MIZAR Automazione in Turin, that implements the "intersection level" control function of the UTOPIA hierarchical and decentralised UTC system.
a) PRIMAVERA in Leeds	TIRIS transponders, loops, reader on roadside, local controllers.
iii) UTOPIA (Traffic responsive UTC) in Turin	Optimise traffic in area level and weighted or absolute priority to bus. Integrated with SIS AVM system.
Other Traffic responsive UTC with public transport priority features used includes SCATS (Sydney Co-ordinated Area Traffic Control System) and PRODYN (Henry et al. '94).	

Research has been undertaken to identify factors affecting the scale of operational benefits, which can be achieved (Crabtree et al., 1998, Hounsell et al., 1996). These factors include:

- *Flow and capacity at junctions* – Priority levels allowed to buses are usually governed by dis-benefit limits to other traffic and hence depend on flow and capacity at junction. The overall junction performance can suffer and buses may themselves dis-benefit when queues extend upstream of bus detectors. Priority may not be optimised when buses are served by conflicting stages.
- *Link type*- For example, benefits are expected to be higher for buses on side roads where delays are naturally higher, although providing priority to such buses could cause higher dis-benefits to traffic/buses on the main road.
- *Bus frequency* - Less benefit is expected per bus for higher frequency routes because of 'conflicting' demands for priority, which cannot be all satisfied.
- *Type of bus priority measure* –For example, whether bus priority is centralised, decentralised or whether in combination with different techniques like gating.
- *Type of signal control* – For example, traffic responsive UTC systems such as SCOOT respond to natural fluctuations in traffic flow and can provide more efficient priority control than fixed time systems.

3.2.3. Automatic Ticketing:

Public transport ticketing has always been a relatively complex area. The privatisation of railways and deregulation of the bus industry have made the situation more complex in the UK. Integration in this area is essential for seamless journeys. As the number of participants increases the formulae for distribution becomes more complex.

Efficient ticketing and fare collection systems are critical to the effective operation of any PT service. They have a direct impact in terms of boarding times and the management of demand. In addition the information they can provide is a key input to the accounting and budgeting process, performance measurement and longer term strategic planning (Mellor, 1991).

Some existing ticketing schemes reduce boarding time, including travel cards (which are valid for different amounts of time), pre paid tickets (which the passenger validates either just before the journey or whilst boarding the bus) and exact fare only buses (where the fare is placed in a container and checked by the driver). Advanced magnetic cards can be used which can reduce the cost of transfers between different operators and modes (Brown, 1991). Examples of such systems are given in Table 3.8.

Table 3.8. Examples of automatic ticketing

Description	Type
PRESTIGE, Harrow, London, 1994.	Contact less smartcard.
CITYCARD, Operated by TRANSMO in various places in UK	Proximity card, which can be read and overwritten from 2 inches taking just 100 milliseconds. Multi purpose card which can be used for photocopying, car parking etc.
INIT (Gerland, 1996)	Contact less cards which is booked in and out while boarding and alighting and fare is debited to bank account
OCTOPUS, Hongkong mass transit.	Contact less cards read when passing through a turnstile and deducts money from its value
Finland (Oorni et al, 1997), Taipei (Taiwan) (Chang et al, 1997)	Multipurpose, multimode, and multi network (Finland) contact less cards
GAUDI, Marseilles, France (Blythe, 1997)	Hand Free card wallet, card in a wallet, which can communicate within a few meters of reading device.

Automatic ticketing systems based on smartcards (with a programmable electronic chips which can read, store and process information and be updated if placed close to reader), can achieve further reductions in boarding time. It also offers secure data transfer, large memory capacity to widen its purpose and can perform complex security validation calculation for higher reliability and resistance to fraud (Casey et. al., 2000).

Automatic ticketing systems can enhance bus services in a range of ways:

- Improved ticketing methods like smartcards reduce boarding time as transactions are quicker, which in turn will reduce the journey time by reducing dwell time (in one example, boarding time per passenger decreased from 7 seconds to 3.2 seconds when smartcards were introduced -Haworth et al, 1995).
- It provides an opportunity for users to have easier transfers and seamless journeys. Integrated ticketing, which can be used over wider areas and multiple service providers help reduce stress in transfers between different services and modes (Gerland 1996).
- It can induce an increase in patronage due to better level of service (Oorni et al, 1997).
- It can also provide data for operators for more efficient operation and management.
- It helps to reduce fraud by checking validity of tickets and concessions.

- It can also help to induce positive response from users due to multiple use (for example 'Hanaro' in Korea, which can be used to pay fare in different modes and buy goods in stores, Nelson et. al., 2001) and ease in transaction where direct debit to bank accounts or deduction of a pre-paid amount is carried out (Oorni et al, 1997).

These impacts will be affected by:

- *Ease and degree of use* of the service by the users. The system has to be easy to understand and used extensively by the users to have the maximum impact.
- *Type of ticket*: Multiple use, which can be used for wider services (like photocopying and even buying goods) and across modes and travel zones are more popular and appreciated (Oorni et al, 1997)

3.2.4. Automatic Enforcement:

The benefits to buses from bus lanes can be greatly reduced if they are violated by other traffic. Enforcement by police officers or patrol vehicles is not always effective as this is labour intensive and is generally not a high priority for deployment of resources (Turner et. al., 1996). Also obstruction at bus stops can increase delay due to reduced accessibility for both the bus and the users (bus stops further away from the kerb at an angle).

Automatic methods of enforcement could play a major role in enforcing viable bus lane and bus stop compliance. Cameras can be used to monitor bus lanes for enforcement purposes. Either a mobile camera is fixed onto buses to monitor the whole length of the bus lane or a roadside camera can be positioned at points along the bus lane (e.g. where regular offences occur). Both types are used to improve the level of compliance and are accompanied by signs advising of the existence of camera enforcement. In some cases, motorists are warned to deter them from repeating the offence (e.g. by display of their registration number in a variable message sign). In other cases legal proceedings may be taken provided the equipment used provides sufficient information of a high quality. Table 3.9 provides some examples of automatic camera enforcement systems.

Offences have been observed to decrease (Wiggins, 1998, Naganuma 1995), which improves access to and egress from bus stops and results in less obstruction of bus lane. Camera enforcement of bus lanes and bus stop offences can bring about reduction in the occurrence of moving and stationary bus lane/stop violations to bring about:

- A reduction in bus journey time due to improvement in access and egress from the bus stops.
- Improvements in reliability and regularity due to the reduced quantity of violations.

Table 3.9. Examples of Camera enforcement:

Description	Type
Birmingham (Wiggins, 1998)	Mobile digital cameras, which can send images directly to the control centre and with VMS to warn driver.
London (Turner and Monger, 1996).	Bus mounted dual camera system (in the bus) recording to a VHS recorder Various types of technology Infra red camera on the bonnet for number plates and colour camera in the bus linked to GPS equipment for location
Japan (Naganuma, 1995).	This system records the time taken for infrared radiation to be reflected from a vehicle back to an overhead supply/detector. The time taken depends on the height, and therefore type, of the vehicle. If a car is detected then a warning message is issued onto a variable message sign.

The scale of these impacts will be affected by:

- *Site condition*, for example if traffic flow is very high and queuing or there is extensive frontage activity, violations may be more likely.
- *Type used* - Used in conjunction with information systems (e.g. VMS sign displaying registration number of offender) increases its effectiveness.
- *Regulation* – There is a less likelihood of these measures being totally self-regulatory. Equipment providing sufficient information of a high quality backed by a legal framework for prosecution can deter repeat offenders.

3.2.5. Demand Responsive Transport System, (DRTS):

Demand Responsive Transport system is an intermediate form of transport, somewhere between bus and taxi and covers a wide range of 'on demand' transport services ranging from less formal community transport through to area-wide service networks (Nelson 2002). DRTS enhances the level of service of PT with a more flexible management of the routes served, thus approaching the flexibility so far provided by individual and collective taxis. However flexibility is dependent on cost and the operator may offer a service with well-defined rules and flexibility. DRTS was first investigated during the late sixties, giving origin to a first generation of applications, largely based upon manual scheduling and advance booking. Subsequently, interest in the concept diminished, but it is now regaining the attention of operators and local authorities due to two main reasons (Morgan et al, 1997):

- Sub-urbanisation, and demand for mobility by the elderly and disabled for which conventional services are less appropriate.
- Technological developments (AVL systems, networking, scheduling and mapping software, improved communication systems etc.) to implement a cost-effective service with enhanced methods of reservation, fleet allocation and route optimisation.

Some examples of DRTS using ITS measures are given in Table 3.10.

Table3.10. Examples of DRTS

Description	Model
ATAF, the PT company of Florence, Italy: (a) Urban transport service for disabled people and (b) Public transport for low demand areas A travel and Dispatch Centre (TDC) manages operations, from processing the user request to trip assignment, services scheduling and user information (Ambrosini, 1996)	Services provided on booking. Predefined set of possible routes. Actual routes followed determined by demand. Flexible time tables. Time limits for presentation of requests. Uses telephone to get requests and a service management workstation with software for trip assignment, service schedule and service data management.
SAMPO, The main objective of this European Commission funded project was to assess the potential and effectiveness of using ATT technologies for the implementation and operation of DTRS. Demonstrations have taken place at four test sites in four different European countries (Nelson et. al., 1997)	Vehicle location and monitoring, static and dynamic scheduling, assignment and route optimisation, booking and reservation systems, smart-card technology, passenger information inquiry and display, in-vehicle terminals, meters and display systems and Travel Dispatch Centre (TDC).

Four levels of DRTS have been generally defined in prevalent systems (Engels, 1996)

Level 1: Predefined timetable and route. The service is different from traditional services according to the length of service operated, which is dependent on bookings.

Level 2: A partially predefined timetable and route with deviations to predefined stops. A basic route is scheduled in advance and a line serving this route is operated, independent of booking. Other predefined stops can be served if requested.

Level 3 Stops in a region: Predefined stops are served on the booking of customers. The route of the vehicle will be optimised according to different optimisation criteria, for example, the minimum waiting time of the customers, the minimum roundabout factor of the customer and the minimum number of vehicles or vehicle kilometres.

Level 4 Point in a region: Lines that transport between all points on demand, at any time, similar to a taxi service. This concept is especially important for specific user groups, for example people with no or very low capability of going to a stop, like the elderly and the disabled. Examples of DRTS systems are given in Table 3.10.

Benefits observed from use of these systems include:

- Improved area wide access to the services and increased reliability by increasing efficiency.
- Helps reduce social exclusion and retain people in areas of declining population.
- Increased patronage in some cases where these schemes were implemented, for example the total number of passenger increased by more than 900 users in Campi (Italy) with improved DRTS system and 74% of passengers interviewed rated the system as either 'good' or 'excellent'. (Nelson, 1997).

These impacts will be affected by:

- Level of service offered and technology used. It can be managed more efficiently using trip assignment algorithms and real time information for both the operators and users.
- Characteristic of the served area, for example demand for such service and how the area is served by regular bus services. For example, in an urban area the regular service may require to adapt to the needs of the mobility requirements of a 24-hour society with such systems.

It should be noted here that most DRTS systems have been run on trial basis and schemes running for longer periods have been subsided (Ambrosini, 1999) and in the urban context the potential for telematics based DRTS is as yet largely unproven (Nelson, 2002).

3.3. Summary of Impacts, benefits and Influencing Parameters:

From the review of ITS user services in section 3.2, it can be concluded that the different ITS measures have different impacts. These impacts can be a direct (primary) impact, for example reduction of journey time due to improved ticketing or bus priority or an indirect (secondary) one, for example increase in patronage due to improved level of service with introduction of bus priority. The major impacts (Tabulated in table 3.11) that can be attributed to these measures include:

1. Behavioural change in user responses. For example passenger information could help users to choose optimal routes to reduce their total journey time and/or for convenience, and selective detection could change choice of route as it helps in reducing journey time of routes where the measure is used. Information can also help users to minimise waiting time (for e.g. with real time bus arrival information, users can time their arrival to reduce waiting at bus stops or can use the waiting time more beneficially if they are already at the bus stops).

2. *Possible temporal behavioural change and positive responses to the measures.* Information disseminated can act as advertisement of services, and along with enhanced ticketing and enforcement can change public attitude towards transport.

3. *Perception of change in LOS of bus service.* ITS measures like passenger information also help to reduce the perceived cost of waiting by reducing the stress of waiting at bus stops. Change in journey time variability with bus priority and enforcement to improve regularity/punctuality can also improve the image of bus service.

4. *Real change in LOS of the service.* Reduction in boarding time (automatic ticketing), delay at stops (enforcement) and junctions (bus priority) improve journey time and reduce operating costs. Reduction of headway variability with 'differential' bus priority using selective detection could help to reduce waiting time. Change in level of access to the service and inter and intra modal transfer can be improved with information and integrated ticketing.

5. *Impact on patronage and mode choice* due to reduction in total cost and improvement of level of service, though not clearly evidenced could have been achieved, however there were evidence of increase in patronage.

6. *More efficient planning and operation* of the service with better data availability and management. ITS can also help the operator by helping to control fraud.

3.4. Conclusion

Different ITS measures can have similar impacts but for different reasons; for example improved ticketing, bus priority and automatic enforcement decrease in-vehicle time but are due to decrease in boarding time, reduction in junction delay and improved access and egress from bus stops respectively i.e., the parameters affecting these impacts would be different for different measures.

For example, passenger information may have a direct impact on both actual and perceived waiting times whereas bus priority may have a direct impact on waiting time whereas the perception may be improved indirectly due to better regularity/punctuality of the bus due to this measure. The impacts can be summarised as discussed in the following paragraphs.

Table 3.11. Summary of Impacts of ITS measures and influencing parameters

Measures	Impacts	Influencing Parameters
1. Passenger Information: a) Pre-trip	1. Change in users responses, which improve optimum route/service selection, reduce waiting time and stress while waiting at bus stops. 2. Ease in transfers at interchange • Perception of improved LOS and change in attitude to PT. • Advertisement of the service • Can induce mode and patronage change	Reliability of the system and bus service • Location and accessibility of the system • Market penetration and extent of use • User friendliness, organisation and display of information, usefulness of the information provided. • User category • Stand alone or a part of package • Network condition
b) At Stops	1. Change in users responses, which improve optimum route/service selection, reduce waiting time and stress while waiting at bus stops and provide a feeling of security/safety • Perception of improved LOS and change in attitude to PT. • Can induce mode and patronage change	• Reliability of system and bus service • Frequency of service • Location of bus stop • User category and period of day
2. Bus priority at signal controlled junction using selective detection	1. Reduce junction delays to improve travel time and reduce operating cost 2. Improve journey time variability to reduce waiting time • Can induce mode and patronage change • Perception of improved LOS and change in attitude to PT.	• Reliability of the system • Flow and capacity at junctions • Link type. • Bus frequency • Type of bus priority measure • Type of signal control • Time of the *day*
Automatic Ticketing	1. Reduction in boarding time to improve travel time and reduce operating cost • Ease transfers and help users to have seamless journeys • Provides planning and operational data for operators and reduce fraud • Can induce mode and patronage change • Perception of improved LOS and change in attitude to PT	• Reliability of the system and ease and degree of use • Type of ticket • Technique
Enforcement	1. Improve access and egress from bus stops and decrease obstruction in bus lanes to improve journey time and variability • Can induce mode and patronage change • Perception of improved LOS and change in attitude to PT.	• Reliability of the system • Site and network condition • Used in conjunction • Regulation
Demand Responsive Transport System (DRTS)	1. Ease of access to service and increase in reliability • Can induce mode and patronage change with actual/perceived change in LOS.	• Level of service offered, technology used and reliability of the system. • Characteristic of the served area

Note: Numbered impacts denote primary impacts.

ITS measures reviewed above could help *to achieve one or more of the requirements* (refer section 2.2) *needed to improve bus service quality.* Measures like bus priority at signal controlled junction and enforcement helps to improve service reliability, regularity and punctuality and passenger information can improve user perception. These measures along with improved ticketing and information could decrease the overall travel time of buses. Valid and useful information can be provided at all stages of the journey, which would along with improved ticketing, help in smoother transfers and seamless journeys for users. All these measures help to improve the image of the service and give a better perception of the level of service provided.

ITS measures can complement measures used for enhancing bus services. For example the barrier of uncertainty of timing and reliability in integrated transportation can be improved with better and reliable information and automatic ticketing methods can solve the complexity of cost. Bus lane enforcement could decrease the amount of violation to make bus lanes more effective. These measures would also help in service enhancements. For example, with the decrease in vehicle running time from various measures operators may be able to increase the frequency of service. Information at bus stops about bus arrival times reduces anxiety and help users to feel safer. With telematics, DRTS could be made more feasible and efficient to serve areas with low demand.

ITS measures can also replace other measures, which may not be feasible in certain circumstances. For example bus priority at signal-controlled junctions can replace the traditional bus lanes where land and road space is at a premium. Improved DRTS can help to alleviate the problem of providing regular bus services where demand is too low to be economical. It should be noted here that these impacts would be influenced by how and to what extent user respond to these measures.

4. Evaluating Impacts of ITS Measures in Bus Service

The Evaluation method of any transport measure is generally governed by the boundary set by the requirements specified by the target audience and the type of the measure used. For example, within the context of ITS measures in public transport, a local authority considering a public transport information system at bus stops requires pre-implementation evaluation of the potential systems and their probable impacts. They might seek information on the system practicality, affordability and sustainability along with social, economic and environmental impacts and benefits. Post implementation evaluation may require evaluation of technical efficiency, optimal use, system accessibility and target achievements.

However in this research we are focussing on pre-implementation evaluation of operational system benefits of ITS measures. In other words, assuming a certain level of operational benefits and behavioural response of the end users to the system how can we present the scale of benefit (specifically journey time) on a bus service network to influence decision makers? We are therefore considering potential operational benefits in different scenarios, rather than the actual performance achieved by specific systems.

This chapter:

- Discusses a model framework for evaluating ITS impacts.
- Outlines the pre-implementation methods currently in use and discuss the role of transport modelling within this context.
- Reviews the features that models need to represent.
- Gives a general overview of the current state-of-art in modelling and the requirements for modelling impacts of ITS measures in public transport within this context.
- The chapter concludes with the selection of ITS applications and modelling approaches, which are taken forward as case studies in this research.

4.1. Evaluation Model

A model framework as shown in figure 4.1 can be used to illustrate the overall evaluation procedure and choices/decisions involved. The model is elaborated step wise below:

- Benefits accrued from any transport scheme can broadly have economic, social and environmental impact.
- The Evaluation method would be bounded by the requirement specification of the

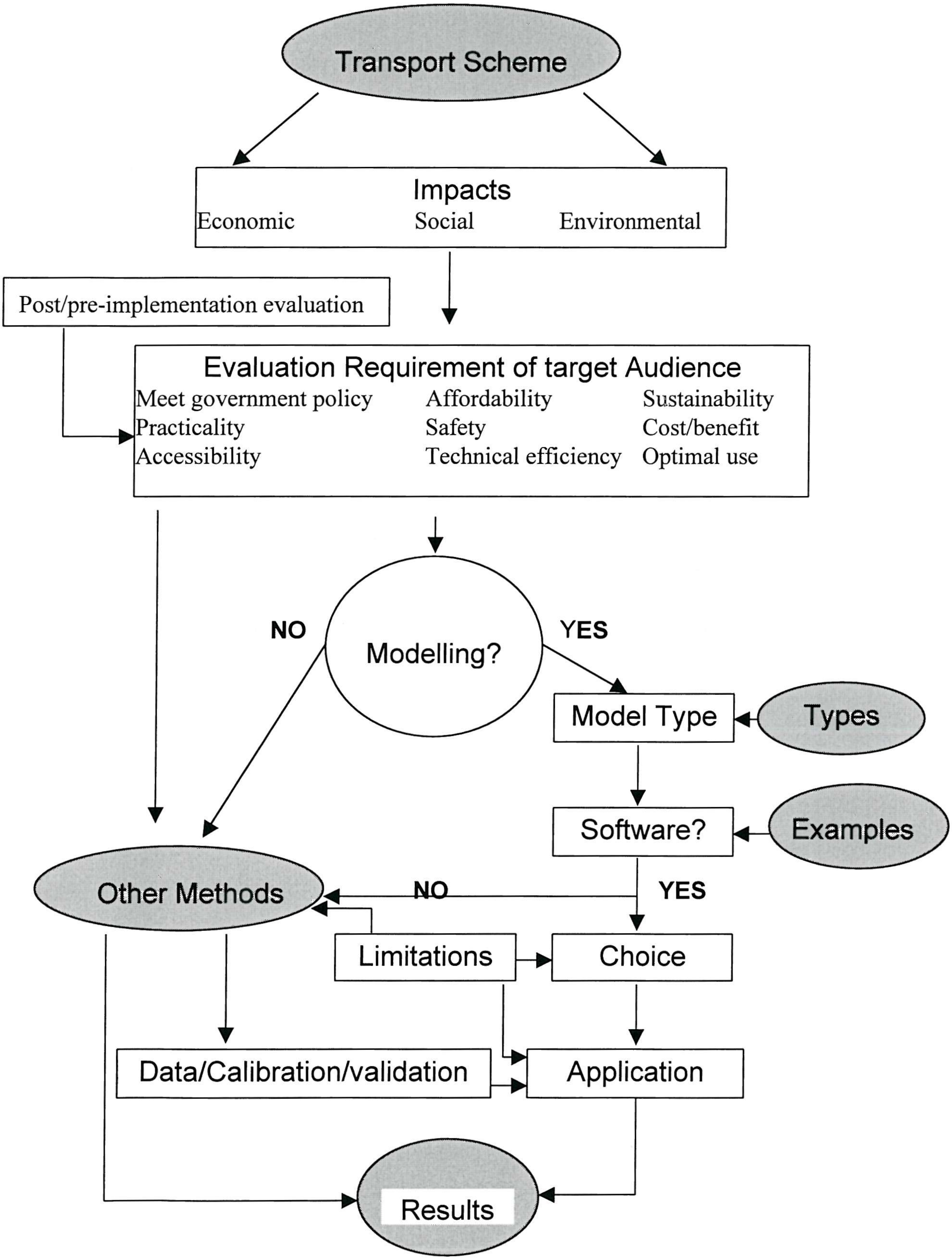
target audience depending on whether it is post or pre-implementation evaluation of the scheme. For example bus operators may be interested in cost benefit evaluation whereas policy makers may also be interested on whether it falls within the transport policy (regeneration, social exclusion, integrated policy etc) and wider environmental and safety implications. Post implementation evaluation would be targeted at evaluating system efficiency, optimal use of system and target achievements whereas pre-implementation evaluation would be targeted at evaluating system practicality, affordability, sustainability, acceptability and potential benefits.

- Different evaluation requirements will require different evaluation techniques. For example, before and after studies can be used to evaluate the benefits of bus priority at signal-controlled junction by measuring the decrease in journey time for buses (link and whole journey) and dis-benefits (increase in journey time) to non-priority vehicles. Changes in boarding times may be recorded for different types of ticketing methods and changes in number of traffic violations may be measured to study the effectiveness of camera enforcements.

  Similarly, video cameras have been used to study user behaviour while waiting (e.g. stress and tendency of leaving the stop to return later) where real time passenger information is displayed. Stated preference surveys can be used to find out how users value the services provided, extent of use etc. Surveys can also be used to find out the extent and category of information sought at information kiosks, uptake of new ticketing systems etc. Impacts of some ITS measures (for e.g., predicting system impacts such as bus priority using selective detection) can be evaluated using analytical methods.
- Transport modelling can be used for evaluating a wide range of transport schemes. For example simulation modelling may be used to evaluate a range of ITS applications such as bus priority at signal controlled junctions to predict changes in journey times, dis-benefits to non-priority vehicles and in the case of selective differential priority to measure difference in the regularity of bus services and waiting time. If modelling is required or have the potential for better evaluation choose the type of model that best suits the purpose and from examples (previous use, experience) a transport model (software) can be selected.
- If an appropriate software tool with all the required attributes cannot be found, evaluation can either be carried out using other methods or choose the best model available depending on the limitations.

- Evaluation of some of the impacts (section 4.2) using other methods than modelling could be necessary for input data, calibration and validation of the model used.

Figure 4.1 Model for evaluating impacts of ITS measures in bus service.



4.2. Pre-implementation Evaluation Methods

It is usually necessary to evaluate the impacts of any measures prior to their implementation to justify their use. Pre-implementation evaluation can be done in a number of ways namely:

Use results of previous relevant studies: The likely impact and benefit of any measure can be approximately gauged using results from previous similar schemes where available. The quality of this approach depends on the quantity and quality of relevant data from other schemes and the similarity of the scheme in question. There are many potential problems. For example, different system operations, user categories and time periods may be involved. This method cannot discern the effect of parameters not represented in the database, which means that the result may neither be transferable nor provide a firm basis for future implementation in a new location. Results from previous studies cannot be used to test a wide range of scenarios, over the whole network and for long term evolution.

Stated Preference Survey: These surveys of the target population may be used to identify user perception, requirements and probable response to schemes before their implementation. However a common problem with this is how realistic the response is. Again, the cost of stated preference surveys could be high when large networks are involved. It is not uncommon, for example, for revealed preference surveys from an ITS application to differ significantly from stated preference survey results for the same applications.

Analytical Methods: Some of the ITS measures impacts can also be evaluated using analytical methods. For example, bus delays savings through the implementation of green extensions may be estimated at isolated junctions according to signal timings and bus detection location. However this method is limited in scope and application. The requirement to overcome limitations of all these methods leads to the use of 'transport' modelling of some form.

Transportation Modelling: 'Any prediction has to be based on sound theoretical statement and assumption. A model is a representation of a system of interest concentrating on certain elements important for its analysis from a particular point of view. Mathematical models attempt to replicate the system of interest and its behaviour using equations based on theoretical statements and assumptions. These models help decision-makers to make decision regarding transport policies for an effective transport system. However we should remember that transportation modelling is only one of the main elements in transport planning and is just a tool to help decision-makers choose the best alternative' (Ortuzar, 1994). Parameters influencing the impacts can be identified and modelled to assess the impacts and benefits of each individual measure. It can then be made transferable to predict the benefits for different scenarios in the whole network for future implementation.

One of the conclusions drawn from the review of ITS measures is that there is variation between impacts of individual measures and even if they have the same final impact the influencing parameters could be different (refer section 3.4). Furthermore different measures could have different impacts, for example passenger information could have implications in optimum route choice but could be unaffected by improved ticketing or enforcement measures. In other words an impossibly thorough transport model would be required to model all the impacts of different ITS measures.

Other evaluating methods could also be necessary to evaluate some of the impacts for input data, calibration and validation of the models. Examples include, the extent of use of the systems, values perceived, reduction in boarding times etc. Some of the impacts of ITS measures may not require modelling for evaluation; for example, bus delays savings through the implementation of green extensions may be estimated at isolated junctions according to signal timings and bus detection location and 'satisfaction/use' evaluation for passenger information systems may require survey/questionnaire approaches.
Therefore we can conclude that:

- More than one evaluation method may be required for pre-implementation evaluation of operation impacts of an ITS measure
- The potential of transport modelling to reduce many of the limitations of the other methodologies underlines its importance.
- Depending on the level and requirement of the evaluation and type of ITS measure different modelling approaches and evaluation methods could be necessary.

4.3. Requirements for Modelling Impacts of ITS:

As stated before the requirement to overcome limitations (refer section 4.1) of other methods lead to the use of transport modelling to evaluate ITS impacts where appropriate. This section reviews the features that models need to represent.

The provision of ITS measures in public transport could bring about behavioural changes in the users and influence the traffic in the network with significant implications in trip generation, trip distribution, mode choices and/or assignment (ref. section 3.3). The model may therefore need to address one or more of the following issues depending on the ITS application(s). Analysis in this research of the impacts of different ITS measures (e.g. Table 3.11) led to the identification of some of the modelling requirements for these measures. These are discussed in the following sections and summarised in Table 4.1.

4.3.1. Behavioural Changes and Response to Schemes

ITS measures could induce short and long term behavioural changes which includes:

- *Perceived change in level of service*: Surveys (Atkins et al, 1994, Brown, 1997) have shown that with introduction of passenger information users may perceive an increase in the level of service in term of reliability, regularity, accessibility (availability and ease in transfer), feeling of security and decrease in stress while waiting. Other ITS measures may also be visually observed (improved ticketing, enforcement and bus priority) and experienced (improved ticketing, DRTS) by the users to give a feeling of an improved bus service.
- *Change in passenger arrival pattern*: Passenger arrival patterns at bus stops could change with the provision of passenger information and changes in regularity or punctuality brought about by bus priority. With pre-trip information and buses being more regular/punctual we can expect users to arrive more closely to the arrival times. With real time information at bus stops, passenger can use the waiting time for other activities instead of waiting for the bus to arrive at the stop (section 3.2.1.2).
- *Optimum route selection*: For example, with pre-trip information, users can choose the route/service most convenient to them. Information at stops allows them to wait for the best service or take the first one that comes to the stop or use some other means to reach to their destination. Bus routes with bus priority may reduce travel time and allow an alternative (re-optimised) route selection. Modelling for route choice with information would therefore require simulating spatial real time passenger and vehicle arrival times and the resulting behavioural responses of the users.
- *Temporal changes*: For example, feedback potentials that are created by enhanced information systems and travel and traffic conditions resulting from all ITS measures could result in a dynamic change in attitudes and lifestyles in the long run and

influence travel decisions in future.

Reproduction of user behaviour *could therefore be an essential requirement of the assessment tool. This gives rise to the second requirement of modelling impacts of ITS measures; passenger modelling*

4.3.2. Passenger Modelling

A key impact of many of the ITS measures has been the short and possible long term behavioural change and user responses to the measures (refer section 3.3). For example, enhanced ticketing methods reduce boarding times and hence journey duration (table 2.8). To model this there needs to be a direct relation between link times and passengers boarding as the number of boarders for different services would be different. Explicit passenger modelling is then required.

With passenger information, the in-vehicle time for a journey between an origin and destination could be reduced due to the choice of optimum routes and services reducing the overall passenger travel time over the network. Passenger information may also affect other aspects such as arrival profiles at bus stops and hence waiting times. Similarly, to determine the benefit accrued by users due to reduction of journey time by bus priority and enforcement, passenger modelling is necessary. *It therefore appears to be imperative for the model to represent passenger demand choices and movements when modelling ITS applications.*

4.3.3. Impact on Travel Demand and Supply

Provision of real time pre-trip and bus stop passenger information, integrated information and efficient demand responsive transport systems have evidenced increase in patronage of public transport. Surveys (e.g. Higginson et al, 1995) have shown that people are more likely to travel more when the service is better, thus **generating** more trips.

Areas with better service (enhanced by ITS measures) could attract more trips. User response regarding destination, travel mode, time and route could vary with real time information (refer section on 3.2.1). This means the trip **distribution** could be affected by ITS measures.

With enhancement in service we can expect **mode change**, while this may not be significant in schemes reviewed in isolation, the combined effects of the measures on the level of service and change in user cost could induce mode change. Use of information to inform car users about traffic congestion and availability of other option like park and ride can also induce change in mode. *In other words, the model may need to address the* ***dynamic change in travel demand and mode choice.***

Impact in traffic assignment: Bus priority measures may change the travel time of private mode, which could induce changes in routes taken by them. It could also lead to an increase in congestion levels and could initiate mode shift (Mannering, 1994); consequent crowding in buses could reverse the situation. With information, users also have more choice in terms of route, mode, service and trip schedule. This could bring about dynamic changes in traffic assignment and hence an ***integrated demand and supply model*** may be necessary.

Interaction between buses and other traffic:

The level of congestion in the network affects bus travel time. Furthermore bus dwell times and hence journey time is also affected by entry and egress of buses at bus stops. This time may be affected by the traffic flow (more congested more difficult the access). Similarly at locations without bus-bays buses could also delay other vehicles by blocking the road. The level of priority given to buses at signal controlled junctions may also depend on the congestion (degree of saturation) on non-priority routes, ***integrated multi modal modelling*** *may therefore be required to address these dynamic changes in traffic assignment and on-street interaction between buses and other traffic.*

4.3.4. System Representation.

Depending on the situation and requirements explicit modelling of the ITS system itself may be needed. For example, ITS measures like bus priority at signal-controlled junction can be more effectively evaluated by modelling the system itself. Firstly this would provide a way to evaluate the technical feasibility and working of the system itself. Secondly as the impact is very site specific, for example it is dependent on parameters like signal types, control and link type and vehicle flows, only the modelling of the system itself would give results comparable to field observations.

Table 4.1. Modelling Requirements for ITS measures

	Behavioural changes and user responses				Passenger Modelling	Integrated demand and supply modelling	Integrated multi-modal modelling		System Representation
	Perception of LOS	User arrival profile	Optimum Route selection	Temporal changes			Traffic assignment	Interaction between modes	
Pre-trip Information	√√	√√	√√	√	√√	√			
Bus stop Information	√√	√√	√√	√	√√	√			
Bus priority at signal controlled junctions	√	√	√	√	√√	√	√√		√√
Improved Ticketing	√		√	√	√√	√			
Automatic Enforcement	√			√	√	√		√√	
DRTS	√			√	√√	√			√√

Note:

√√ Model attribute required to evaluate primary impacts of the ITS measure

√ Model attribute required to evaluate secondary impacts of the ITS measure

4.4. Modelling Procedures and Transport Models

This section consists of an overview of modelling procedures and examples of commercial transport software that are used in practice or have been proposed. A more detailed review is given in Appendix A.

4.4.1. Classic Transport Model

Developments over the years have resulted in a general structure of transport models, which has been called the classic transportation model. It is more commonly known as the four stage model as it is generally presented as a sequence of four sub-models:

1. *Trip generation* – The first stage, trip generation, is the estimation of the total number of trips generated and attracted (trip ends), by each zone of the study area depending on demographic and economic characteristics of an area.

2. *Trip distribution* – In the second stage the trips generated in the first stage are allocated to particular destinations, in other words their distribution over space to produce a trip matrix.

3. *Modal split* – In the third stage the issue of mode choice, that is allocation of the trips to different modes, usually private and public transportation is determined. Modal split models can be *trip end models* where the mode choice is made before distribution or *trip interchange models* where the mode choice is done after trip distribution.

4. *Assignment* – The last stage requires the assigning of trips by each mode to their corresponding networks, typically private and public transport. Though the assignment in public and private transport is carried out separately there can be interaction where the output from one network can be used in the other. It is usual to seek network *equilibrium* where the allocation of trips is such that all the travellers are using the best route.

Some examples of the widely used transport models based on four stage models are:

- ***EMME/2:*** EMME/2 is a 'state-of-the-art' multi-modal transportation planning system based on the four stage model system, which offers users a wide ranging sets of tools for demand modelling, network analysis and evaluation across all the models. It can be used as a classical four-step model to multi-modal assignment with direct demand function as well as trip chains (INRO consultants, 1993).

- ***EmandS:*** EmandS links EMME/2 and SATURN to result in a detailed junction modelling integrated with a multi-modal package (Bolland et al., 1992)

- ***TRIPS:*** TRIPS (MVA Sytematica, 1996) is an integrated transportation model package which represents the state-of-art for modelling based on the classic model structure using aggregate and zonal data. It has a flexible structure allowing independent use of elements such as highway assignment while also being suited to a more comprehensive approach. Its trip generation, trip distribution and modal split components are based on conventional methods (multiple linear regression, gravity model, growth factoring, logit model). It also provides matrix estimation model, which can take advantage of a variety of data sources including trip ends, link counts, license plates etc.

4.4.2. Disaggregate Models.

In contrast to the aggregate methods used in classic four stage models disaggregate models (second generation) operate at the level at which the travel decision is made, i.e. the household or individual, and can be expected to capture the behavioural processes that determine trip making behaviour. In general, discrete choice models postulate that: 'the probability of individuals choosing a given option is a function of their socio-economic characteristics and the relative attractiveness of the option.' (Ortuzar et.al., 1990)

Discreet choice models are a powerful method for disaggregate demand modelling and are usually based on random utility theory. Individuals are assumed to act rationally and possess perfect information and thus select the best option from a set of alternatives to maximise their net personal utility. Some examples of models based on disaggregate models are introduced in the following paragraphs.

- ***Dutch National Model system:*** Dutch National Model system (Gunn & Ben-Akiva, 1993 in Chaterjee 1999.) is a good example of the practical application of disaggregate modelling principles. It is designed to be a system of models to predict long term developments in travel by all land-based travel modes under various explicit hypothesis about developments in national socio-economic structures, land use patterns and transport policy scenarios (increased fuel taxes, vehicle purchase taxes, improvement of public transport, etc.).

- ***SATURN**:* SATURN (Simulation and Assignment of Traffic to Urban Road Networks) is a combined simulation and assignment model more suitable to analyse relatively minor network changes such as the introduction of one-way streets, changes to junction controls, bus only streets in other words traffic management measures where detailed analysis of traffic behaviour at junctions is required. However it can also be used as a conventional assignment model (Willumsen 1993). It looks at bus services as sharing road space and not as alternative mode connecting origins and destinations and providing interchange facilities.

- ***SATCHMO**:* SATCHMO (Saturn Travel Choice Model) is a multi-modal transport package to complement SATURN providing the facilities required to model behavioural responses by the trip makers (Arzeki et al., 1992).

4.4.3. Land Use Models.

Land use transport models like; LILT, MEPLAN, and TRANUS (Chaterjee 1999, www.modelistica.com/tranus/index.html) include the interaction between land use and transportation. Trip generation and destination are more directly related to land use attributes than in conventional methods, the choice of mode is dependent on the generalised cost of travelling by each mode and mathematical algorithms are used to assign trips to the network. They are largely based on spatial interaction modelled at an aggregate level and so do not simulate individual processes. Other problems with these models are a requirement for a large database, transferability to other areas, and the implied strengths of relationships between transport and land use.

4.4.4. Activity -Travel Models

The activity-based approach explicitly recognises the fact that the demand for activities produces the demand for travel. In other words, the need or desire to engage in an activity at a different location generates a trip. Therefore a rigorous understanding of travel demand will only follow from an understanding of how activities are engaged over a day or week. This approach is entirely different from the approach taken for the development of the classic models where statistical rather than behavioural relationship drove model development. Another important decision is the following recognition: as the activities engaged during a day are linked to each other, trips made to pursue them are also linked to each other; they cannot be analysed independently (Kitamura et. al., 1996).

Some examples of transport models based on Activity-travel models are:

- ***ELASIS model system:*** This model system uses trip chaining as part of a conventional modelling approach (Chaterjee 1999).
- ***AMOS:*** AMOS (Kitamura et al., 1995) uses travel pattern of individuals to generate response for different circumstances.

4.4.5. Dynamic Models

Traffic conditions in a network can be labelled dynamic whenever travel patterns change over the course of the day or day-to-day adjustment. Static network models fail to capture essential features of traffic congestion where traffic is not uniformly distributed over the modelled time interval and the temporal distribution of the traffic is not constant from day to day or within day where information is provided (Ben Akiva et al 1991). Fixed trip matrices are not expected to be a reasonable assumption in a congested transport environment where information is available. In such cases users respond dynamically by making adjustments to their journeys.

In response to the above requirements equilibrium models have developed, for example dynamic models such as CONTRAM (TRL, 1989) incorporate within day dynamics and simulation models such as SATURN (Willumsen, 1993) incorporate traffic interactions at junctions but they are still confined by equilibrium assumptions.

A number of frameworks have been proposed to account for these changes, for example the probability model for day to day, pre trip choices of departure time and route (Ben Akiva et al., 1991). Other examples are, non-equilibrium approach where both within day and day to day fluctuations are modelled as a stochastic process in an assignment model (Cascetta et al., 1994) and doubly dynamic framework to consider system evolution both during a single day period (within day) and following periods (day to day) (Nuzzolo et. al 1999).

Some examples of transport models based on Dynamic Models are:

- **CONTRAM:** CONTRAM is an assignment models which calculates time varying traffic flows, queues and delays in a network from a set of time varying demands on the assumption that drivers are familiar with traffic conditions and choose routes which minimise their journey time or cost. It gives the flow, delays and queues for each link of the network, travel times and route for selected vehicles for different intervals of time, which enables a range of economic and environmental impact to be assessed (TRL, 1989). It assigns fixed routes to model public transportation.

Simulation models like MIDAS, INTEGRATION, DYNASMART (refer section 4.4.8.) also uses the concept of dynamic changes in traffic demand and supply.

4.4.6. Artificial Intelligence Techniques

Artificial intelligence techniques have been used to model travel behaviour. This approach includes expert/knowledge based systems, fuzzy logic, neural networks and approximate reasoning to emulate and advance current understanding of the ways in which perception and cognition interact to produce intelligent behaviour (Yang et. al., 1993, Lotan 1993 and Vythoulksa 1994). The basis for this use is that the human brain possesses a complex way of thinking, remembering and problem solving capability, which cannot be represented by conventional computing techniques.

4.4.7. Evolutionary Method:

This is an alternative approach to travel demand modelling, which explicitly considers changes over time in work trip distribution (Levinson 1995). The behavioural theory underlying this model is not perfect network equilibrium of Wardrop or the supply/ demand equilibrium. It is more comparable to bounded rationality, where the costs of changing behaviour need to be considered as well as the possible sub optimality to that behaviour.

4.4.8. Micro-Simulation Models.

Simulation models attempt to simulate the network conditions. Macroscopic models like SATURN model the traffic flow in a network and attempt to use the concepts of cyclic flow profiles to simulate flow conditions. Microscopic simulation models attempt to model individual behavior.

- **Micro-simulation models**: MIDAS (Goulias et. al., 1992,) combine dynamic simulation of population with dynamic models of travel behavior. Assignment models like INTEGRATION (Berkum et. al., 1996), NETSIM (Smartest, 1997), PARAMICS (DRUITT, 1998) attempt to model the behavior of each driver and vehicle in a network.

Other models like DYNASMART (HU et al 1995 integrates macroscopic traffic flow models, path processing methodologies, behavioural rules (bounded rational), and information availability status into a single simulation assignment framework. Models like DRACULA (Liu et al., 95) with separate demand and supply model uses a framework of micro-simulation to model the day-to-day evolution of a traffic network.

4.4.9. Timetable Based Models

Public transport assignments have been using frequency based networks which could not address the problem of overlapping routes with corresponding lines and frequency aggregation . By using timetable based models, for example, TPSchedule (Pedersen, 1999) it is possible to describe travel behaviour more accurately. It is possible to use exact interchange times, to model hidden waiting time consistently and apply capacity restraints within each. Furthermore it is possible to distribute fares to every vehicle making it possible to predict economic feasibility of new lines and/ or new fare structures (Pedersen, 1999).

Nielson (1999) outlined a timetable based probit model for public transport assignment with an error component attached to the coefficient in the utility function making it possible to describe different aspects of passenger's choices, for example partial knowledge of the traffic network means they choose rationally according to their perceived utilities, different routes are often chosen for the sake of variation and different persons may have different preferences.

4.5 Comparative Evaluation of Transport Models

This section provides a comparative evaluation of existing transport models according to their capability for modelling ITS measures in bus services (Requirements for the modelling of these ITS measures are set out in section 4.3). It sets out the limitation of transport models based on four stage models and developments to address these problems using models based on other modelling procedures.

Limitation of four stage based models

1) These models can be used to model behavioural changes and user responses to schemes but have a number of limitations including:

- Aggregate methods: these methods cannot account for differences within user categories. The concept of different user categories having different perception of cost and value of time and different response to information and guidance is not addressed. For example, females are more likely to change their travel plan with pre-trip information (Mannering – 1994), and males with en-route information (Khattak –1993). Lower income groups and those with lower access to car adjust travel plans more readily (Mannering – 1994). People are more likely to alter or cancel trip plans for shopping than for commuting (Polak –1993).
- Deterministic and reproducible choice assumptions: There is no modelling of temporal changes in user behaviour, which may be brought about by the use of ITS measures.

2) These models are also limited in modelling the dynamic changes in travel demand, mode and assignment. For example, increase in patronage of bus services have been observed with introduction of ITS measures like passenger information and DRTS. These models however do not model variable trip matrix. Trip generation is made inelastic to the level of service provided, this can be unrealistic; for example, an increase in level of service would tend to increase travel demand and could influence the entire trip plan, including the decision to make the trip.

These models use static trip rates and traffic patterns. In unpredictable traffic conditions that exist in congested networks, with real time information, a trip maker is more able to respond with a range of simple changes to the route, mode, time, destination and frequency of trips. This could result in a dynamic trip matrix and flow pattern both within day and day-to-day. Furthermore any change in mode could result in spare capacity in the network. This new capacity of road networks can induce new trips and run counter to scheme appraisal with fixed trip matrix assumption (Hall, 1995).

3) Integrated demand and supply modelling is limited due to its rigid sequential decision process. Travel decisions are not always necessarily taken in that order depending on individual user characteristics. Travel decision is a complex function where a traveller decides to make a trip to a choice set of destinations in temporal space using other choice sets of modes and routes. With real time passenger information and public transport services like DRTS this rigid sequential process may not hold true as travellers may decide on a trip, mode and destination due to availability of a better information /service.

4) These models can be used for multi-modal traffic assignments but due their macroscopic nature interaction between modes, for example between buses and other traffic at bus stops cannot be modelled. The inability of simulating the functioning of ITS systems would also be a disadvantage in evaluating impacts of ITS measures like bus priority at signal-controlled junctions. Despite these limitations, these models still provides a point of reference to contrast alternative methods and compare different scenarios in strategic modelling.

Disaggregate models

Second generation, disaggregate demand models attempt to address behavioural change and rigid decision structure using a utility maximisation concept. Properties of disaggregate models include (Willumsen et al. 1993, Bates et al. 1997, Ortuzar et al 1994):

- They are based on theories of individual behaviour to enable better understanding of the underlying factors that influence travel decision, and are more likely to be transferable than conventional models.
- The consistency between supply and demand is improved by use of convergence procedures to ensure demand consistent with travel cost or using incremental equilibrium modelling which predicts the changes that would occur relative to the base cost to model variable trip matrices.
- They are generally more efficient statistically in terms of information usage of sample data as unlike in aggregate models, observations are not averages.
- As individual data is used all the inherent variability in the information can be used and less likely to suffer from biases due to correlation between aggregate units. For example individual behaviour may be hidden by unidentified characteristics associated with zones.

- They can be calibrated using revealed preferences or stated preference surveys, which may be helpful in exploring future scenarios.
- These models do not indicate which choice is selected but yields the probability of choosing each alternative and thus uses probability concepts.
- In principle, the utility function allows any number and specification of the explanatory variables, as opposed to the case of the generalised cost function with limited number of parameters. It therefore allows a more flexible representation of the policy variables, and the coefficient of the explanatory variable reflects the relative importance of each attribute.
- It is possible to specify disaggregate models to model:
    a) Time series models using multinomial probit model with panel data
    b) Bounded rationality decisions (where travellers exhibit inertia, i.e., seek to achieve a level of satisfaction than optimise, where options are eliminated using a set of criteria or some attributes may be more dominant)

Limitation of Disaggregate models

Within the context of modelling impacts of ITS measures, limitations of disaggregate models include:

- The underlying assumption in these models is that transport systems reach some form of economic equilibrium. Equilibrium approaches has been widely applied in practice. The use of models to provide advice on transport decision requires comparing alterative measures for which consistency is a pre-requisite provided by this approach; the state of art of such modelling is such that one seldom has to sacrifice too much realism to achieve it and it reduces the dependency on initial assumed costs (Ortuzar, 1994). However, the assumption that the system has settled down runs counter to among others, the dynamic changes due to introduction of ITS measures like real time passenger information.
- Change in user behaviours are modelled, for example individual choice is affected by the level of service (relative attractiveness) but it is more at an aggregate level. These models may not be able simulate individual choices in a dynamic network conditions. For example real time information would allow users to opt for a service which may in paper take a longer time to reach their destination but may suit their timetable/schedule or would actually be more optimal as the 'quicker' service has been delayed due to network condition. Utility maximisation approach

does not address the problem of trip chaining (trips are linked to each other) or initial inertia of choices (users do not change their behaviour up to certain threshold levels).

- There is a consistent use of variables in these models. At the end of assignment new flow levels and hence travel times will be obtained which could be different than the one assumed in demand modelling and reiterations does not always lead to a stable set of equilibrium (Ortuzar '94). In other words integrated demand and supply modelling is limited in scope.
- Similar to aggregate models the macroscopic nature of these models would not be able to simulate interactions of buses and other vehicles at bus stops for a fully integrated multi-modal modelling or functioning of ITS systems required to evaluate impacts of some of the ITS measures.

Further developments and their limitations

Activity based models like VISEM (Fellendorf et. al., 1995) classify population into behaviourally homogeneous groups and generate trip chains derived from activity chains. These models are more suited than conventional models to account for travel behaviour and models travel demand combining the first three steps of the classical four-stage model. However they are:

- Very dependent on activity travel diaries from which an heuristic procedure is applied to transform the empirical mobility of travel diaries to a reduced set of selected activity chains. Relationships may still need more research to be used confidently.
- Data availability for modelling may not be complete.
- The available models do not take into account the temporal behaviour changes in users and a lack of assignment module would hamper in providing a total picture where the dynamic network conditions would affect demand modelling.

Dynamic models like CONTRAM incorporate within-day dynamics but are still confined by static trip matrix. Furthermore they are usually assignment models and would not deal with travel demand. Dynamic models based on simulation like DRACULA evolves day to day and consist of separate demand and supply models. Like other simulation models these model vehicles and may not be suitable to model individual user behaviour.

Models like SATURN are assignment models and are not multi-modal models, however bus routes can be entered explicitly. Demand responsive modelling (SATEASY) allows trip generation and suppression using elasticity concepts but does not reflect what these diverted or suppressed trips do. Public transport modules in SATCHMO build multi-modal transport network and provide facilities to model behavioural responses by trip maker. The macroscopic nature of these models would still inhibit modelling of individual behaviour in a dynamic network.

Micro-simulation models like INTEGRATION, DYNASMART and STEER analyse traffic flows in terms of vehicles as individual entities. These are however assignment models (therefore the impact on trip generation, distribution or mode choice cannot be modelled) which use driver behaviour (gap acceptance, car following and lane changing behaviour and range of parameters like speed acceleration chosen from a distribution), information, experience etc to assign vehicle flow from a given or generated demand matrix (fixed or dynamic).

Packages like NETSIM, PARAMICS have a facility to model public transport as individual vehicles but do not model passengers and thus do not account for change in passenger behaviour. These models can however be used to model ITS systems like bus priority at signal controlled junctions.

Packages like MIDAS and DRACULA combine dynamic simulation of population and dynamic models of travel behaviour. The framework consists of separate demand and supply models. These are however developed for car trips and model driver behaviour. Though there is a growing use of micro-simulation models, most of the models are still in the research stage and concern over the validation of parameters used have been voiced by professionals (Flyod, 2000). Data requirements are also greater than conventional measures and they would also be deficient in modelling strategic behaviour like route choice.

- On the basis of the preceding discussion, Table 4.2 presents a matrix of requirements for modelling impacts of ITS measures and model attributes. Comparing this matrix with the

Table 4.2. Matrix of requirement for modelling impacts of ITS measures in bus service and model attributes:

	Behavioural changes and user responses				Passenger Modelling	Integrated demand and supply modelling	Integrated multi-modal modelling		System Representation
	Perception of LOS	User arrival profile	Optimum Route selection	Temporal changes			Traffic assignment	Interaction between modes	
Four stage models									
EMME/2	p				√	P	√	P	
TRIPS	p	√	√		√	P	√		
Disaggregate models	√		√		√	√	√		
Land use Models									
TRANUS/MEPLAN						√	√		
Activity Travel models									
VISEM	√		√	√	√		√		
ELASIS	√		√	√	√	√	√		
Dynamic Models									
CONTRAM							√		
DRACULA				√		√	√		
Simulation models									
SATURN									
SATCHMO	√		√		√		√	P	
Micro-Simulation Models									
INTEGRATION							√		√
DYNASMART							√		√
NETSIM							√	P	√
PARAMICS							√	P	√
STEER							√	P	√

Note:

√ : denotes that the model can be used to model the impact due to ITS measure in bus service

P: denotes that the model can be used to model the impact due to ITS measure in bus service to some extent, for example perception of level of service can be reflected in TRIPS public transport module by changing the weight of parameters like boarding penalty, waiting time, and mode specific penalties

Table 4.1, which shows the matrix between individual ITS measure and modelling attributes required to model their impacts we can deduce that:

- Different ITS applications have different characteristics and impacts, which may require differing modelling approaches. The approach selected may therefore have to be application specific.
- There is no single model available that can be used to address all the requirements.

A single model may not be adequate to address all the impacts of one ITS measure.

These facts lead us to many options within the broader objective of this research, i.e., to evaluate and illustrate the impacts of ITS measures in bus services. Some of the options are given below:

a) Develop a modelling package, which can be effectively used to model all aspects of ITS in public transport. Given the range of ITS applications possible, this is unlikely to be achievable in the short/medium term, and is well beyond the scope of this research.
b) To prepare a detailed specification of an evaluation framework. This will lead to a more rigorous and detailed review on evaluation techniques and modelling procedures but could be too subjective without any validation.
c) For this research, the practical option adopted has been to evaluate the impacts of selected ITS measures (more widely used and from which benefits are more tangible – refer section 4.6 below) to develop a method to evaluate and analyse the operational benefits of these impacts on a transport network to ease the task of making decisions for further implementation.

4.6. Focus

The decision to follow the third option led to the focus for the objective of evaluating and illustrating the impacts of selected ITS measures in bus service. Three ITS user services in passenger transport, passenger information, bus priority at signal controlled junction using selective detection and automatic ticketing are selected for further evaluation and using modelling. The reasons for this were:

- These measures can improve bus service quality (refer section 3.2) one of the main reason cited for not using the bus. Unreliability, long journey time, lack of information about availability choice, etc (Higginson et al, 1995, Harrison et al 1995) were among the reasons cited for using bus services less.

- These measures are also more extensively used and are more likely to be used. For example, most urban areas have UTC and therefore selective priority at junctions can be easily incorporated. With AVL, both passenger information and bus priority at signalised junction can be implemented as a further step.
- For any new scheme to be implemented, the consent and interest of the concerned operators is vital. These measure are also of more importance to the operators to help them for a more integrated management, data collection for management, reduction of fraud, and reduction in cost.

- Benefits of these measures are more evident to the users. They have direct access to the information and are the end users of the ticketing procedure. Effects of bus priority in form of better journey times and bus regularity have direct impact on the users. All these impacts can act as a catalyst to improve patronage and induce mode change.

- In other most common use of ITS measures, DTRS is demand specific as it caters more to a specific type of demand, where regular service cannot be effective and so is limited in scope. In the urban context the potential for telematics based DRTS is as yet largely unproven (Nelson, 2002). Enforcement works in conjunction with conventional bus lane priorities and at bus stops its enforcement is still voluntary without change in regulation. (Wiggins, 1998).

The need to model the impacts using existing available models also limited the range of impacts of the measures that can be modelled. In this study the focus is on the following impacts and resulting changes due to the implementation of the selected ITS measures:

- Wait time changes: Wait time is a major portion of travel time and is perceived as twice the in-vehicle time when deriving generalised cost of travelling by public transport and therefore is a major proportion of the total cost of travelling by this mode. Passenger information can have a major impact on this (sections 3.2.1.1 and 3.2.1.2). Bus priority at signal-controlled junction can also improve waiting time by improving regularity and punctuality.

- Journey time changes

  One of the major impacts of bus priority at signal-controlled junction and improved ticketing is the saving in the journey time with reduction in junction delays and boarding (dwell) time at bus stops. Journey time reliability is also improved with improvement in regularity and punctuality.

- Route choice
  Pre-trip information directly assists optimal route choice and real time information at bus stop could also help in optimal route selection. Journey time saving accrued form improved ticketing and bus priority measures could induce change in route choice.

4.7 Conclusion

More than one evaluation method may be required to evaluate the impacts of an ITS measures. Depending on the level and requirement of the evaluation and type of ITS measure different modelling approaches and evaluation methods could be necessary as illustrated in figure 4.1. The potential of transport modelling to reduce many of the limitations of the other methodologies underlines its importance.

Depending on the ITS application(s) models may require to address one or more of the following issues:

- Behavioural changes and response to schemes
- Passenger modelling
- Integrated dynamic demand and supply modelling
- Integrated multi modal modelling
- System representation

Current modelling, whilst useful, has revealed limitations in a number of areas in their structure and functions. Therefore, there is a need for developing integrated modelling tools, which can simulate temporal and dynamic behavioural responses of users to ITS measures and the potential impact these responses have in demand and supply of both public and private trips.

5. ITS Modelling using TRIPS and SPLIT

5.1 Introduction

The modelling case studies in this research have concentrated on the main impacts (change in waiting time, journey time and optimal route choice) of three ITS measures, namely passenger information, bus priority at signal controlled junctions and automatic ticketing as discussed in section 4.6.

The review of transport models in chapter 4 showed that:

- Different ITS applications have different characteristics and impacts, which may require differing modelling approaches. The approach selected may therefore have to be application specific.
- There is no single model available that can be used to address all the requirements.
- A single model may not be adequate to address all the impacts of one ITS measure.

Therefore this chapter will:

- State the reasons for using the TRIPS public transport model and the SPLIT (Selective Priority to Late buses Implemented at Traffic signals) simulation modelling to achieve the stated aim.
- Review how the models work.
- Show how they can be used to analyse the impacts of ITS measures in a transport network.

5.2 Choice of Models

For the purpose of this type/category of research, the choice of model depends not only on its attributes but also on its availability. The model has to be either commercially available and affordable or available in-house with a proven track record and be able to address the concerned issues. For the tasks specified (section 4.6) the discussion in section 4.3.2 shows that the model has to model passengers. This limits the use of existing modelling packages to models based on four stage models, disaggregate models, activity models or macro simulation models like SATCHMO.

Data availability for using activity-based models can be extreme. The heuristic procedure applied to transform the empirical mobility of travel diaries to a reduced set of selected activity chains still need more research to be used confidently (Chatterjee, 1999). Outputs and analysis package for public transport in SATCHMO has been found to be poor, with little support and development. Furthermore, it is rooted to DOS platform and hence is not user friendly (Burden 1999). However four stage based models like TRIPS and EMME/2 models can be used as they are more readily available and also fulfil this requirement.

The impacts due to bus priority at signal controlled junction is very site specific, for example it is dependent on parameters like signal types, control and link type and vehicle flows. Only the modelling of the system itself would give results comparable to field observations. In other words models like TRIPS or EMME/2 may not be able to effectively model impacts of this ITS measure. Simulation models like NETSIM, VISSIM and PARAMICS have the facility to model public transport within this context.

However two limitations discussed below worked against choosing one of these models:
a) One of the main focus of the study is the impact in waiting time due to these ITS measure. Bus priority at signal-controlled junction can improve the waiting time by making the service more regular or punctual. This effect is compounded by the use of selective differential bus priority (refer section 3.2.2.1) where the level of priority given to the buses depends on lateness or irregularity thresholds. The models mentioned above did not have the option of modelling scheduled based selective differential bus priority at signal-controlled junction.

b) One of the main impacts of bus priority at signal controlled junction and improved ticketing is the reduction in journey time. However the time saved by a passenger would depend on where they board and alight the bus. For example a passenger boarding at the start and alighting at the end of the service route would benefit more than a passenger boarding further down the line or alighting earlier. The change in the total in-vehicle time (number of passenger multiplied by the in vehicle time of each passenger) will show the total benefit in the network by the reduction in link times. The models mentioned above do not model passengers to illustrate this issue.

The improvement in journey time due to improved ticketing is primarily due to the reduction in boarding time. Therefore to compare different scenarios, i.e., different ticketing option with different boarding times the model needs to address the issue of dwell time at bus stops. This again requires passenger modelling.

These issues could be addressed using a simulation model developed in TRG, University of Southampton to model. SPLIT (http://www.soton.ac.uk/~fnn/split.htm, described in section 5.6) was originally developed in 1996 to support field trials of *selective* bus priority in London. In these field trials, selective or *differential* priority was awarded to buses according to their headways, with the buses having the greatest headways receiving the highest levels of priority.

SPLIT models a linear network defined as a series of bus stops and signalised junctions. In practice, priority is given to buses at traffic signals using signal extension and signal recall depending on bus regularity or punctuality and constrained by dis-benefits to other traffic. It explicitly models passengers using arrival rates at bus stops and calculates the journey time using user specified 'cruise' time, junction delays and a dwell time formula (described in section 5.6.3). SPLIT does not model traffic explicitly but the effects of bus priority on traffic are estimated from data obtained from many field trials and is based on the traffic flow at the junctions.

However, SPLIT does not take into account the possible change in passenger arrival profile or route choice when information is provided to the users. It models linear networks and therefore is not able to reflect a typical network wide impact. Furthermore as there is no origin destination demand matrix it cannot reflect any possible change in demand due to the influence of ITS measures on origin destination cost matrix. In other words two models, a strategic network wide model like TRIPS or EMME/2 and SPLIT model is required to achieve the objective of modelling impacts of the selected ITS measures on a transport network. The modelling procedure developed and applied in this research is detailed in section 6.2.

5.3. Reasons for using TRIPS

TRIPS was selected over other similar modelling packages due to the following reasons:
Though other similar models can also model passenger trips, the advantage of using TRIPS is that it allows users to have a great deal of control over the parameters and to choose and develop the level of detail of the model. Therefore though the modeller cannot implicitly model the ITS measure it can reflect the changes in user behaviour and responses to the measures (section 5.5.4. describes how TRIPS can be used in this context).
The change in waiting times due to the impact of various ITS measures is an important

aspect of this study. TRIPS uses a user specified waiting time profiles (refer section 5.4.2) to calculate the waiting time instead of default values giving more realistic values.

TRIPS has a more realistic representation of passenger route choice and path building (as described in section 5.4.2). For example for the same origin destination if there are two services available the passenger distribution depends on both the frequency of these services and the relative attractiveness of the routes which can be calibrated using a logit model. This is important when studying the impact of ITS measures on route choice.

The model can be built to include a module (MVMODL –detailed in section 5.4) to model modal shift or increase in patronage. This module can also be used to generate an O-D specific cost matrix. With the change in this cost due to impacts of ITS measures it can be used to show the changed patronage with assumed elasticity values (as illustrated in section 7.1.2)

5.4. Introduction to TRIPS Public Transport Module

The public transport module of TRIPS is a multi - modal stochastic user equilibration assignment model which predicts user controlled multi route paths between zones, journey time matrices, transit and walk links, interchanges and impact of different fare systems and congestion by line and links (MVA, 1995). It allows the user to have a great deal of control over the parameters and to choose and develop the level of detail of the model. It is capable of addressing complex issues such as:

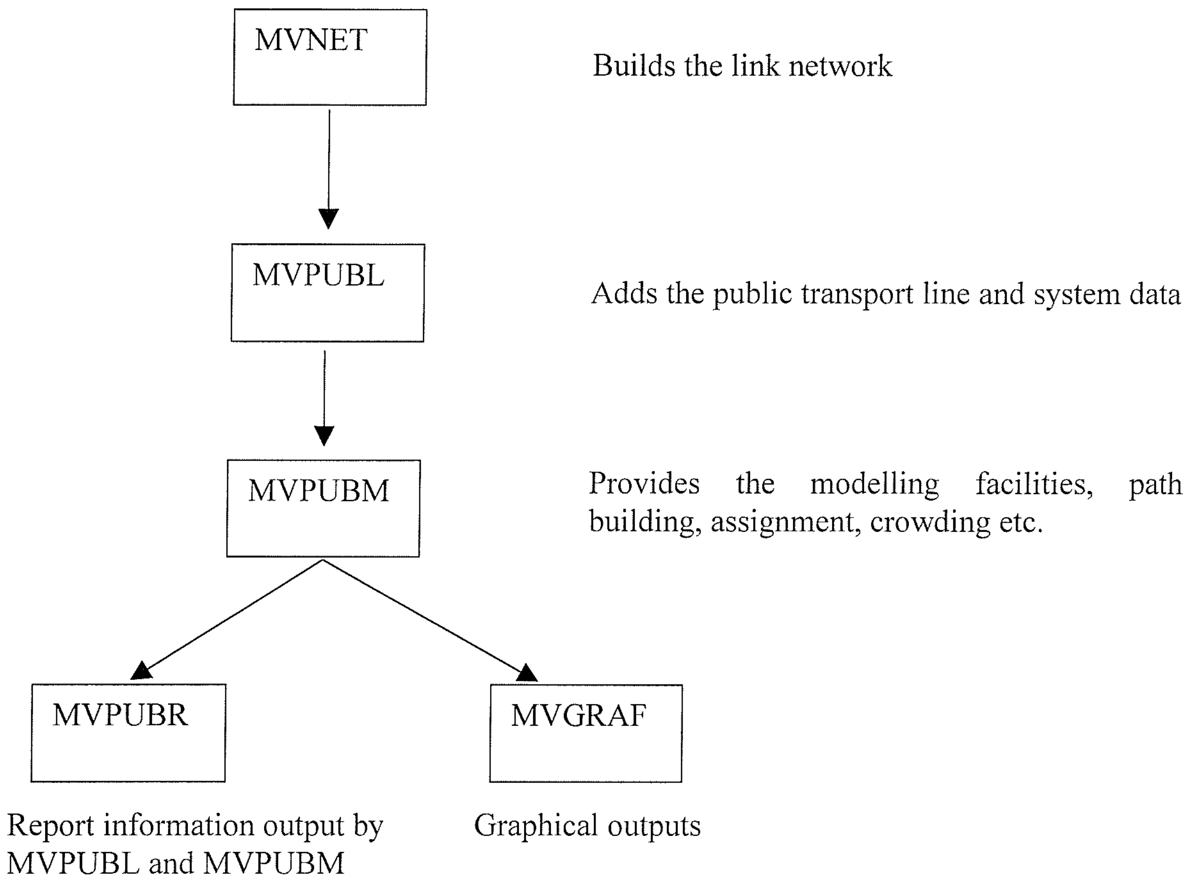
- Realistic representation of passenger route choices (section 5.4.2 and 5.4.3)
- The impact of different fares system (section 5.4.4)
- The effect of crowding on route choice (section 5.4.5).

The public transport module in TRIPS comprises of programs used in sequence (as shown in figure 5.1). These are:

- MVNET: builds the network (network file) using the data in link data file
- MVPUBL: builds service lines (lines file) using data in Line/system data file and network file from MVNET.
- MVPUBM: Provides modelling facilities to load passengers onto the network using the network file from MVNET, lines file (lines file) from MVPUBL and demand matrix from MVTRIP (this module is common for both highway and public transport module – it builds a demand matrix that can be used in modelling using the OD demand matrix).
- MVPUBR: Prepares reports using input (PT lines file and network files) from

MVPUBM. Other modules like, MVGRAF, to view results and network, graphically (figure 5.2) and MVMODL, a tool for general-purpose data processing module can be used for specific purposes (section 5. 5).

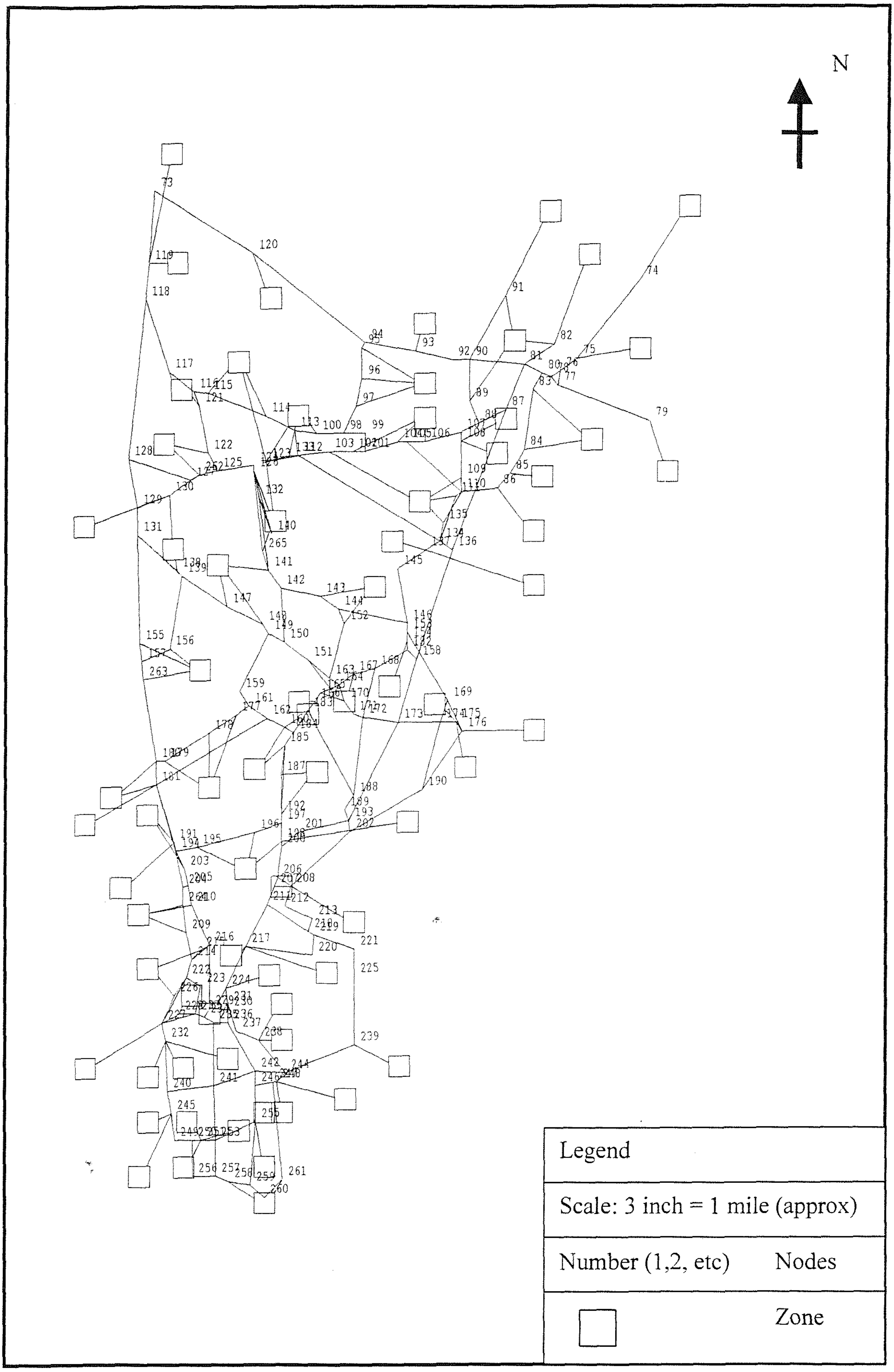
Figure 5.1 TRIPS model overview



5.4.1. Network Building:

Zones, nodes and links represent the public transportation model. Zones are joined together to the network by zone centroid links and can only be walk links. Nodes are points at which links are joined together and represent decision or interchange points within the network. It can be at the very fine level of individual bus stops or aggregate groups of bus stops. Co-ordinates for nodes are defined to view the network graphically (figure 5.2) using the MVGRAF module. A network of links (1 or 2 way) connects all the nodes along which public transport services, or lines, operate. Links are defined by link types (transit type, walk or both), capacity (capacity of links) and jurisdiction codes (to allocate the link to a user defined administrative or spatial grouping).

Figure 5.2 TRIPS Public Transport Network



5.4.2. Precise System Representation:

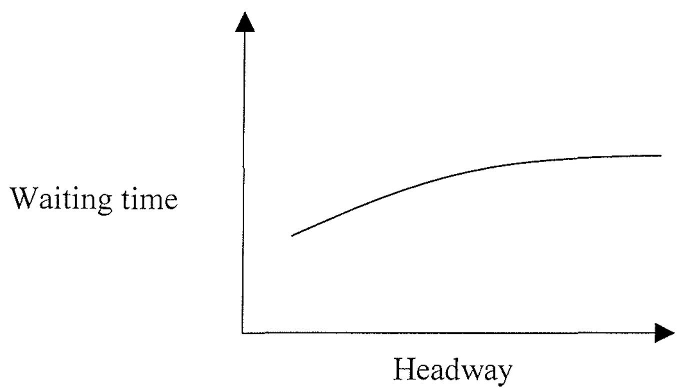
Having defined the base network, the public transport system is mapped on to it by specifying:

- The modes in the system (up to 20 types – bus, train etc)
- The operating companies (up to 999 types, useful in generating reports)
- The fares system (optional)
- The crowding model (optional)
- The services running through the system. Services require some basic operational information, such as specifying which mode and company they belong to, one or two way, route they take and their relationship to the underlying coded network speed. Services can run at either the coded link speeds or at factored link speed which allows different services to operate over the same links at different running speed times.

Associated with each service, at the users discretion, the following data can be defined:

- Line capacity: Capacity of the buses
- Fare attributes: Different fare structure
- Waiting behaviour: By default, the average time spent waiting for a service is half the headway. This can be redefined by using user-defined curves where the waiting time depends on the specified headway. Up to 99 wait curves can be defined. (Fig. 5.3)

Figure 5.3 Wait curve in TRIPS



5.4.3. Path Building

Generally passengers have a choice of routes for their journey. TRIPS acknowledges the fact that trips will not be concentrated on the shortest or fastest route but will be spread across a range of possible routes. TRIPS uses a multi-routing algorithm to identify all feasible route choices using the concept of generalised cost. The details of walking, waiting, in vehicle time and fare are calculated from input network; boarding and transfer penalties are mode-based variables, which are added at the users discretion.

TRIPS also builds a best path between any origin destination pair. This is the most attractive alternative found in the choice set of possible multiple paths. All other paths are judged against the best path and carried forward to the loading stage. Once the paths have been built, MVPUBM module uses them to load trips on to services (lines) and walk links using a series of loading models. The main components are summarised below:

- *Walk Choice Model*

The logit model is used to decide between walk choices at a node.

- *Service Model*

The allocation of passengers between alternative lines at a node. This allocation is based on the relative frequency of alternative lines.

- *Enhanced Service Model*

An alternative to the service mode, this model uses a logit model to allocate passengers between alternative lines at a node depending on generalised cost.

- *Sub-mode Choice Model*

The selection of a mode before the choice of routes at a node. Within this model, the choice of initial mode and subsequent modes are treated separately.

- *Alternative Alighting Model*

The choice of alighting point from a line if alternatives exist.

The models can be calibrated and validated using user specified factors to shape the distribution curves. A range of parameters are available to control the path building process, including:

- Mode specific in-vehicle time weighting factors;
- Mode specific waiting time factors;
- Link specific walk time factors;
- Mode specific boarding penalties;
- Mode to mode transfer penalties;
- Mode specific minimum and maximum wait times.

5.4.4. Fares

An important aspect in the representation of a public transport network is the structure of the fare system. Fares play an influential role in the path building process and are, of course, vital for the derivation of revenue estimates. The TRIPS Public Transport module incorporates fares explicitly and enables the impact of changing fare levels and even varying the fare system to be assessed.

A range of alternative fares models is available, covering the most common systems:

- Distance - fares are calculated as a function of distance travelled.
- Zonal - fares are based on the number of zones traversed or the difference between the lowest and highest fare zone numbers travelled through. Through ticketing is assumed in each case.
- Stage - fare levels are derived from the number of stages crossed, where the stages are selected nodes along the line.
- Step-down - the fare is dependent on the location of the boarding point rather than the distance travelled.

The relationship between the journey characteristics and fare may be defined either as a linear function or as a curve/profile. The fare levels may be varied by line, if required, or defined globally by mode.

5.4.5. Crowd Model

In complex urban networks, the level of crowding on vehicles or within stations may be an important determinant of the path chosen by passengers who will tend to avoid congested routes. The modelling of crowding is a particular problem facing the analyst. The TRIPS module uses an innovative approach, derived for the London Transport Studies (LTS) model, which incorporates crowding within an iterative process. The crowd model firstly identifies where congestion occurs in the system, i.e. where the modelled passenger flow exceeds the capacity of either the vehicle or walk link, and then adjusts the link times accordingly. These new link times then form the basis for the path building in the next iteration.

Flow profiles are applied with the capacity on the line or walk link to derive utilisation; based on the level of utilisation, crowding adjustment factors are calculated to amend the input times for each link. While crowding will normally be associated with vehicles, the TRIPS public transport module also considers congestion on walk links, for example within stations or interchanges. In this way the impact of crowding on, say, escalators and lifts or along passageways may be estimated.

The use of the crowd model requires the specification of the following additional data:

- Capacity – for each public transport line and walk link

- Arrival Profiles – used to allocate the flow during the modelling period into shorter, equal length, intervals. Separate profiles are defined for vehicles and passengers.

Figure 5.4 Passenger Arrival Profile in TRIPS

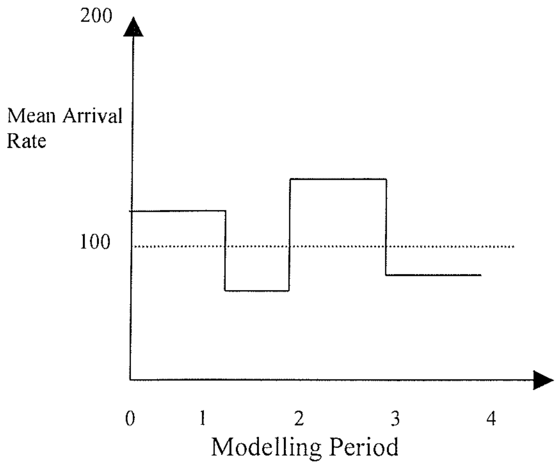
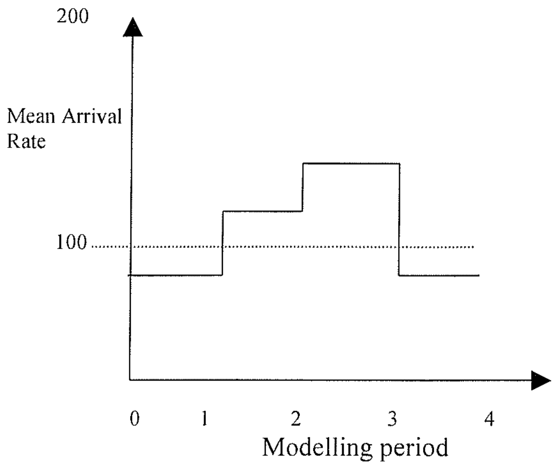
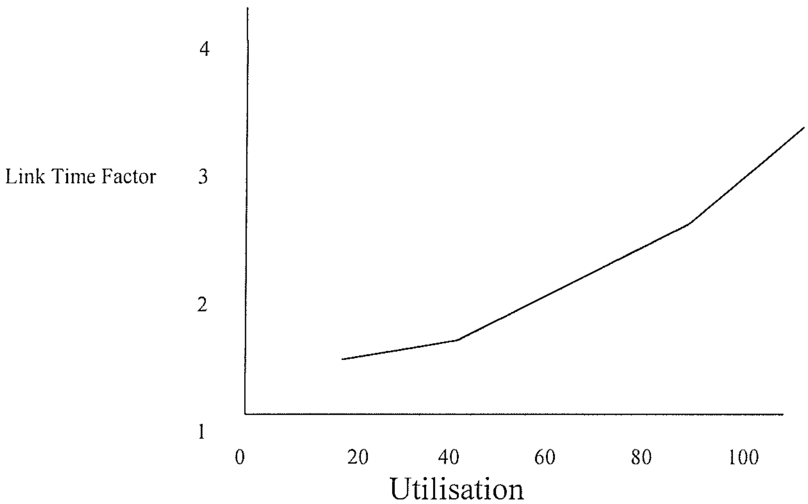


Figure 5.5 Vehicle Arrival Profile in TRIPS



- The passenger arrival profile (Figure 5.4) reflects the distribution of passenger journeys within the modelling period and the vehicle arrival profile (Figure 5.5) defines the different rates at which vehicles may arrive within the modelling period.

Figure 5.6 Multiplicative Curve in TRIPS



- Crowding factors – two types of curve may be defined to reflect the adjustment to the input link times; 'additive curve' through which a value, based on the level of utilisation, is added to the input time and 'multiplicative curve' (Figure 5. 6) through which a value, based on the level of utilisation, is used to factor the input time.

5.4.6. TRIPS Outputs

Within the TRIPS public transport module all principal reports are generated by the MVPUBR module. This module can be specified to generate a series of reports. The reports can be grouped under six headings:

i) Line Reports: These reports details the contents of an existing line attributes, for example number and names of modes, companies, passenger loadings (boardings / alightings) at each bus stop for each line, crowding factors, vehicle and passenger arrival profiles etc. In addition, some calculated statistics are also reported, for example route distance, vehicle time and distance per hour, number of vehicles required, average speed etc.

ii) Link Reports: These reports can be generated to report link attributes. Link data such as link type, jurisdiction code, distance, time or speed and capacity of walk links is extracted from the network file and details of lines running on links are reported from the lines files. Transit loadings, walk and transit crowding factors or any user specified link attributes are also reported.

iii) Path reports: The model also produces a report showing the best path from selected or all origin zones to selected destination zones. A full path report can also be generated to show all the paths used.

iv) Screen-line / Cordon reports: To aid analysis users may define a set of screen-lines formed by a series of links. Link and line reports for these screen-line/cordon can also be generated.

v) Analysis file reports: The analysis files generated can be used to report the turning movements for selected nodes and selected station-to-station (node-to-node) movements.

vi) Adhoc report: This report can be generated to present the information in the coordinate file, which details the node number, and label (name) of each node.

In addition to these reports the network can also be visually presented (figure 5.2) using MVGRAF module. Outputs like passenger loadings on each links/lines can be visually presented using density bands or histograms.

5.5.Modelling Approaches to model ITS Impacts using TRIPS

The TRIPS public transport module can be used to model ITS impacts in the following ways:

A. Change in waiting time: As discussed in section 3.3 waiting time at bus stops could decrease with the introduction of

- Pre-trip passenger information –users coming closer to the expected bus arrival time
- Passenger information at stops – users choosing to use the wait time for other purpose
- Improved regularity and punctuality of the bus service with bus priority at signal-controlled junctions.

By default, TRIPS defines the average time spent waiting for a service as half the headway. This can be redefined by using user defined curves where the wait time is depends on given headway. Up to 99 wait curves can be defined (section 5.3.2.). In other words depending on the impacts of the measures these wait time profiles can be changed to reflect the scale of change in a transport network.

B. *Reduction in Wait time weights due to elimination of uncertainty:* The value of perceived waiting time is usually taken to be twice that for in-vehicle time for economic analysis purposes (Brown, 1997). One of the reasons for this perception is due to the uncertainty associated with bus arrival times (Brown, 1997). With passenger information, this perception can be reduced as the uncertainty of bus arrival is reduced. The change in cost due to the reduction in perceived waiting time at bus stops can be modelled by specifying wait time weights in the TRIPS model. In TRIPS a matrix of waiting time costs of travelling from all origins to all destinations can be skimmed. Multiplying this matrix with the demand matrix produces the total waiting cost in terms of passenger–minutes, which can be used to show the scale of change in the network.

C. Optimum route selection: With passenger information, users may be able to make an informed choice to wait for a convenient bus or take the one at the bus stop depending on whichever is more convenient or quicker. A logit model is used in TRIPS to distribute passenger between O-D pairs depending on the frequency of services and the relative attractiveness of alternate services available. This logit model, used in TRIPS, can be calibrated with data to relate route choice with difference in travel time.

D. Decrease in Journey time: The link travel time in TRIPS is constant. Any change in link travel time, for example with improved ticketing or delay savings at signalised junction with bus priority have to be directly re-entered by the users. However, the link file (with all link related data) is in a text format. Any changes due to the above measures if entered in excel spreadsheet can be saved as a space delineated text file and used as the new link file. This will remove the requirement to enter all the individual link travel time. This new link file can be used to analyse changes in route choice due to changes in travel time or simply to illustrate the change in travel times over the whole network.

E. Change in regularity and punctuality: For frequency (headway) based services, the change in standard deviation of actual headways is a measure of regularity of bus service. Similarly for scheduled based services, the standard deviation from scheduled time is a measure of bus punctuality. The higher the deviation, the lower the regularity/punctuality of a service. Both of these deviations are a measure of variability in bus arrival times and any improvement can be argued to be improvement in level of service. Any improvement in these deviations can be reflected in TRIPS by varying the value of user specified penalties (for example mode specific boarding penalties) as illustrated in section 7.1.2.

F. Change in patronage – With the introduction of passenger information (Geoff et. al. 1997) and improved ticketing (Oorni et. al., 1997) increases in patronage have been evidenced. This is probably due to the overall improvement in the service, i.e., due to the combined effect of all the benefits accrued from such schemes. One major factor could be the improvement in journey time.

Use of various elasticity values between patronage and in journey time for public transport have been evidenced. For example in a study conducted by TRL (1982) elasticities are given as –0.3 to –0.5, i.e., a reduction of 1% in travel time will increase patronage by 0.3% to 0.5%. Similarly Miller et. al., (1984), uses –0.29 +/- 0.13 for peak period and the Australian Road Research Board (http://www.vtpi.org/tdm/tdm11.htm) uses –0.60 for urban passengers. Skimming the matrix of cost between origin and destination for different scenarios, MVMODL module can be used to calculate the change in patronage.

5.5.1. Mode Split Modelling using TRIPS Public Transport Module

Although there is a consensus that ITS can help to induce mode change, no significant mode change has been observed with implementation of individual ITS measures in bus services (Aron et.al., 1995, Ampelas 1999). It would be logical to assume that if more than one of these ITS measures are implemented in a transport network the combined impacts could influence mode choice. Any change in mode (and patronage as detailed above), from private car to buses could have implications on traffic assignment. In other words to model this impact the model has to be able to model mode change and the resulting effect on traffic assignment, i.e., an integrated private/public transport modelling package.

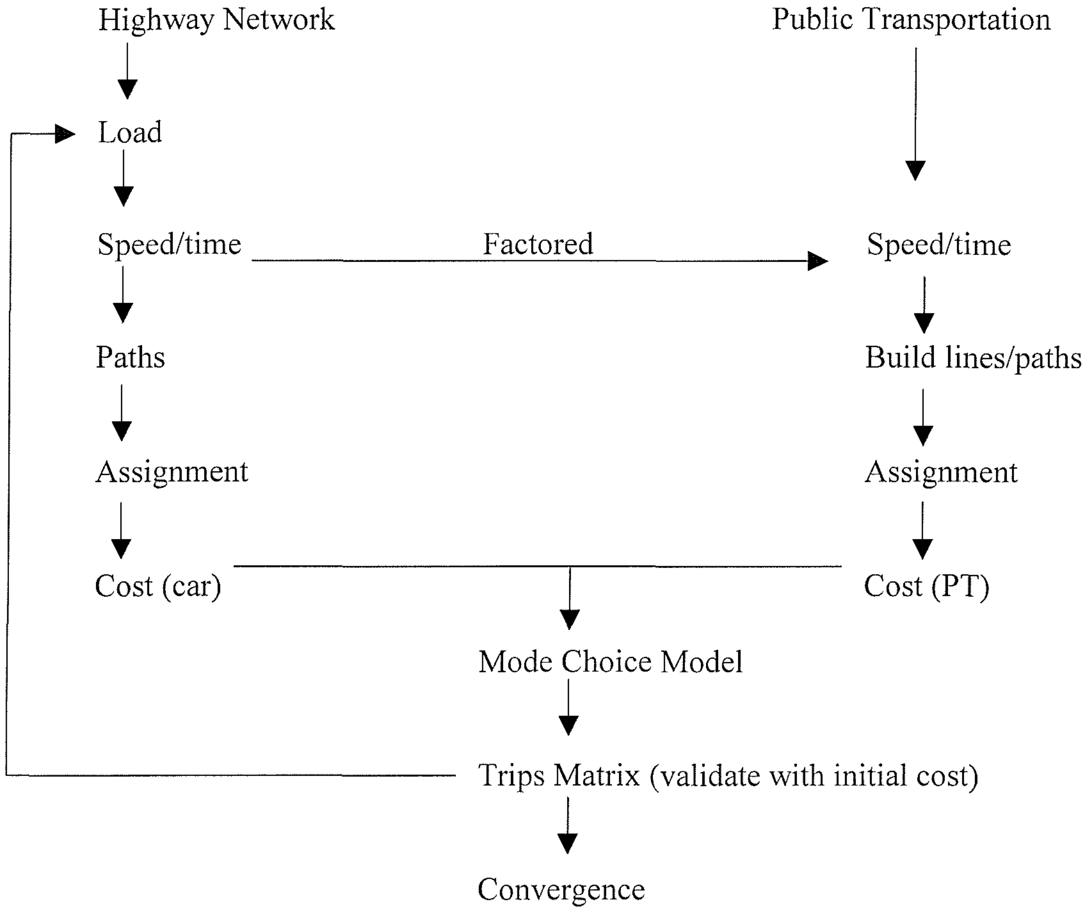
The TRIPS public transport module was selected for this research, as modal change was not found to be a primary impact from ITS implementation for the applications under study. However, options to use TRIPS as an integrated private\public transport-modelling package to model mode change and resulting changes in assignment (including due to increase in patronage) were investigated as part of the research.

Two options were explored:

Option A: Option 'A' concerned building separate networks for highway and public transportation, i.e., to use both the highway and public transport modules in TRIPS. The highway network can be loaded with the base vehicle trip matrix to get the prevalent link speed or journey time in the network, which can then be used (factored to take account of dwell times, both due to boarding and physical interaction between the two modes at the bus stops) in the public transport model with the base demand matrix.

The next step would be to extract (skim) the costs of travelling by the two modes to use in a mode choice module in TRIPS with the combined demand to get public and private trip matrices, which can be compared with the initial demand matrices (car and bus demand matrix) for validation/calibration. The public transport module can then be re-run to get new costs due to the impact of ITS measures. This new cost will change the output trip matrix in the mode choice module, which can then be used in the highway and public transport module to get a new cost. This process can be re-run for a number of times to reach convergence. A schematic diagram of the model is shown in figure 5.7.

Figure 5.7. Option A (Modelling Mode Split with TRIPS)

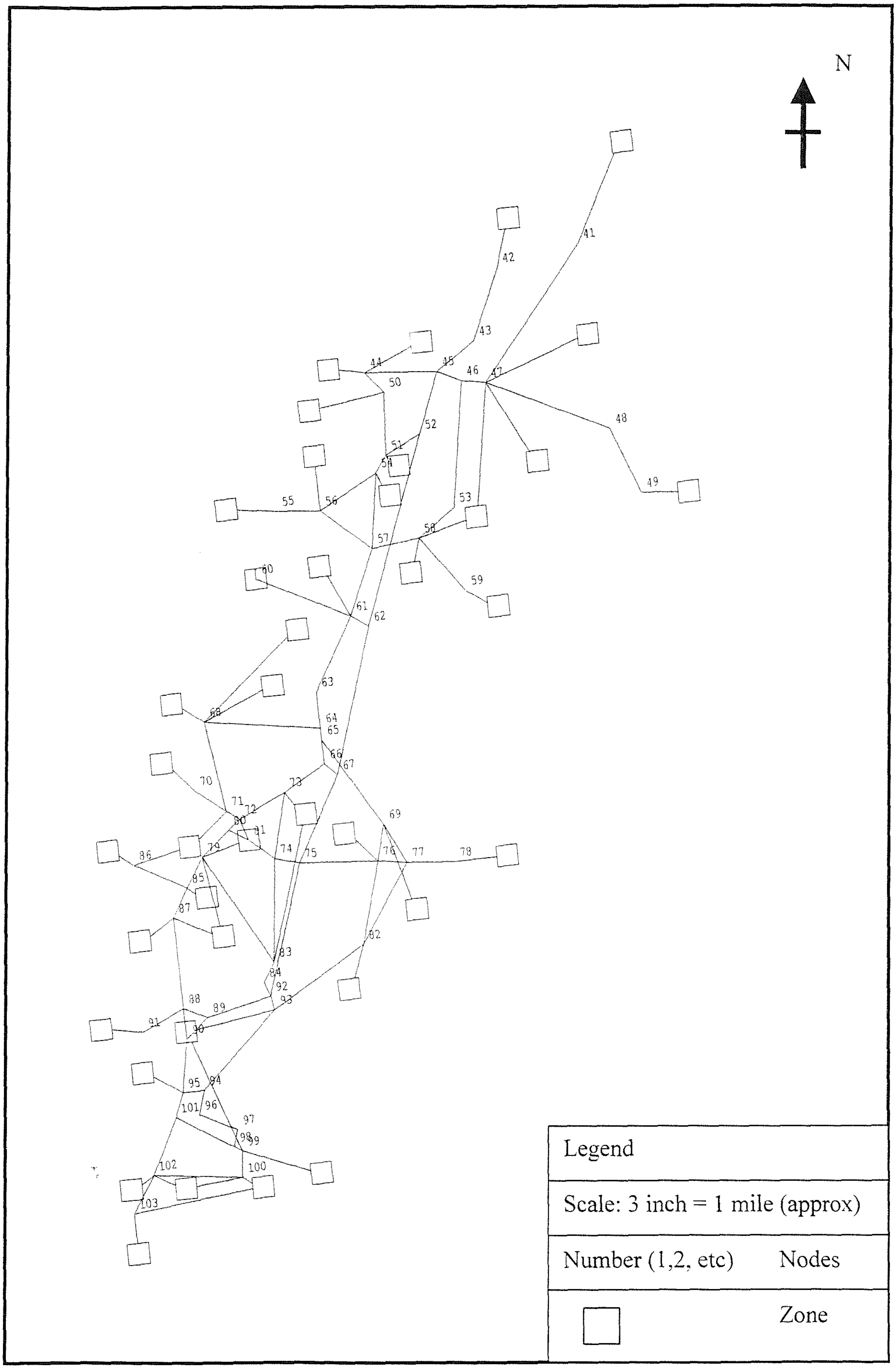


This option could potentially be very time consuming, firstly due to requirement of building two networks and secondly the user will have to iterate between the three modules.

Option B: Another simplistic option would be to use only the public transport module and to use car as a public transport mode in the public transport module. In TRIPS a sub mode choice model allows the building of different paths for different modes and trips are distributed using a logit model to different modes before assigning them to the paths built for one mode. The distribution of the trips to different modes can be changed using a scaling factor. This option was tested in a linear network shown in figure 5.8, which is a part of figure 5.2 along a bus corridor (Portswood – refer figure 6.2).

Network description: A public transport network was built using data from the existing network of Southampton City in a CONTRAM model (calibrated and used for other research in TRG, University of Southampton). Within this network the Portswood corridor (figure 5.8), a busy corridor with relatively high bus flows was chosen for detailed study.

Figure 5.8 Portswood Corridor Network



Bus flows were derived from the bus time- table for services plying in this section and the stops were added as nodes to the network extracted from the existing CONTRAM network. All other relevant data, for example link types, distance, speed/time, capacity, zones were also extracted from the CONTRAM network. The Portswood corridor runs from north to south starting from the Swaythling junction between the A27 and the Stoneham Lane and continues along the Portswood road to the City Centre. The total length of the corridor was 5.22 kilometres with 44 junctions and 24 bus stops. There were 40 zones (32 original zones from the CONTRAM network and 14 new zones to represent the flows in the links joining this corridor with the Southampton network), and 103 links.

Modelling: Modelling was carried out by assuming the vehicle demand matrix as the passenger demand matrix. The demand matrix was extracted from the existing CONTRAM demand file. For private mode (cars) each link was assumed to be a separate service. Crowd model (section 5.4.5), which is similar to the capacity restraint model in highway modelling was used to model congestion. Multiplicative curves required for this modelling were generated using speed flow curves from COBA for urban roads.

Results: The comparison of output flows from the two models is given in Table 5.1. The flows were similar where there were limited alternate routes available but different where there were more alternatives. This was probably due to the fundamental difference in assignment technique of the two models. In the CONTRAM model the least cost paths are identified and trips are assigned to it. Using an iterative procedure trips are assigned to different paths so that equilibrium is achieved, i.e., where traffic is assigned to competing routes the cost of travelling between an OD pair by these routes would be same. In the public transport module of the TRIPS model, the number of trips allocated to different paths depends on the relative attractiveness of the path and there is no concept of the system reaching equilibrium.

Though model parameters, including the multiplicative curve parameters, sub-mode choice model parameters could be varied to change the output flows from TRIPS this option was not pursued due to the following reasons.

- The scale of work required for calibration of the TRIPS model and the validation of the output from TRIPS model would be very high.
- The demand matrix for the test model was relatively easy to extract and validate as the number of zones is relatively low and the flows from outer zones (from rest of the

whole Southampton network) were low. However for a bigger network demand data could prove to be very time consuming (as found in preliminary estimation).

As both the mode change and patronage increase are secondary impacts of the selected ITS measures and given the evidenced scale of change, the impact on assignment would probably be very small. It was felt that it did not warrant the amount of time and effort required to pursue this option.

Table 5.1 Comparison of flows between TRIPS and CONTRAM assignment

	Node		Flow		
Line Name	From	To	TRIPS	CONTRAM	Remarks
1	41	47	543	580	The flow in the links at the end of network, for example 1 to 6, were nearly same due to limited alternate routes.
1	47	41	447	510	
2	42	43	3036	2560	
2	43	42	4985	5070	
3	43	45	3036	2560	
3	45	43	4985	5070	
4	47	48	1095	1220	
4	48	47	785	720	
5	48	49	1095	1220	
5	49	48	762	7 20	
6	46	47	2314	2210	
6	47	46	2404	1870	
7	45	46	2244	2150	The difference here could be due to the fundamental difference in assignment technique of the two models.
7	46	45	2440	4430	
12	45	52	4297	4430	
12	52	45	6115	5220	
17	57	58	431	610	
17	58	57	517	870	
20	54	56	274	260	
20	56	54	42	500	

5.6. Introduction to SPLIT

SPLIT (Selective Priority to Late buses Implemented at Traffic signals) is a simulation program (http://www.soton.ac.uk/~fnn/split.htm) developed by TRG, University of Southampton. It was originally developed in 1996 to support field trials of *selective* bus priority in London. In these field trials, selective or *differential* priority was awarded to buses according to their headways, with the buses having the greatest headways receiving the highest levels of priority. Priority was controlled by the SCOOT UTC system. Bus headways were derived from the London 'COUNTDOWN' AVL system.

SPLIT has been further developed to model scheduled based priority for this research (where priority to buses is given depending on how late a bus is running from the scheduled time at a bus stop) and is also being developed to relate priority to bus occupancy (i.e., where priority to buses is given depending on the occupancy of a bus). The model was for further enhanced, for example facility for user to define dwell time formula to account for dwell time at bus stops, during the course of this research. The validation of results /model (Table 2 appendix B) were carried out using the data from survey one (section 6. 4).

5.6.1. Model Inputs

SPLIT models a linear network defined as a series of bus stops and signalised junctions. It defines the network using the following input data in a number of text files. Bus routes, services and demand (passengers) are defined using the following input files:

- *Bus data*: Individual bus number, the time it enters the network, occupancy at entry time and the service number where there are more than one service.
- *Bus stop data*: Each bus stop is identified using a bus number and a passenger arrival rate is assigned to each individual bus stop which is used to calculate the number of users boarding a bus. The number of signals between this and the next stop, cruise journey time between bus stops in seconds excluding junction delay and dwell time average junction delay totalled over all signals between bus stops are used in the link travel time calculation.
- *Signal data*: Signal stages, minimum green and maximum degree of saturation of non priority stages, extension and recall target saturation levels of non priority arms, total priority bus flows and bus journey time from bus detector to the stop line are used to calculate the benefit to the buses.
- *Schedule data*: Schedule time of bus at bus stops is used by the model to determine the level of priority.
- *Routes data*: The demand is defined by passenger arrival rates at each individual stop but the alighting number is calculated using user specified percentages (on board users) at each stop and at stops where more than one service operates the % of users boarding each service is also specified to calculate the number of boarders on each bus.

5.6.2. Priority Implementation

In practice, priority is given to buses at traffic signals using signal extension and signal recall depending on bus regularity or punctuality and constrained by dis-benefits to other traffic. User defined parameters determines the priority type and level using the ratio between actual and scheduled headway or the difference between the actual and scheduled arrival time. One of up to four priority level requests (PLR) is transmitted to the bus at each polling occurrence. This PLR will then be communicated to each roadside beacon positioned for bus priority and transferred immediately to the signal controller of the next downstream junction, using radio communication. The signal controller will then interpret the PLR locally, or via UTC, and carry out the appropriate priority action.

Heuristic algorithms (McLeod, 1998) based on headway ratio and difference in scheduled and actual arrival times is used to give selective priority. For each bus the headway ratio or the difference between scheduled and actual arrival is calculated and then compared with predefined threshold levels. The threshold levels used in this modelling are given in Table 5.2. The delay savings accrued by a bus at a traffic signal is derived from field studies undertaken in Camden and Edgware road in London since 1994 (Hounsell et al, 96).

Table 5.2 Threshold levels for priority in SPLIT

Priority level	D= (actual-scheduled) arrival time	Description
0	$D \in (-\infty, dif1)$	No priority
1	$D \in (dif1, dif2)$	Extension only
2	$D \in (dif2, dif3)$	Extension and recalls (constrained by DOS)
3	$D \in (dif3, \infty)$	Extension and recalls (unconstrained)

SPLIT does not model traffic explicitly but the effects of bus priority on traffic are estimated from data obtained from many field trials and is based on the traffic flow at the junctions. The effects of traffic on buses are implied by average bus journey times, specified by the user, which should include typical junction delays but exclude bus stop dwell times, as they are modelled separately.

5.6.3.Modelling of Dwell time

One appeal of this model is that a dwell time formula can be user specified to account for change in dwell time due to improved ticketing methods. Bus stop dwell times are estimated based on numbers of boarding and alighting passenger. The dwell time formula by York (1993) (dwell time = maximum (6+1.4*alighters, 8+4*boarders)) is used by default.

SPLIT explicitly models numbers of passengers on board a bus and waiting at bus stops using user specified occupancies for each individual bus and a passenger arrival rate for all the bus stops. The original SPLIT model assumed that passengers arrive at bus stops uniformly. This has been modified to model non-uniform passenger arrivals at bus stops, to reflect situations where bus arrivals are not so frequent (say every 30 minutes) and passengers arrive at bus stops to meet particular buses. The number of users alighting at a bus stop is calculated using the specified alighting percentage for the stop. The model uses these figures in the user specified dwell time formula to calculate the dwell time at a bus stop. It should be noted here that the bus dwell time could be influenced by when drivers vary their departure time targeting more patronage where competing operators ply along a common line (Boddy, 1993). Furthermore operators also build in 'float' time into the schedule to offset delays due to traffic variation.

5.6.4. Modelling of Overlapping Routes

Bus services overlap if they serve same stops over a section of their route, either physically overlapping the links or using different links. In such situations users would have different alternatives to choose form. Some users may choose to use the first bus that comes and others wait for a later service. Waiting time of passengers willing to take two or more different bus services will be less than the passenger willing to take only one particular bus. The percentage of passengers that choose to board the different services would be different at different stops due to routes taken, bus frequency, convenience, comfort, journey time etc. In SPLIT passenger percentages are allotted to different services depending on which bus services they are willing to take.

5.6.5. Model Outputs

Output is written to screen and appended to a file in a text format. The standard outputs are

- Average and standard deviation of headway at each stop to illustrate the improvement in bus regularity.
- Individual journey time for the each bus and an average for a service to illustrate the

improvement in journey time.

- Overall Passenger waiting time at each stop.
- Overall Passenger travel and waiting costs.
- Percentage of buses receiving different priority levels.
- Overall costs and dis-benefits to the non-priority traffic.

5.7. Conclusions

This chapter has described TRIPS public transport and SPLIT simulation model. It has outlined their characteristics, limitations and their suitability for this study. Simulation model SPLIT can be used to implicitly model bus priority at signal controlled junction and the change in boarding time with improved ticketing methods. The model uses bus, passenger, route and signal data to simulate field condition. It implements selective differential priority depending on user specified threshold levels and calculates the benefits to buses using heuristic algorithms. The option to use user specified dwell time formula makes it suitable to model changes due to improved ticketing systems. This model however model linear routes only and so will not be able to reflect a network wide impact of these measures. However outputs from these measures, like change in link time, waiting time and deviations from headway and schedules can be used as inputs in TRIPS model to reflect a network wide impact.

Public transport module in TRIPS is a multi - modal stochastic user equilibration assignment model which predicts user controlled multi route paths between zones, journey time matrices, transit and walk links, interchanges and impact of different fare systems and congestion by line and links. It does not model any of the ITS measures implicitly but can model primary impacts of some of ITS measures like change in waiting time, route choice and change in level of service in a transport network changing user specified parameters like wait time weights, scaling parameters for route choice and boarding penalties. The option to use user defined waiting curves allows modelling of impact of ITS measures in waiting time at bus stops.

A general modelling procedure using these two models can be developed and applied (refer section 6.2) to illustrate impacts of selected ITS measure in a transport network.

6. Methodology used to Illustrate ITS Impacts

To illustrate the impacts and benefits of selected ITS measures in a public transport network, a modelling procedure using SPLIT and TRIPS public transport module was used. The focus for this illustration is on the change in waiting time, route choice and reduction in link travel times as discussed in section 4.6.

This chapter will:

- Outline the issues related to the above focus.
- Outline the modelling framework used for illustration.
- Set out the data required to address the issues and illustrate the above objective.
- Describe the surveys that were carried out to collect the relevant data, which include data to build a public transport network, determine passenger arrival and bus departure profiles, outline a rigorous method used to calculate average waiting time at bus stops using these profiles and relation between route choice and travel time.
- Describe the transport networks developed for the modelling.
- Analyse the data collected from the survey and literature reviews to derive appropriate relationships required for the modelling.

6.1.Issues

1. Passenger waiting time at bus stops: Passenger waiting time at a bus stop depends on the passenger and bus departure profiles. *Passenger arrival profiles could be affected by:*

- Frequency of service – Jolliffe et.al., (1975) states that 'In general 10 minutes is taken as upper bounds for a threshold below which passenger arrival can be taken to be random and for services with lower frequencies passenger arrival will have some association with the scheduled time'. Users of high frequency services do not need to wait long for the next bus if they miss a particular bus and therefore may be less concerned with vehicle departure times and arrive randomly. However for lower frequency service users, missing a particular bus could well mean waiting for an unacceptable amount of time for the next bus, for example being late for work.
- Journey purpose – Passenger arrival profile could also depend on the user category, for example commuters travelling in the morning peak would be more sensitive to schedules as they need to reach their destination within a specific time period than users involved in other activities like shopping and leisure.

- Punctuality (adherence to schedule) of service – when buses are usually more punctual, users would have more confidence to arrive closer to the scheduled time and reduce their waiting time. If a bus service is often early, users may prefer to arrive earlier and conversely if services are consistently late. The network area used in this study is served by a bus service running with a scheduled time-table, therefore the relation of passenger arrival profile with punctuality (adherence to schedule) was pursued. Regularity (buses arriving at regular intervals) of bus service is more of an issue in headway based services where service frequencies are generally 10 minutes or lower.

Bus arrival/departure profiles could be affected by:

- Operational efficiency, i.e., how well the service is managed by the operators.
- Passenger loading, i.e., the more the passenger volume fluctuates the higher the irregularity of the bus due to difference in boarding times.
- Network conditions, i.e., the journey time will fluctuate depending on the traffic volume in the network. Congestion would decrease both the average speed of the bus and increase the access and egress time of the bus from bus stops.

Rather than exploring the impact of these factors on bus arrival/departure profiles this research has concentrated on using scheduled based services for which bus departure profiles have been surveyed as part of this research. Bus departure profile is defined in terms of the percentage of service that was on time (punctual), late (degree of lateness) and early (degree of earliness). This is elaborated in section 6.10.

2. Perceived and actual Punctuality

The waiting time component in generalised user cost in public transport is generally accepted to be twice the in-vehicle time in standard UK practice (Brown, 1997, Ortuzar, 1994). In other words perceived waiting time is valued as twice the actual waiting time.

Among other factors like stress due to uncertainty of bus arrival time, a key factor affecting the higher perception of waiting time could be that users perceive the buses to arrive later than they actually do. A survey for the COUNTDOWN project in London (Atkins et. al. 1994) showed that passengers perceived waiting time dropped from 11.9 minutes to 8.6 minutes though there was no difference in bus service reliability. This could be due to the fact that with real time bus arrival information, users have more exact knowledge of the expected arrival time and also the certainty of the bus arriving. In other words as users now have knowledge of expected arrival time they would know how long they need to wait and depending on the accuracy of the system, perceive the waiting time closer to the actual waiting time.

Similarly, with information user perception of punctuality could be closer to the observed punctuality as they would base their perception on actual arrival times (with real time information) and not on the perceived bus arrival times (past experience or worst experience). The waiting time weight can therefore be related to the difference in perception of punctuality to the observed punctuality and reduced in proportionate to this amount when real time bus arrival information is provided at bus stops.

3. Timing of passenger arrivals – To estimate passenger waiting time at bus stops it is also necessary to find out how users time their arrival with respect to bus schedule. With pre-trip information users may be able to time their arrivals closer to the expected arrival time and hence reduce their waiting time. In other words, the amount of 'slack' time allowed by the users in arriving at a bus stop may be reduced.

4. User Behaviour at bus stops with passenger information - There is also evidence of users leaving bus stops when the waiting time is longer than 10 minutes to engage in other activity and certain proportions returning later to catch the service (refer section 3.2.1.2). This would effectively reduce the waiting time if the users were able to use the time for some useful purpose. Passenger information at stops would help users to decide on this option even in cases where the bus is late. The results from previous studies (eg., Backstorm, 1997) have been used in the modelling.

5. Route Choice – With the introduction of passenger information users can make a more informed route/service choice (as described in section 3.2.1.1, 3.2.1.2 and 3.2.2) to reduce travel time. Route choice could also be affected by the difference in travel time for alternative services, i.e., if an O-D pair is served by two different services with different travel times a higher proportion would choose the service with lower travel time.

6. Change in Link travel time – Link travel time can be reduced using bus priority at signal-controlled junction (refer section 3.2.2.2) and improved ticketing methods (refer section 3.2.3). The scale of change in a transport network can be illustrated by modelling.

6.2. Modelling Framework

The following general modelling framework has been developed (see figure 6.1) and applied in this research to illustrate the impacts of selected ITS measures in a public transport network.

1. A TRIPS public transport network was developed (as described in section 6.5.1) which included two busy bus corridors of Southampton City (figure 6.3) using data collected from a survey (Survey 1, referenced in section 6.4) and an existing CONTRAM network (referenced in section 6.5) of Southampton City.
2. Surveys of passenger arrivals and departure at bus stops were used to establish the passenger demand matrix. The model was validated by comparing the output boarding and alighting at each bus stop for individual service with the observed value (as illustrated in Table 1, Appendix B).
3. A SPLIT network was developed (as described in section 6.5.2) for the same area (figure 6.4) using data collected from survey 1, the existing CONTRAM network and SCOOT data (as described in section 6.5.2.1). The data for passenger arrival rates and the percentage of boarding and alighting at each stop for each service was derived from the output of TRIPS modelling. The SPLIT model was validated by comparing the output link travel time with the observed link travel time (as illustrated in Table 2, Appendix B).
4. ITS scenarios were developed/specified for modelling.
5. SPLIT modelling was undertaken for the different ticketing and priority scenarios (section 7.1)
6. The outputs from SPLIT (link travel times, punctuality, and waiting times) were used to calculate the changes due to the ITS measures (section 7.1 and 7.2).
7. The changes calculated from the SPLIT output were used as input in the TRIPS model to illustrate the scale of impact due to these measures.
8. A procedure to calculate the average waiting time for bus services was established using data from survey 2 (section 6.10). Using the observed and assumed impacts of passenger information in public transportation the waiting time profiles (section 5.3.2) were adjusted to illustrate the impact of passenger information (section 7.3.).

9. Using data from survey 2 the proportion of users choosing routes with shorter travel time, where choice is available, was established (section 6.8.5). Probable scenarios with passenger information were illustrated using TRIPS model (section 7.3).
10. With the reduced costs predicted for the users from the ITS measures, the potential change in patronage using different elasticity values were illustrated using the TRIPS model (section 7.1 to 7.3).
11. An overall evaluation of the impacts of the ITS measures was undertaken to illustrate their relative performance.

6.3. Data Requirements

In addition to the results used from other studies (as noted in section 6.1, specific results used given in section 6.9.) the following data sets were required to address the issues (section 6.1) and set up the models to illustrate the impacts of ITS measures in a network.

1. Network data and demand matrix: The reason for using Portswood network in Southampton (figure 6.2) for all the modelling work is given in section 6.5. Sections 6.4 and 6.5 outline the process of collecting the relevant data for building the SPLIT and TRIPS network and for the passenger demand matrix.

2.Passenger and bus departure profiles: These were recorded for services with different frequency, punctuality and for different periods of the day, to calculate the average waiting time at bus stops.

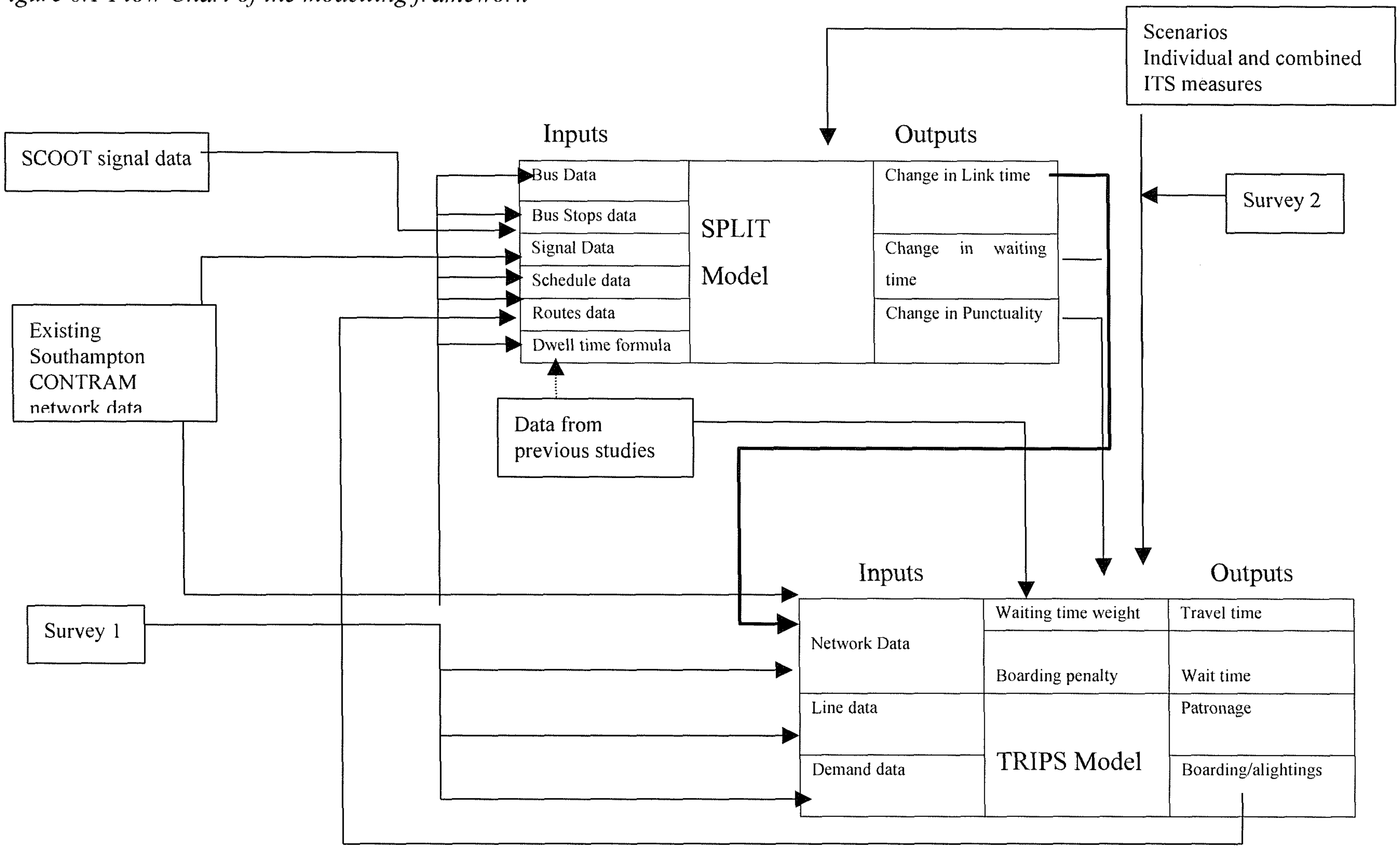
3. User behaviour:

- *Perception of Punctuality* – Surveys were undertaken to relate users perception of the service punctuality with waiting time weights as discussed in section 6.2.
- *Timing of arrivals* – Surveys were undertaken to measure the amount of 'slack time' users allow to arrive at a bus stop for later exploration of potential changes in arrival profiles with passenger information.

4.Route choice: Users choice of alternative bus services was surveyed, where these choices may have differing journey time for the same O-D pair.

5. Dwell times: Relationship between bus dwell times at stops and number of boarders/alighters were derived, to illustrate the overall impact of reduction of link travel times due to improved ticketing.

Figure 6.1 Flow Chart of the modelling framework



6.4. On-board Survey (Survey 1)

This survey was conducted to collect data required, namely passenger movements (demand), link journey times and delays at junctions of the bus lines and dwell time at bus stops for network building and to set up the passenger demand matrix.

Survey framework: The survey was conducted through the modelled period, 7:30 to 9:30 am over a period of four weeks between 3rd March 1999 and 15th April 1999 on weekdays. For each individual line in the network (referenced in section 6.5.1) all the buses operating between the modelled period was surveyed by boarding the bus at the start of the line. For example for a service frequency of 15 minutes 8 to 9 buses (depending on schedule time) were surveyed on 2 different weekdays (total bus journeys 176). Collection of other relevant data for individual models is outlined in section 6.5.1 (for the SPLIT model) and 6.5.2 (for the TRIPS model).

Methodology: A surveyor travelling on the buses using a palm top computer registered:

- The travel time between adjacent nodes (node – bus stops and junctions) for each bus
- Junction delays and dwell time at bus stops
- Numbers of users boarding and alighting at each bus stop

A sample of the survey data is shown in table 6.1.

Table 6.1. Sample survey data for the modelled Network Project (service 101)

Time	0753				0816					0839				0859			
Anode	Bnode	T. time	S. Time	B	A	T. time	S. Time	B	A	T. time	S. Time	B	A	T. time	S. Time	B	A
74	75	16.0	9.2	0	0	18.0		0	0	17.9	5.8	2	0	17.0	0.0	3	0
75	76	10.4	0.3			12.0	0.3			10.4	10.1			9.6	15.9		
76	77	5.0	0.3			5.0	0.3			4.5	0.4			3.8	0.3		
77	78	4.0	0.4			3.2	0.3			5.2	0.3			3.6	0.3		
78	80	10.6	0.4			11.1	0.4			41.8	0.6			33.3	0.5		
80	83	9.5	19.2	0	0	9.5	24.2	1	0	9.9	42.7	1	1	9.5	1.6	2	0
83	84	49.3	0.3	0	0	44.9	24.1	0	0	70.9	13.3	1	0	42.5	22.3	0	0
84	85	28.4	0.3	9	0	26.5	0.3	41	0	37.9	17.5	44	0	34.0	0.3	52	0
85	86	14.3	34.2			20.5	142.9			20.0	160.2			20.3	204.3		
86	110	16.2	0.3			24.2	3.4			19.0	3.2			14.9	0.3		
110	109	6.4	12.3	0	0	8.1	0.5	0	0	9.3	49.0	0	0	6.3	18.9	0	0
109	108	22.4	12.3	1	0	25.3	0.4	0	0	24.1	0.4	0	0	6.3	0.4	2	1
108	107	4.5	28.4			3.0	1.3			6.9	11.5			23.1	14.8		
107	106	10.4	33.8	0	0	12.0	37.8	0	1	11.6	19.8	0	1	5.4	20.8	0	0
106	105	9.8	0.4			20.6	7.4			10.3	6.5			10.4	0.4		

Note:
T. time - Travel (cruise) time (seconds)
S. time - Stoppage time (junction delay or bus dwell time depending on whether the node is a bus stop or a junction)
B - Number of users boarding
A - Number of users alighting. Refer figure 6.3 for node numbers.

6.5. Network

This network, shown in figure 6.2 (key hole shaped), was chosen to illustrate the impacts of the selected ITS measures. The reasons for choosing this network are given below:

- A calibrated CONTRAM network for Southampton City (figure 6.2) was available with TRG colleagues having substantial knowledge of it. This could provide key data required for TRIPS (for example link distances, signal data and zoning structure).
- Proximity of the site to the University allows easier data collecton.
- The two main corridors in this network, the Avenue and Portswood corridor had a good mix of congested and less congested conditions to evaluate impacts of ITS measures.
- The destination of services is the City Centre, overlapping in some stretches and using different routes on the rest, which could be useful to model route choice.
- Some of the bus stops are equipped with STOPWATCH (display of bus arrival information at bus stops), and so could provide useful information.
- The services operating use UNI-LINK cards, a magnetic card, which is inserted into ticketing machine on board. There is a provision for upgrading the system, which can be used to study boarding times for different methods of ticketing.

6.5.1. TRIPS Network

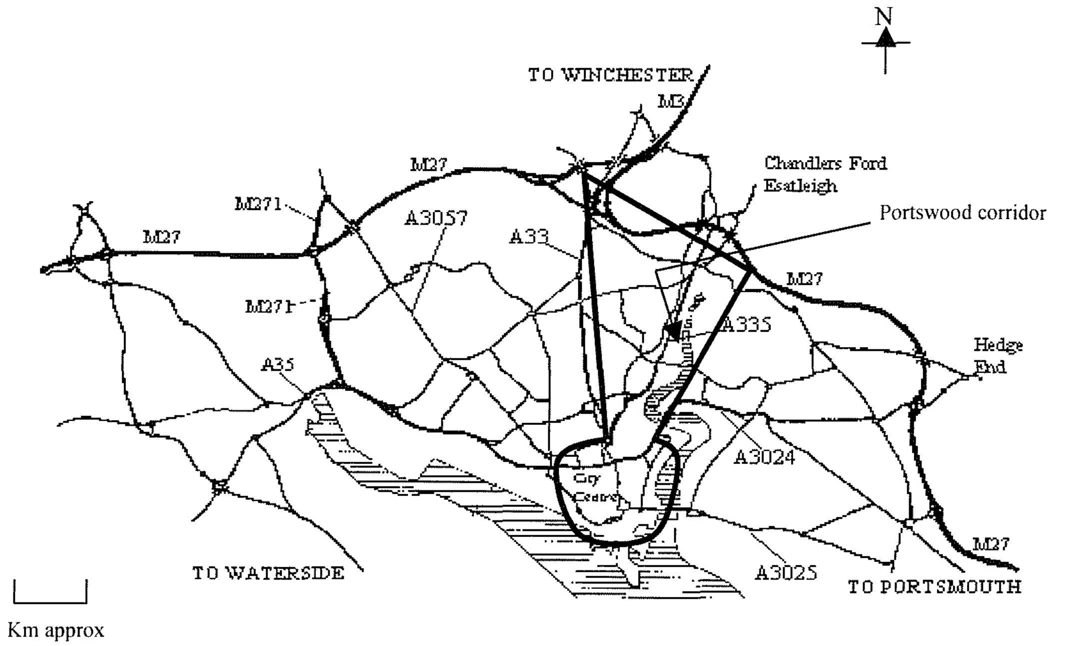
The network is a part of two busy corridors of Southampton. The Portswood corridor runs from north to south starting from Swaythling junction between the A27 and the Stoneham Lane and continues along the Portswood road and ends at the City Centre. The Portswood corridor is one of the major bus corridors in Southampton. Similarly the Avenue corridor running from north to south starts from the junction between the A33 and A 35 and runs along the Avenue and ends at the City Centre. The location of the network (key hole shape) is shown in figure 6.2.

The following services (figure 6.3) operated by Southampton First Bus have been used in the study:

- Service 101 (Airport to city centre), service 11 (interchange to city centre) and service 13 (interchange to city centre (Converted to 11A recently) running in the Portswood corridor.
- Service 20 (Bitterne to city centre), services 102 A & B (Interchange, Bencraft, Avenue campus to city centre) and services 103 A & B (City centre, Avenue campus, Interchange) running in Avenue.

- Service no 4 (Converted to 6A recently) and service 6 which runs through the interchange and Portswood and other services connecting areas not adjacent to the network running through the Portwood area (services 3, 14, 47) to city centre, and have not been included to make the study less complex. This network was made up of 72 zones, 265 nodes (82 bus stops and 183 junctions) and 369 road links.

Figure 6.2. Location of Network



6.5.1.1. TRIPS Network Inputs

The input data required to run TRIPS were collected as explained in the following sections.

Link file: The network, being art of the Southampton City network, zones 15 to 72 are the same zones from the original CONTRAM network. Zones 1 to 14 are zones added to cater for the flows from and to the major severed links from the whole network. The link travel times used for TRIPS were average of all the observed link times from survey 1 (Table 6.1). The link distances were extracted from the CONTRAM network. Nodes for bus stops were added at appropriate locations.

Lines File: Bus routes were entered as observed in survey 1. Bus headways / frequencies were extracted from the scheduled timetable. The waiting curve calculated for different headways were used, as explained in section 6.5.2.

Demand file: The number of passengers boarding and alighting had been recorded in the survey. TRIPS uses an origin destination demand matrix. The surveyor had to record each individual passenger's boarding and alighting stop to produce this matrix from the observed data. While this could not be achieved entirely accurately, subsequent validation fared satisfactorily (Table 1, Appendix B).

6.5.2. SPLIT Network

The Southampton SPLIT network covers the same area and bus services as the TRIPS network. However, for SPLIT, the network had to be divided into 12 individual 'networks/routes' because:

- SPLIT can only model linear networks. The in bound routes for some of the services were different than the outbound routes and some services overlapped over a significant stretch of their individual routes before/after using different routes.

The networks are illustrated in figure 6.4 and tabulated in table 6.2. An example of a service included in different routes is explained below:

Table 6.2. List of individual SPLIT Networks

Individual Network	Services in the Network	Stops (from – to)	No of signals
1	101 (F)	1 – 19	6
	20 (F)	3 – 13	
2	13 (F)	1 – 29	17
	11 (F)	1 – 22	
	101(F)	22 – 26	
3	20 (F)	1 – 14	7
4	11 (F)	1 – 9	5
	20 (F)	4 – 9	
	102	4 – 8	
5	102	1 – 16	7
	102A	7 – 16	
6	101 (F)	1 – 6	2
7	101 (B)	1 - 5	3
8	103	1 - 21	7
	103A	1 - 11	
9	11 (B)	1 - 10	5
	20 (B)	1 - 6	
	103	2 - 6	
10	20 (B)	1 - 15	7
11	13 (B)	1 - 29	16
	11 (B)	7 - 29	
	101(B)	7 - 17	
12	101 (B)	1 - 19	6
	20 (B)	7 - 19	

Note: See figure 6.4 for location and the bus stops of the network
Letter 'F' denotes services running towards City Centre.
Letter 'B' denotes services returning from City Centre.

Network '1' includes services 101 and 20 running towards City centre; service 101 starts from stop 1 and exits at stop 19 (stop numbers are shown by numbers of the same colour as that of the service in figure 6.4) and service 20 starts from stop 3 and exits at stop 13. Service 101 continues in network '2' by entering at stop number 22 (Table 6.2) and exiting at stops number 28. It further continues on as network '6' and exits the network at stop 6 of this final network at City Centre.

6.5.2.1. SPLIT Network Inputs

The input data required to run SPLIT were collected as explained in the following sections.

Network data: Link travel times, delays and passenger arrival rates were extracted from survey 1 data as required by the model. A sample is shown in table 6.3. The link travel time and delay at junctions were the average of all the observed values. Passenger arrival rates and bus occupancy at each stop were calculated using the output from the first TRIPS run.

Table 6.3. Data Sample for Signal Controlled Junctions in SPLIT :

Entry Time	07:53	Route	101(F)		
Bus Stop/signal Upstream	Bus Stop/signal Downstream	Cruise Time (seconds)	Stop time (Seconds)	Boarding Number	Alighting Number
1	2	16	9.2	0	0
2	3	10.7	0	0	0
3	Signal 1	20.7	19.2		
Signal 1	4	9.8	0	0	0
4	5	49.6	0	0	0
5	6	28.4	34.2	9	0
6	Signal 2	30.8	12.3		
Signal 2	7	6.4	12.3	0	0
7	8	22.4	28.4	1	0
8	Signal 3	4.5	33.8		
Signal 3	9	10.8	0	0	0
9	10	22.7	0	0	0
10	11	24.3	0.3	0	0
11	12	14.7	0.3	0	0
12	Signal 4	16.3	10.4		
Signal 4	13	9.8	22.8	1	0
13	Signal 5	12.3	7.3		
Signal 5	14	6.4	220.4	0	4

Figure 6.3 TRIPS Public Transport Network

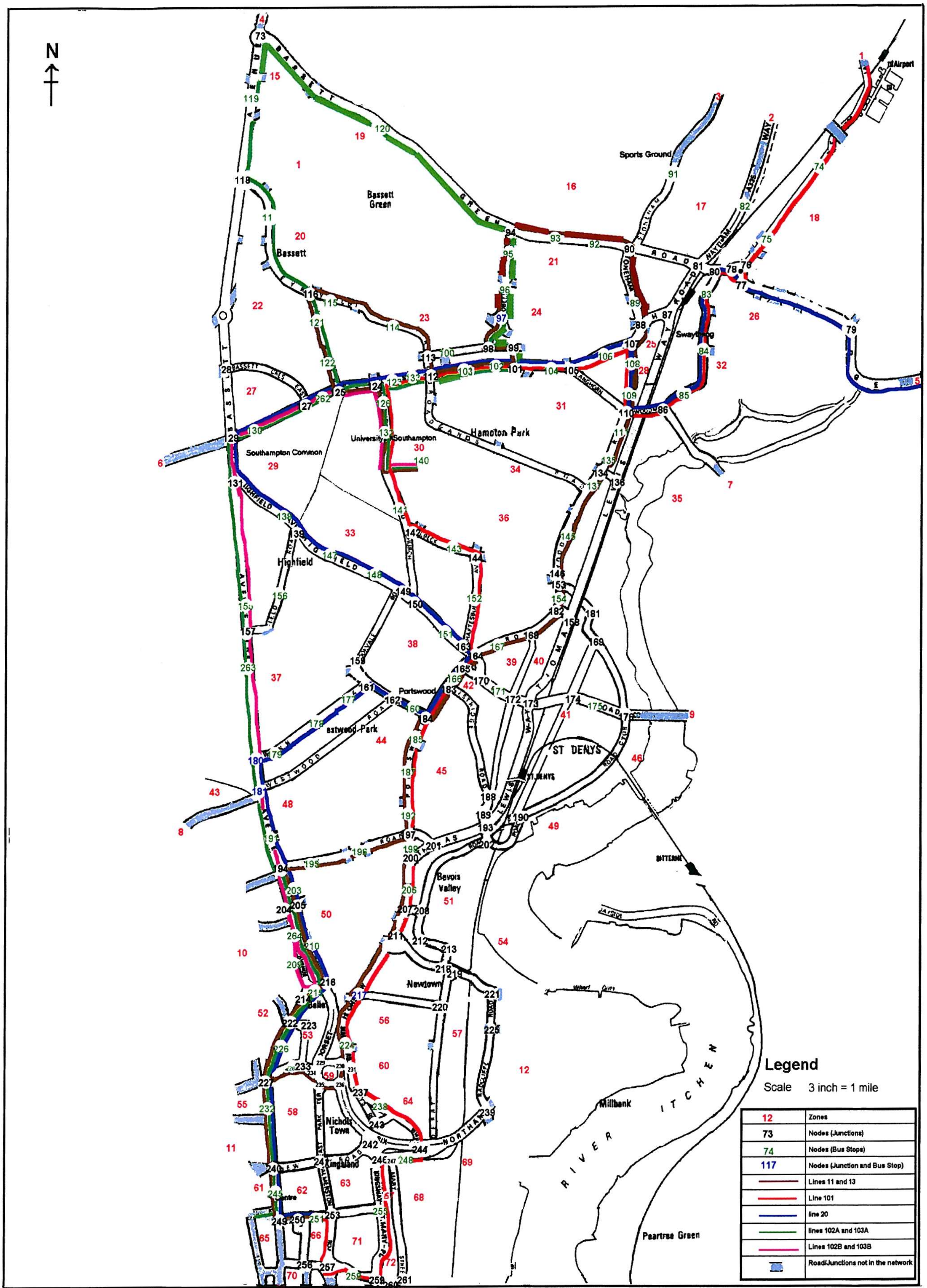
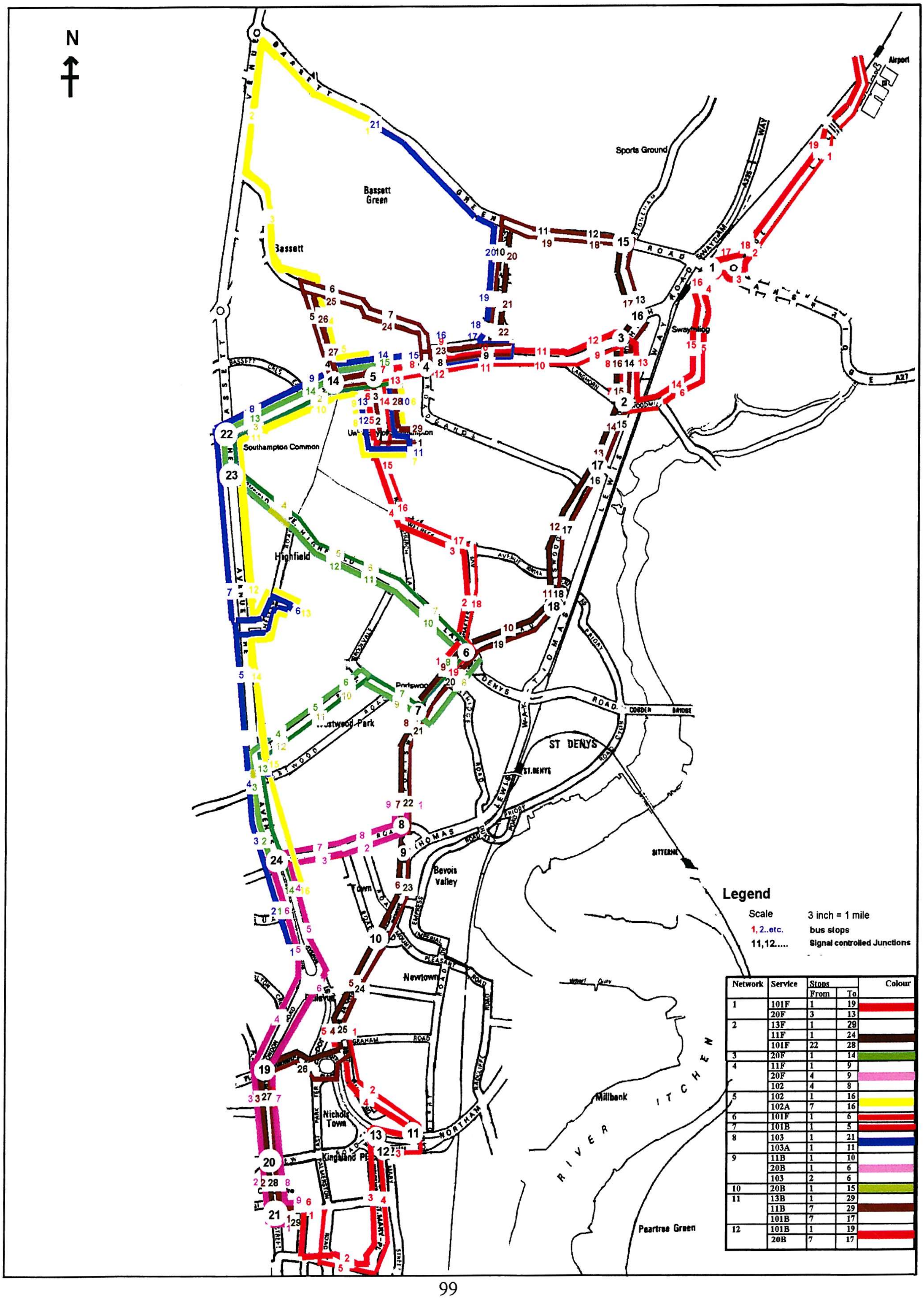


Figure 6.4 SPLIT Public Transport Network



Network	Service	Stops From	Stops To	Colour
1	101F	1	19	
	20F	3	13	
2	13F	1	29	
	11F	1	24	
	101F	22	28	
3	20F	1	14	
4	11F	1	9	
	20F	4	9	
	102	4	8	
5	102	1	16	
	102A	7	16	
6	101F	1	6	
7	101B	1	5	
8	103	1	21	
	103A	1	11	
9	11B	1	10	
	20B	1	6	
	103	2	6	
10	20B	1	15	
11	13B	1	29	
	11B	7	29	
	101B	7	17	
12	101B	1	19	
	20B	7	17	

Bus Schedule: SPLIT compares the bus arrival time and schedule to decide the level of priority for scheduled based differential bus priority. The printed timetable published by the bus company was taken as the basis to calculate the scheduled time at each stop. This gave scheduled time for only the major stops. In SPLIT each bus stop has to be assigned a scheduled time. The scheduled time for intermediate stops (not shown in the published timetable) was calculated by dividing the time interval based on the link distance between the stops. Link distance was extracted from the CONTRAM network (referenced in section 6.5) of Southampton City.

Signals: The signal data is used in SPLIT to calculate the priority benefits to the buses. The number of signals in each individual network is tabulated in table 6.2.

Table 6.4. Cycle time at different junctions (SCOOT data):

S.N. in	**Jn No. in**		**Stage Time**				**Avg. Cycle**	**Effective Green for**	**Lost**
(fig. 6.3)	**SCOOT**		**1**	**2**	**3**	**4**	**Time**	**Priority stage**	**Time**
S17	5121	Average	91	10	13	21	135	13	26
		Intergreen	6	5	6	9			
S3	5131	Average	66	12	21	45	144	94	24
		Intergreen	6			18			
S2	5111	Average	38	53	27	14	132	32	29
		Intergreen	7	8	7	7			
S18	5142	Average	28	15	-	-	43	22	14
		Intergreen	7	7					
S19	6252	Average	30	15	-	-	46	25	13
		Intergreen	6	7					
S6	6121	Average	27	11	29	19	86	21	34
		Intergreen	7	6	13	8			
S7	6111	Average	40	12	18	13	84	47	24
		Intergreen	6	6	6	6			
S8	6211	Average	40	20	14	-	74	7	24
		Intergreen	8	8	8				
S25	4141	Average	50	15	46	-	111	41	21
		Intergreen	9	6	6				
S20	7331	Average	71	21	25	-	117	13	32
		Intergreen	13	9	10				
S21	7411	Average	65	20	28	20	134	13	45
		Intergreen	8	10	16	11			
Note:			Priority Stage						

Data of the signals shown in Table 6.4 are in the Portswood corridor of the network. The stage time is the average value over a time period of 2 hour in the morning peak.

All the relevant signal data, stage times, cycle time, effective green, lost time were derived using the SCOOT data made available by the ROMANSE office in Southampton. A sample of data collected is shown in table 6.4. The 'detection time' (time interval between the detection of the bus and its arrival at the junction, which is used to calculate delay savings at signals) at a signal controlled junction were estimated for each signal controlled junction depending on the observed minimum travel time for the bus to travel from an adjacent upstream point where the bus stops (usually a bus stop, or an upstream signal/junction) to the signal.

The degree of saturation for non-priority arms (links) is used by SPLIT to calculate the bus priority benefits. It was calculated using the average flows obtained from the SCOOT data and the link capacity values obtained from the CONTRAM network.

Dwell time: Dwell time formula is used in SPLIT to calculate the time a bus stops at a bus stop. York (1993) used the following format for a dwell time formula, where all the users alighting get off before other users board.

Dwell time = A + B* number boarding + C* number alighting.

The formula for buses where user can board and alight at the same time and is given as:

Dwell time =maximum (A_1+B_1*alighters, C_1+D_1*boarders)

All of these coefficients (A, B, C and D) differ for different types of buses (double and single-decker buses, boarding and alighting sequence, i.e., allowed simultaneously or not) and fare systems (travel card, exact change, etc). In Southampton the buses are a mix of single and double-deckers, with the design of some buses allowing both boarding and alighting simultaneously and the fare system is a mix of cash fare given to the driver and travel cards. Therefore, the structure of the formula developed by York was maintained but recalibrated for Southampton. The dwell times at each stop where boarding and alighting occurred had also been noted down. Multivariate regression analysis (r value =0.8) was used to derive the following dwell time relation:

Dwell time = 5.9 + 6.59*number boarding + 3.16* number alighting.

6.6. At-stop Survey (Survey 2)

This survey was carried out on weekdays between 5th February 2001 and 15th March 2001 to collect the rest of the data required as outlined in section 6.3. This was carried out to:

- *Determine passenger arrival patterns.*

- *Study the relationship between bus punctuality and passenger arrival patterns.*
- *Compare the perceived and actual punctuality.*
- *Determine how users time their arrival (determine slack time) and*
- *Discuss how users choose from alternate routes/services with different journey times serving the same OD pair.*

Methodology:

The Southampton First bus service area was taken as the study area. A surveyor stationed at bus stops recorded passenger arrival times and bus departure times, which were subsequently converted into profiles. Bus users were interviewed at bus stops using a questionnaire shown in Table 6.5 designed for the purpose of the survey. The format of this survey reflects the fact that it was a personal interview survey – an improved format/clarity would have been used had the questionnaire been self completion.

Question Framing:

Questions 1, 9 10 and 11 were asked to determine the user category as:

- User purpose could influence passenger arrival profiles as explained in section 6.1.
- Comparison of perceived and observed punctuality would be more logical based on responses from regular and frequent users than occasional users.
- Similarly users arrival time at bus stops could also be different according to journey purpose or other characteristics.

Questions 2 to 5 were asked to users at stops with multiple bus services to analyse route/service choice. Question 6 was asked to determine the users knowledge of the schedule and question 7 to analyse how users time their arrival. Perception of bus punctuality (to compare with observed punctuality and relate to the reduction in waiting time weights as explained in section 6.1) was worked out from the answers to question 8 using the following method.

- 'Mostly' was assumed to be 95% (mid point of 90% and 100%), similarly more than 3/4th was assumed to be 82.5% (mid point of 75% and 90%) and ½ to 3/4th was assumed to be 62.5% (mid point of ½ to 3/4th) for calculations.
- The five categories, '>5 minutes early', '2-5 minutes early', 'on time', '2-5 minutes late' and '>5 minutes late' were grouped into three bands, 'on time', 'late' and 'early'. The Traffic Commissioners favoured (http://cpt-uk.org/cpt/cptsite/sfset.htm) definition

of 'on time' was used which meant that buses departing within the time window of 1 minute early to 5 minutes late from scheduled time was taken as buses 'on time'. In other words the first two categories, '>5 minutes early' and '2-5 minutes early' were in the band 'early', the third and fourth categories, 'on time' and '2-5 minutes late' were in the band 'on time' and the last category '> 5 minutes late' was in the band 'late'.

- For each respondent the band of their highest choice is noted to determine the maximum percentage of time the service falls on one of the three bands. For the remaining percentage of the time, the service is allocated to the other bands as indicated by the respondent. For example:
  - If the respondent indicates that the bus is 2-5 minutes late more than 3/4th of the time and >5 min. late as less than ½ then the punctuality will be, 82.5% on time and 17.5% late.
  - If the respondent chooses less than ½ for both 2-5 minutes early and >5 minutes late along with his first choice than the punctuality will be, 82.5% on time, 8.75% early and 8.75% late.

- This was carried out for all the respondents for a particular stop and then averaged to get the perceived punctuality.

Sample frame and sample size:

The following sample frame and size was chosen to collect data sufficient for this element of the research. The data was collected from a wider service area of First Bus in Southampton than the modelled network as the issues were not specific to it. This is therefore a generalised analysis and could be applicable to other areas.

- Four different typical frequency band services were selected: 10 minutes (the highest frequency service available), 15 minutes (14-15 minutes were available), 20 minutes (18 to 20 minutes were available) and 30 minutes (30 –32 minutes were available).
- 2 to 4 bus stops were surveyed for each frequency band service covering the three main bus corridors (Bitterne, Portswood and Shirley) in Southampton (bus stops were selected according to the availability of stops with reasonable patronage, where users usually had to come to the stop to wait for the bus and not run to it after observing its approach).

Table 6.5 Questionnaire for At-stop Survey

1. *How often do you use bus?*

___**more than 2/week** ___ **1-2/week** ____ **less than 1/week** ___**less than 1/month**

2. *Which bus number are you waiting for?* _____*(at stops with multiple bus services)*

3. *Where will you get off?*____

4. *Which alternate bus service can you use to reach your destination?*______________

5. *What is the main reason for choosing this service (if they have an alternative)*

- **I have to reach my destination within a specific time** _____________
- **I can use both the service but have chosen this because**
  - **This is quicker**
  - **It is more convenient as** ______________________________
  - **No particular reason.**
- **Other** ____

6. *What form of information did you use to find out about the service and schedule of the service you are planning to use?*

- _____ **Your own paper timetable.**
- _____ **Your own experience of bus service.**
- _____ **No prior information -learned about it at stop**

7. *I normally try to reach the bus stop within* ___ **minutes to scheduled time.**

8. *The service in your experience is*

> 5 min. early __Mostly,(>9/10th) ___more than 3/4th __1/2 to 3/4th ___less than 1/2

2 – 5 min. early __Mostly, (>9/10th) ___more than 3/4th __1/2 to 3/4th ___less than 1/2

On time __Mostly, (>9/10th) ___more than 3/4th __1/2 to 3/4th ___less than 1/2

2 – 5 min. late __Mostly, (>9/10th) ___more than 3/4th __1/2 to 3/4th ___less than 1/2

> 5 min. late __Mostly, (>9/10th) ___more than 3/4th __1/2 to 3/4th ___less than 1/2

9. *What is the main purpose of your trip? Please tick one.*

__Commuting __Education __Shopping ___Leisure __Other

10. *Which age group would you say you are in?*

__<20 __21-34 _35-60 __>60

11. _____**Male** ____**Female**

- Passenger arrival and bus departure profiles were noted on two different week days and at each stop over a period of one and half hour for the peak periods, i.e., for each stop depending on the scheduled time different number of passenger arrival and bus arrival times were noted, for example for a 10 minutes frequency service 9 to 10 number of profiles would be noted.
- Three different peaks were surveyed. Morning peak (08:00 to 09:30), off-peak (10:30 to 15:30) and evening peak (16:30 to 18:00).
- Interviews were conducted during the same time period. Two interviewers carried out the survey interviewing 200 respondents and 283 bus departure times over a period of four weeks at 21 different stops.

Interviews were carried out randomly among the users who arrived at the stop. Depending on the volume of users the number of users interviewed at a stop varied from 50% to 100%. It should be noted that with the available resources and time the survey was carried out for only two weekdays at each bus stop and may not be representative of the actual street scenario. In other words sampling error due to this limited data could affect the variability around the estimated parameters and the degree of confidence that may be associated to the means. However no events/conditions (adverse weather, function etc), which could affect the data were noted during the data collection period.

6.7. Survey Findings:

The purpose of this survey was to look for indicative results for some elements, e.g., user categories and perceptions. Based on the variations of these elements, the data was then analysed to derive ***relationships*** between more robust data like passenger arrival profiles and punctuality, service frequency and time of day (section 6.7.2), the difference between perceived and observed punctualities (section 6.7.3) and route choice with variation in journey time (section 6.7.4) which are used in the modelling. Other data obtained from the survey included, bus departure times from which bus departure profiles could be derived (section 6.10.1) and preferred 'slack times' which are used in the modelling.

6.7.1. User Category and Behaviour:

This analysis was carried out to see if there was any difference in user categories and behaviour for different peak periods and service frequencies. If so, it may then be necessary/desirable to relate passenger arrival profiles to user categories and behaviour.

User category and behaviour is tabulated in Table 6.6 and the following points can be noted from the survey.

- 'Regular' passengers (using buses more than two times a week) and 'frequent' passengers (using buses 1 to 2 times a week) were between 71% to 83% of total public transport users.

Table 6.6. User Categories observed in Survey 2.

User Category	Service Frequency (min)	Morning Peak (%)	Off Peak (%)	Evening Peak (%)
(a) Average percentage of Regular /Frequent /occasional users.	10	76 /24 /0	39 /42 /19	38 /38 /24
	15	67 /11 /22	60 /33 /7	54 /27 /19
	20	66 /10 /24	22 /52 /26	29 /50 /21
	30	67 /11 /22	27 /31 /42	23 /23 /54
Average across all services		69 /14 /17	37 /40 /23	36 /35 /29
(b) Commuters and Students (average across all services)		67	25	61
(c) Percentage of users that referred to a printed timetable before coming to the bus stop.	10	29	12	0
	15	28	40	20
	20	31	67	30
	30	61	74	31
(d) Knew about the scheduled time from previous experience before coming to the stop.	10 *	100	91	100
	15	78	60	73
	20	86	67	50
	30	78	54	54
Average across all services.		86	68	69
(e) Had knowledge of the scheduled time either by experience or by referring to a printed timetable before coming to the bus stop.	10 *	100	91	100
	15	100	93	85
	20	100	90	50
	30	100	81	70
Average across all services Note; * for high frequency services users were aware of the frequency of the service		100	89	76
(f) Percentage of users stating that they try to be within 3-5 minutes/ 5-6 minutes of the scheduled time	10	62 / 0	12 / 0	0 / 0
	15	90 / 0	93 / 0	69 / 0
	20	58 / 31	70 / 18	50 / 0
	30	61 / 22	31 / 50	0 / 69
Average for lower frequency services		87	87	63

- Morning peak had a very high percentage (67% compared to 25% in off peak) of users who had to get to their destination within a specific time (e.g., commuters going to work). For all frequency services, referral to timetable was less for evening peak. It is thought that such passengers were mostly returning from work (61%) or other activities and the time window to reach their destination is more flexible and/or they are less concerned with time. In other words there is a distinct difference between the user journey purpose between the peaks and hence they have been used to represent 'journey purpose' in subsequent analysis.

- All 'regular' and 'frequent' users of high frequency services (10 minutes) knew the service frequency; however 29% (morning peak) and 12% (off peak) users referred to a printed time-table before coming to the bus stop and 62% (morning peak) and 12% (off peak) stated that they try to be at the bus top within 3 to 5 minutes of the scheduled time. In other words users may not be arriving randomly as generally assumed in other studies (Jolliffe et. al. 1975).

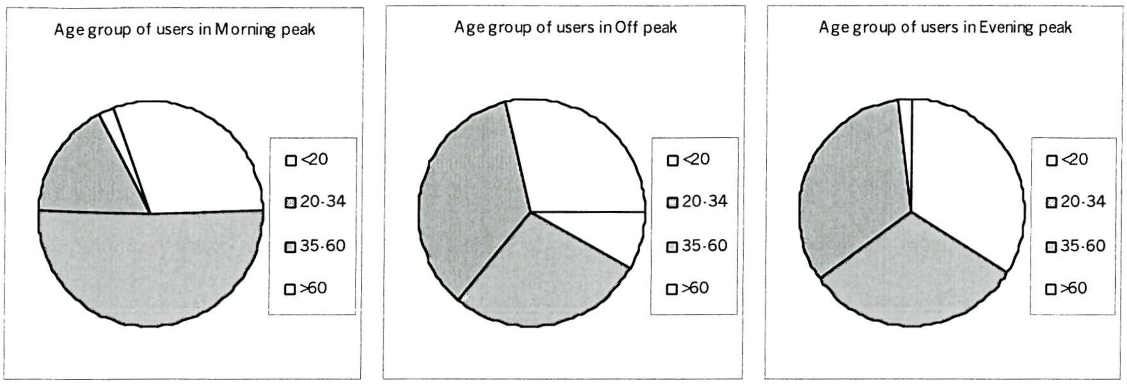
- Results for lower frequency services (15 to 30 minutes) showed that the higher the headway the more users tend to refer to the timetable before going to the bus stop. This is logical because if users miss one bus they have to wait longer for the next one. Even some users having knowledge of the scheduled time from previous experience were referring to the printed timetable, which probably indicated their fear of missing a bus. Off peak users tended to refer to timetable more than morning peak users. This is probably due to the higher percentage of 'frequent' users in off peak period, 40% compared to 14% in morning peak who were probably not very sure of the schedule and had to refer to a printed timetable.

- Results for lower frequency services indicate that a higher percentage of such users stated that they try to reach the stop within a certain time before the scheduled time. Users stated this 'slack time' to be between 3-5 minutes. It increased to 5-6 minutes at stops where users perceived the service to be sometimes early. As with high frequency services evening peak users were less concerned with slack time.

- Respondents questioned why they arrived early (for those who came more than 7 minutes early) while stating that they try to arrive within the last 5 minutes (of the scheduled time) responded with answers to the following effect:
    - Buses are sometimes early, or afraid they will miss the bus
    - They do usually try to come within the time they stated

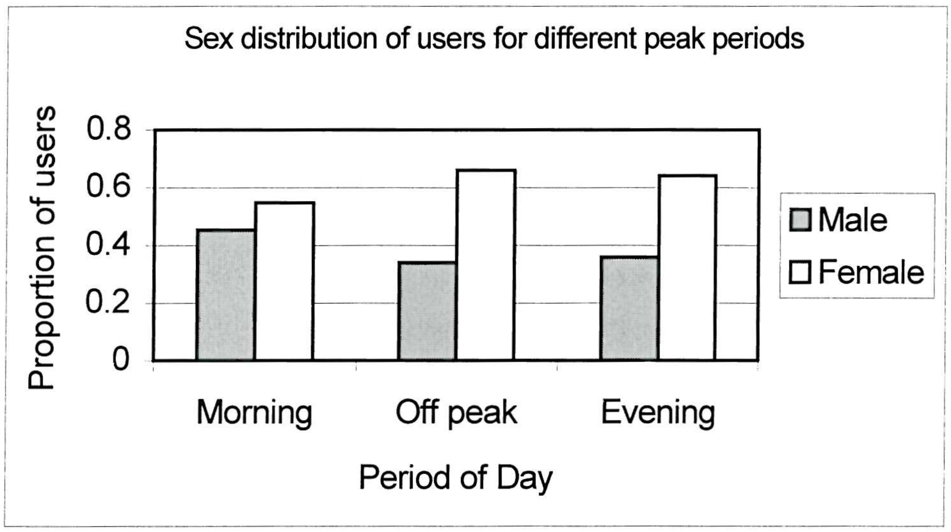
The age and sex distribution of users over the three peak periods is shown in figures 6.5 and 6.6.

Figure 6.5. Age distribution of bus users



The main difference observed were that female users were higher for all periods of the day and over 60 age group users made up 29% of the users for off peak period but were only 2% for other peak periods.

Figure 6.6. Sex distribution of bus users by peak period



6.7.2. Determination of Passenger Arrival Profile:

Passenger arrival profiles are required to calculate the waiting time at bus stops. In this analysis we have assumed that passenger arrival profile could depend on service frequency, journey purpose and service punctuality as explained in section 6.1. To analyse the relationships, passenger arrival profile has been defined using proportion of users arriving in 5 minutes intervals for a given headway due to the reasons stated below.

- 63% to 87% of the users, (Table 6.4) stated that they try to be within 3-5 minutes of the scheduled time (or within 5-6 minutes where services were sometimes early).
- The surveyed service frequencies were 10 minutes, 14-15 minutes, 18-20 minutes and 30-32 minutes.

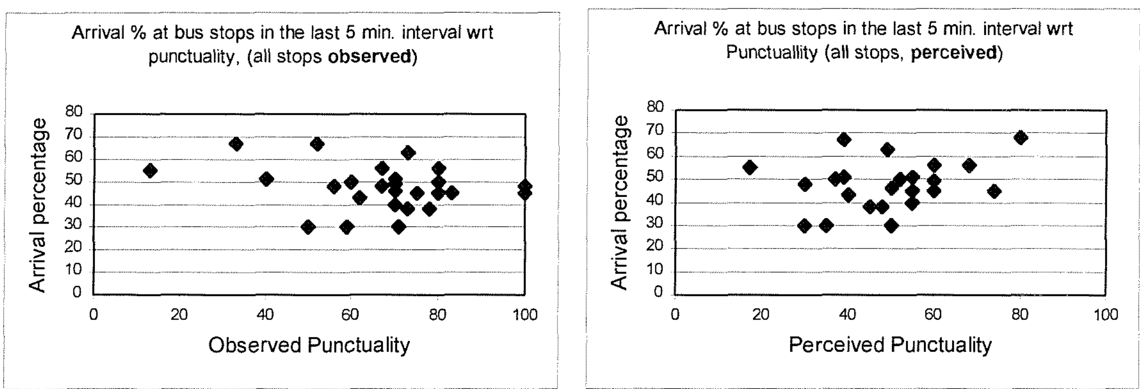
6.7.2.1. Analysis Steps for Determining Passenger Arrival Profiles

The analysis developed and undertaken to determine passenger arrival profile at bus stops (data used are for single service stops or where passenger arrival for particular service would be differentiated at multiple service stops) followed the steps given below:

STEP 1. Relationship between passenger arrival profile and punctuality (observed and perceived) for all frequency services: The data was first analysed to see if the arrival profile depended only on observed punctuality irrespective of service frequency and peak period (Different peaks represent different journey purpose, as explained in section 6.7.1). The first figure in figure 6.7 showed no significant relation between *observed punctuality* and *passenger arrival percentage* in the last five minutes (i.e., 5 minutes before the scheduled bus departure time). This is confirmed from regression analysis given in Table A, appendix B.

The observed punctualities have been quantified from the limited number of observed data. Ideally, observed punctualities from recent past could have been a better measure to affect arrival decision. In this context perceived punctuality could be a better measure than observed one as users could be arriving with respect to their perceived (based on past) punctualities. The second figure in figure 6.7 (arrival percentage vs. perceived punctuality) too showed that there was no significant relationship between the passenger arrival profile and perceived punctuality.

Figure 6.7 Relationship between arrival % and punctuality (observed and perceived) in the last 5 minutes interval ***for all services***:



Note:

In the figure each point represents a bus stop, where observed punctuality was calculated by dividing the number of buses departing within the generally accepted window of –1 to +5 minutes of the scheduled time with the total number of buses over the surveyed period (generally between 1.5 to 2 hours for two days). The passenger arrival percentage was calculated by dividing the number of user arriving in the last five minutes with the total users arriving between two consecutive scheduled bus departure time. The value for each bus stop is the average of all the observation over the surveyed period. The calculation of perceived punctuality is explained in section 6.6.

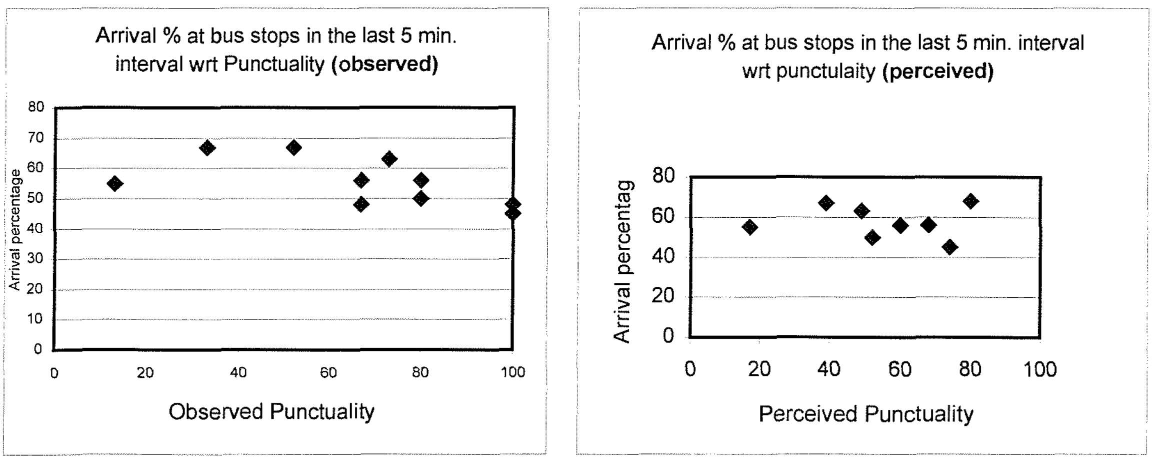
STEP 2. Relationship between passenger arrival profile and punctuality (observed and perceived) for high and low frequency services: The reason why no significant relationship was observed between punctuality and the arrival profile could be due to different frequency services being affected differently by the punctuality of the service. The services were divided into two categories, high (10 minutes) and low frequency (rest of the frequency band) services, to analyse relation between punctuality and arrival profile for different frequency band services due to the following reasons.

There were two distinct differences in user characteristic and behaviour between users of high and low frequency services. High frequency service users stated that:

- They knew that the service was of a certain frequency but a lesser proportion knew about the exact schedule/time and they referred less to a printed timetable (29% compared to 61% for 30 minutes frequency service) before coming to the bus stop.
- Lower percentages of users stated that they tried to arrive within a certain time of the scheduled time (62% for higher frequency services compared to 87% for lower frequency services, Table 6.6)

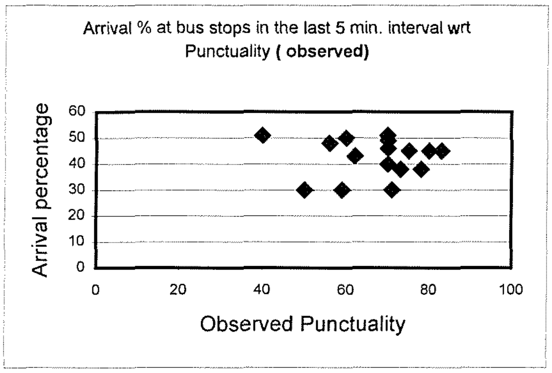
Therefore users of these services could be arriving in a different pattern than the users of the three other lower frequency services. The other three different frequency services have been grouped together as low frequency services due to the similarity between the users in the above context. The relation between arrival percentage and observed and perceived punctuality at stops with high frequency service are shown in figure 6.8.

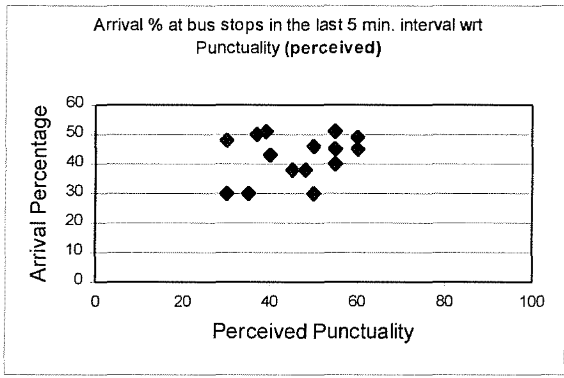
Figure 6.8 Relationship between arrival % and punctuality (observed and perceived) in the last 5 minutes interval for high frequency services:



Regression analysis as shown in Table B and C (appendix B) showed no significant relationship between the arrival percentage and punctuality. Again, no significant relationships were found for low frequency services as shown in figure 6.9 and by the regression analysis given in Table D (appendix B).

Figure 6.9. Relationship between arrival % and punctuality (observed and perceived) in the last 5 minutes interval for low frequency services:





STEP 3: Multiple linear regression: One reason why no relationship has been found between punctuality and arrival percentage could be due to the fact that the punctuality of a service is quantified by two factors, lateness (the percentage of time the service departs late) and earliness (the percentage of time the service departs early) of the service. The punctuality value decreases with increases in either of these factors but they could affect arrival percentage in different ways. If the buses are late than people would prefer to arrive late or nearer to the schedule and if buses are early users would prefer to arrive earlier as stated by the respondents (Table 6.6). In other words the passenger arrival profile could be dependent on two separate variables, the degree of lateness and degree of earliness. In other words the relationship could be between three variables.

To determine the relationship between three or more variables multivariate regression analysis can be carried out. Assuming, that frequency of service and peak period (journey purpose) had no effect on passenger arrival profile, the three variables here would be arrival percentage, which depends on the two punctuality factors. As regression analysis (Table E, appendix B) showed that there was no significant relationship between the degree of lateness and the degree of degree of earliness of a service multiple linear regression analysis for two independent variables was carried out.

The multiple correlation coefficients for the relation between arrival percentage in the last five minutes and punctuality in the case of all stops (all frequency services and period of time, Table F) and for high frequency services (Table G) were not significant i.e., the linear regression equation derived was not a good fit. However when the same analysis was carried out for low frequency services (Table H) the multiple correlation coefficient was significant. In other words there is a significant relationship between the arrival percentage and the two variables for low frequency services.

The relationship derived for arrival percentage in the last 5 minutes with *observed* punctuality:

Y (arrival %) = 39.07 – 0.55*Earliness +0.33*lateness **1**

(refer Table H, appendix B, for calculations).

Similarly arrival percentage in last 5 minutes with *perceived* punctuality:

Y (arrival %) = 39.01 – 0.58*Earliness +0.32*lateness **2**

(refer Table I, appendix B, for calculations).

Note:

This relationships have been derived from services where variation in punctuality were:

Maximum degree of lateness of 50% and maximum degree of earliness of 30% and therefore could give unrealistic results for values outside these ranges.

Equations 1 and 2 showed that when the buses are often late a higher percentage of users come closer to the scheduled time but when the buses are often early, a lower percentage of users come closer to the scheduled time, probably fearing that they would miss the bus. The passenger arrival percentages for the last 5 minutes for different value of punctualities using relations 1, and 2 were not statistically different (Table O, appendix B) and as it is easier to obtain observed punctuality, only equation 1 is taken up for further analysis.

STEP – 4: Arrival profile Variation within day:

The results from step 3 showed that there was no significant relationship when all the services were grouped together but gave significant relationships when carried out for lower frequency services with observed and perceived frequency. However the difference in user categories and behaviour within different peaks, as elaborated below, could also be influencing the passenger arrival profiles.

The difference between user characteristics/ behaviour in different periods of time is apparent from Table 6.6. These include:

- That there are more regular users in the morning peak (69%) than in off peak (37%) and evening peak (36%).
- That there are more users in the morning peak (67%) than other periods who need to reach their destination within a specific time.
- That users of other periods were less aware of schedule time prior to arriving at the bus stop than morning peak users (only 89% in the off peak and 76%in the evening peak compared 100% in the morning peak).

a) High frequency (10 minutes or less) services:

Within day changes – For a 10 minute frequency service average passenger arrival percentages in the two 5 minute intervals were found to be statistically similar for all time periods as shown in Table J in Appendix B. In other words any differences in user characteristics did not affect the arrival profiles for these high frequency services.

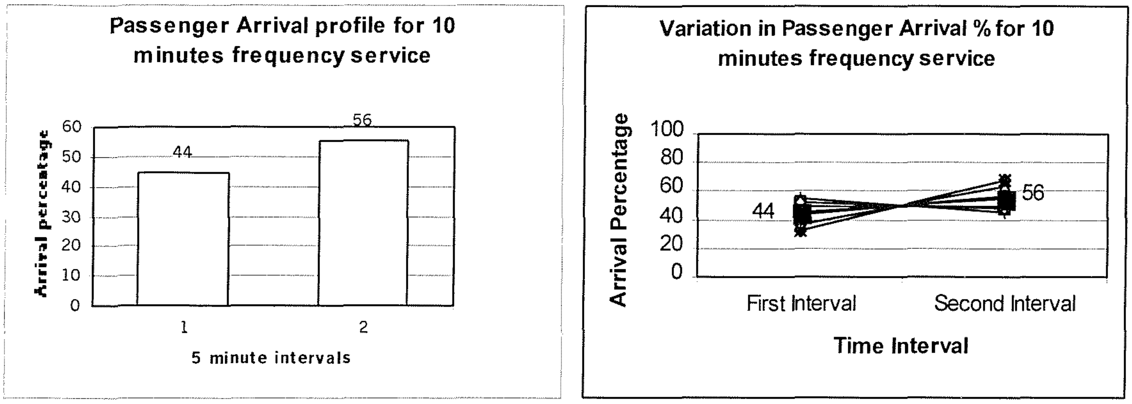
The comparison would be more conclusive if all the data were for services with same punctuality as this may affect the passenger arrival profile. However we have concluded above that there is no relationship between arrival percentage and punctuality in the case of high (10 minutes or less) frequency services. *Hence we can state that there is no within day difference between passenger arrival profiles for high frequency services.*

Difference between the first and second time interval - A paired t-test between the arrival percentage of the first and the second 5 minute interval is tabulated in Table K, Appendix B. Results showed that there was no significant difference between the arrival percentage of these intervals.

Average profiles

The average and variation in passenger arrival profiles for the 10 minutes frequency service are illustrated below (figure 6.10). The profile represents the average of different arrival percentages at 6 bus stops (surveyed for 90 minutes at each of the bus stop for two days).

Figure 6.10. Average Passenger Arrival profile for high frequency services.



Though figure 6.10 shows variation at some stops for the first and second interval it is not statistically significant as explained in the previous paragraph. Statistic calculation (Table L, appendix B) showed that the expected arrival percentage for either of the time intervals to be 50% and the chance of this result holding good for the whole population is 95%. In other words the passenger arrival percentage in each interval can be expected to be 50%. Table M in appendix B shows that the arrival percentage in each 5 minutes interval of a 10 minute frequency service is random, which supports the evidenced random arrivals (Jolliffe et. al, 1975) for high frequency services.

b) Low frequency (more than ten minutes) services:

In the case of low frequency services we have ascertained that there is a relation between arrival profile and punctuality of the service. The relationship was derived using data for all three periods of the time bands. The arrival profile could be different for different periods of time due to the changes in user characteristics and behaviour as stated above.

The following relationship between arrival percentage in the last 5 minutes and punctuality were derived for low frequency services for morning and off peak services (as shown in Table N, Appendix B). The relationship derived for arrival percentage in the last 5 minutes with observed punctuality for the morning peak is:

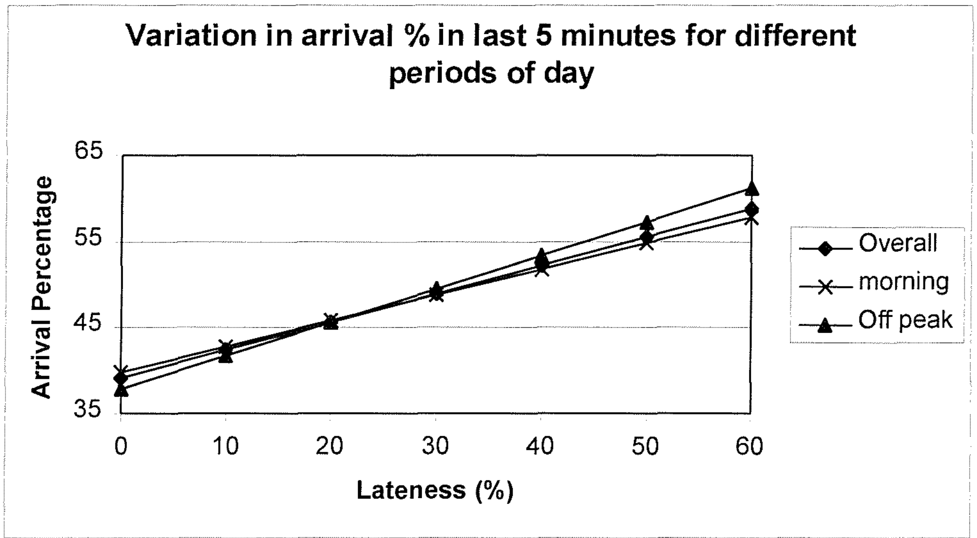
Y (arrival %) = 39.8 – 0.57*Earliness +0.30*lateness 3

Similarly the relationship derived for arrival percentage in the last 5 minutes with observed punctuality for off peak is:

Y (arrival %) = 37.8 – 0.56*Earliness +0.39*lateness 4

The values obtained from equation 1 (using data for all time periods), 3 and 4 were not statistically significant (illustrated in Table O, Appendix B). The statistics showed that the difference in the calculated values were not significant at the 5% significance level, i.e., the relation between arrival percentage and punctuality is the same for both the time periods; the difference is illustrated in figure 6.11). This result could be due to the fact that a similar percentage of total users stated that they try to be within 3-6 minutes of the schedule time for am and off peak. This was not true for evening peak users, where lower percentage of users stated the above view. However, there proved to be insufficient data for a sufficiently robust analysis of evening peaks.

Figure 6.11 Variation in arrival percentage in the last 5 minutes for different peaks:



As the values obtained using relation 1 were not significantly different than the values obtained by using relations 3 and 4 as discussed above the first relationship is taken forward as it covers all the time periods.

***STEP 5** – Passenger arrival profile for low frequency services:*

Arrival percentage in the last two 5 minutes interval for low frequency services

In high frequency services there was no significant difference between the passenger arrival percentage in the last five minutes interval and the first five minutes interval. However for frequencies lower than 10 minutes there was a significant difference between last 5 and the 5 minutes interval before the last (penultimate) interval (as shown in Table P, and Q appendix B). *Relationships between the arrival percentage in the penultimate 5 minutes interval with observed and perceived punctuality for low frequency services are given below* (Tables R and S in appendix B describes the regression analysis). The relationship derived for arrival percentage in the penultimate 5 minutes with *observed* punctuality:

Y (arrival %) = 33.5 – 0.30*Earliness +0.13*lateness **5**

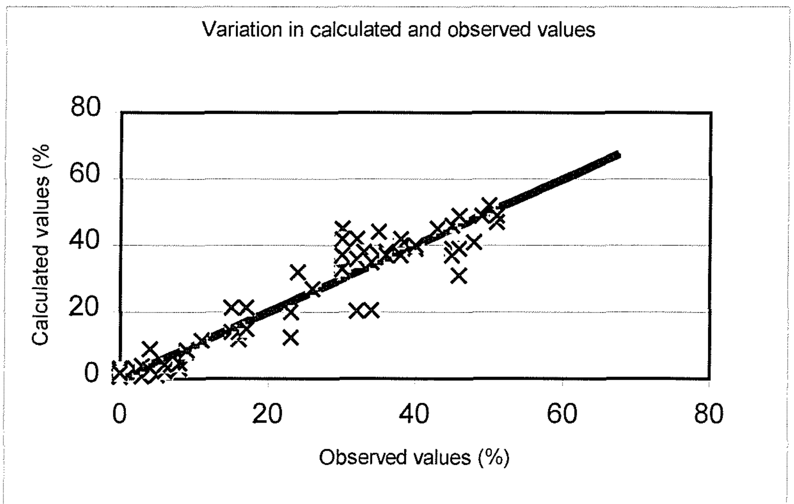
Similarly the arrival percentage in penultimate 5 minutes with *perceived* punctuality:

Y (arrival %) = 31.2 – 0.33*Earliness +0.21*lateness **6**

In both the relationships the multiple correlation coefficient was close to one, which showed that the linear regression equation was a good fit, i.e., there was a significant relationship. The passenger arrival percentages for the penultimate 5 minute interval for different values of punctualities using equations 5, and 6 were not statistically different (Table O) and as it is easier to obtain observed punctuality, only equation 5 is taken up for further analysis.

Comparison between observed and calculated arrival profile for low frequency services: The relationships derived in the sections above (equations, 1to 6) have shown a significant relation between passenger arrival profile and punctuality for low frequency service. The following section illustrates the difference between the observed and the calculated (using the equations derived) arrival percentages (figure 6.12) to show the validity of the derived relationships.

Figure 6.12. Comparison between observed and calculated arrival profile for low frequency services:



The observed arrival percentage value and the value calculated for the same stops using the observed punctuality and the relationship derived (Relations 1 and 5) were not significantly different at 5% significance level as shown by the calculations in Table T, appendix B. This further support the use of the relations derived to calculate the arrival profile for low frequency services.

Arrival percentages in the initial 5 minutes interval for low frequency services

The arrival percentages in the penultimate and the final 5 minute interval for all low frequency services (15, 20 and 30 minutes frequency service) will be equal as the relations used to calculate the arrival percentage is the same one. However the arrival percentages in the initial 5 minute intervals will be different as there will be one such interval in a 15 minutes frequency service, two in a 20 minutes frequency service and three in a 30 minutes frequency service.

The following procedure was used to calculate the values for these intervals:

- The sum of the arrival percentages for all the initial 5 minute intervals would be equal to 100 – the sum of arrival percentages in the last two 5 minutes intervals (calculated using the equations derived).
- Due to the low percentage of passenger arrivals in these intervals the arrival percentages in these intervals were calculated by dividing the remaining arrival percentage (which is 100 – sum of arrival percentage in the last two intervals) by the ratio of the average arrival percentages of these intervals obtained from the surveyed data.

For example, if the arrival percentages calculated from the relation for the first and second time interval for a given punctuality service of 20 minutes frequency were 40 and 35% the arrival in the first and second interval will be:

1st 5 minute interval $= \frac{(100 - 40 - 35) * 3}{(20 + 3)} = 3.26$, and

2nd 5 minute interval $= \frac{(100 - 40 - 35) * 20}{(20 + 3)} = 21.74$

Where '3' is the observed average arrival percentage in the first 5 minute interval and '20' is the observed average arrival percentage in the second 5 minute interval.

6.7.3. Relation between Perceived and Observed Punctuality:

Observed punctuality values were derived using vehicle times noted at bus stops for a period of 90 minutes for the same time period for two days. Buses arriving or departing between –1 and +5 minutes were assumed to be punctual. Perceived punctuality was derived using the procedure described in section 6.6. The data showed that users generally perceived punctuality to be worse than it actually was, as illustrated in figure 6.13. The difference could be due to the observed data not being typical one (average of two days) or users biasing their response more towards their worst experiences.

Figure 6.13 Observed and perceived punctuality

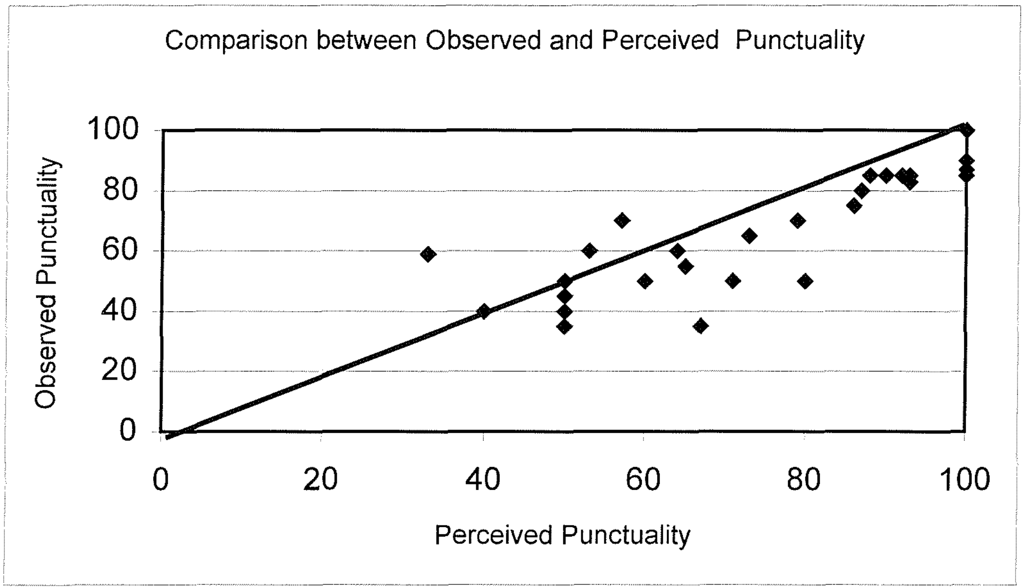


Figure 6.13 shows that the perceived punctuality is consistently lower than the observed value. The perceived value lies 6 to 38% below the observed value as illustrated in Table U, Appendix B. In other words the perceived punctuality value is on average 22% lower than the observed value. As discussed in section 6.2 this perception of lower punctuality than its actual value can be related to the weight of waiting time and reduced where passenger information is provided.

6.7.4. Route Choice:

The survey carried out at three stops, where two alternative bus services provided services for a particular destination was used to analyse route choice. The result is tabulated in Table 6.5. The result from bus stops 'a' and 'b' showed that 2 to 3 minutes difference in travel time for a O-D pair or the difference in the frequency of the two alternate service did not affect route choice. All respondents said that they would choose the first bus that comes along. When the time difference is 4 minutes, users/per bus for the quicker route was 69% and when the time difference is 9 minutes all the users choose the quicker one. Respondents at the bus stop 'c' (with a time difference of 4 minutes between the services) said that they would catch the first bus that comes along and respondents at the bus stop 'd' (with a time difference of 9 minutes between the services) said they would prefer to wait. Most respondents choosing the longer journey time services stated that it was due to the schedule.

Table 6.5 Observed bias in Route choice

Destination and Service no.	Journey Time (min)	Diff in time (min) as per schedule	Frequency (Min)	Boardings (pass/bus)	No. of users Interviewed
a) Burgess road to Portswood		Service 101 is 2min quicker			56
101 (10 bus)	7		15 min	2.05	
20 (6 bus)	9		30 min	2.05	
b) Burgess road to C/Centre		Service 101is 3min quicker			
101 (10 bus)	14		15 min	1.3	
20 (6 bus)	17		30 min	1.45	
c) Swaythling to C/Centre		Service 11is 4 min quicker			32
101 (11 bus)	20		15 min	0.73	
11 (15 bus)	16		10 min	1.6	
d) C/Centre – Bitterne		Service 8 is 9 min quicker	Both 20 min		15
8 (6 bus)	14			2.5	
8A (6 bus)	23			0.0	

As discussed in section 5.5, scaling factor of a logit model in the TRIPS module 'MVPUBM' can be user specified to reflect the route choice with change in travel time. From this result the scaling parameter (SFESM) in TRIPS module was set, which would result in 70% higher patronage (per bus, as patronage for a service will be weighted by the ratio of the frequency of the services with combined frequency of all services) for quicker routes (shorter in-vehicle time) when the time difference is 4 units (minutes).

6.8. Data from Literature Review:

Some of the data required for the modelling could be best drawn directly from the literature. The change in the boarding time with improved ticketing and the potential of users, provided with real time information at bus stops, utilising the waiting time at bus stops has been used in the modelling to illustrate the impacts in the modelled network. The required data included:

1. Boarding times:

Some existing ticketing schemes like travel cards, pre-paid tickets and exact fares only buses reduce boarding time. The boarding time can be further decreased and Hook (1998) suggests that boarding time will be reduced to the amount of time that it takes people to board as it takes around 100 milliseconds for a Smartcard to be read. Other schemes like Octopus Smartcard (ITS International, 1998), 'Multiservice' (Ampelas, 1999), 'hands free card wallet' (Blythe, 1997) and Smartcard used by a consortium of private bus operators in Finland (Oorni, 1997) have also noted the decrease in boarding time with such technology. A survey of boarding times undertaken in London (Haworth et. al. 1995) showed that boarding times are reduced with more efficient type of ticketing. For illustration purposes a boarding time of 4 sec (adult travel card) and 3.2 sec (smart cards) have been taken used in the modelling to illustrate the impacts in the modelled network with these improved boarding time.

2. Use of waiting time:

Passenger survey have shown that 43.3% of passengers regard estimated arrival time to be the most important passenger information (Kim, 1997) to avoid unnecessary waiting by arriving closer to the bus arrival time. A survey for the STOPWATCH system in Southampton (Leach et.al., 1995) showed that when bus stop information indicated that the bus would arrive in 5 minutes, and there was no other alternative service then 93% of passengers chose to wait at the stop. However for 10 minute and 20 minute waiting times, 24 and 36% of users chose to walk away from the stop and return later. This is consistent with other studies (Backstrom, 1997) where 20 percent of respondents stated that they would leave the stop and come back later if the waiting time is more than10 minutes. These data have been used to illustrate the reduction in waiting time due to provision of real time information at bus stops.

6.9. Average Waiting Time at Bus Stops:

The average waiting time users have to wait if they arrive randomly at a bus stop given by Jolliffe et. al., (1975) is:

$$\text{Waiting time} = \mu\,(1 + \sigma^2 / \mu^2)\,/2,$$

where μ and σ are respectively mean headway and standard deviation of the time headways between the buses.

However for situations where there is a fixed timetable for the service (i.e. a time-table based service where the buses will run at certain fixed times) and a proportion of the users are regular or frequent users, passenger arrivals will depend on bus scheduled time (they will tend to come closer to the scheduled time to reduce waiting time, especially for low frequency services as shown in section 6.7.2.1). O'Flaherty et. al., (1970) and Seddon et. al., (1974) support this in form of an equation:

$$\text{Waiting time} = A + B\,\mu, \text{ where } \mu \text{ is mean headway.}$$

Jolliffe et. al., (1975) too gave a relation to support this aspect and formulated an expression where the waiting time depended on three types of users, the first type are those who arrive causally whose waiting time is zero, i.e., they arrive when they see the bus, the second type are those who correlate with bus arrival time and arrive to minimise their waiting time and the third type are those who arrive randomly. However the situation here is different as the waiting time for low frequency services also depended on punctuality of the service and were affected differently by earliness and lateness (as shown by the relationships derived in section 6.7.2). A procedure was thus devised to calculate the average waiting time as discussed in section 6.10.

6.10. Calculation of Average Waiting Time

TRIPS public transport module uses a user specified waiting curve (section 5.4.2), which gives the average waiting time for a range of headways, to calculate the average passenger waiting time at bus stops. Therefore to illustrate the change in waiting time due to provision of information and improvement in service with ITS measures, average waiting times is required for all frequency services.

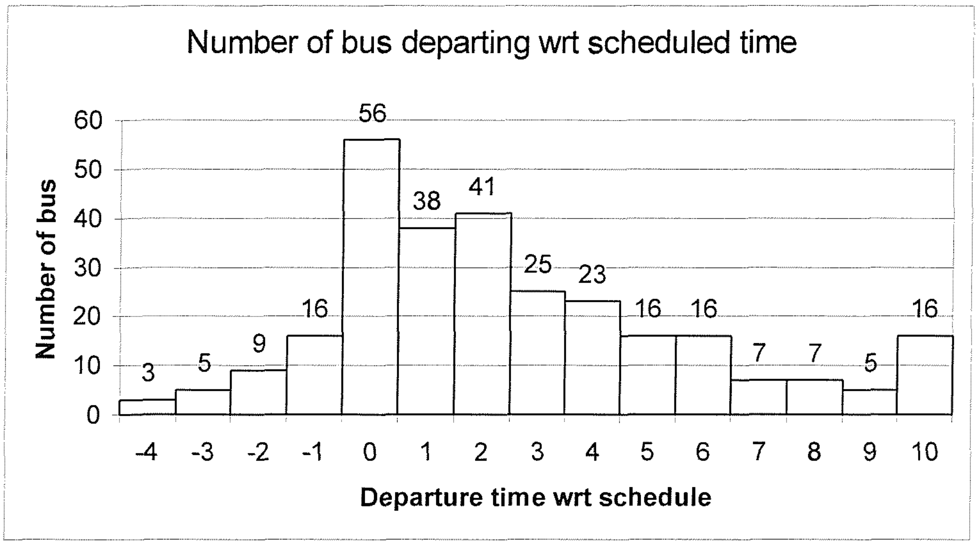
The average waiting time for passengers at stops depends on both the way they arrive (passenger arrival profile) and the way the buses depart (vehicle profile). In this study the bus departure profile has been observed and expressed in terms of percentage of buses 'on time', 'late', and 'early'. For example, 10% late, 10% early, and 80% on time. Passenger arrival profiles for different service frequencies have been discussed in section 6.7.2, and the profiles can be calculated using the relationships derived. To calculate average waiting time at bus stops we need to determine at what point and what rate the vehicles arrive when we assume values as discussed above.

6.10.1. Bus Departure Probability Distribution:

Buses may not depart uniformly but could have a distribution around the scheduled time. From the surveys of bus departures at bus stops in Southampton, covering all the service frequencies, times of the day and different punctualities, the distribution of buses departing around the scheduled time is given in figure 6.14.

Figure 6.14 shows the number of buses departing in one- minute interval around the scheduled time, '0'. The earliest bus departed 4 minutes prior to schedule and the latest bus departed 14 minutes after the scheduled time.

Figure 6.14 Distribution of bus departures:



The services were divided into three categories.

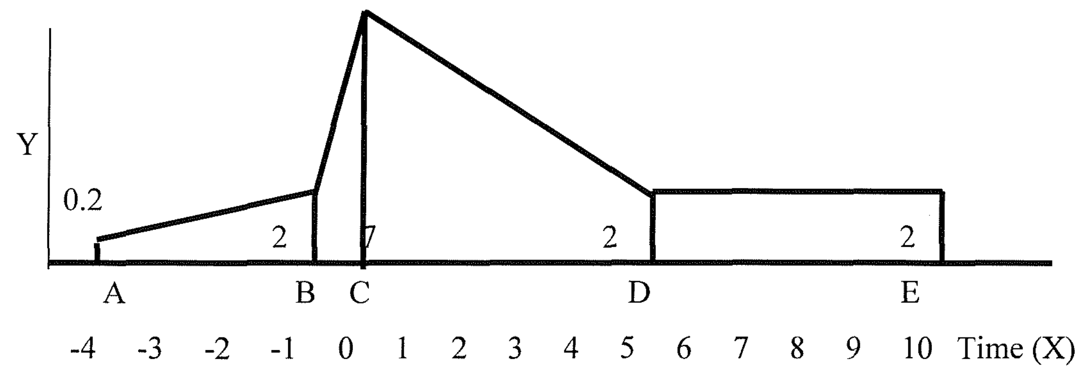
a) Punctual bus (buses departing between –1 min. to +5 min. from scheduled time (source: http://cpt-uk.org/cpt/cptsite/sfset.htm)

b) Late bus (buses departing after + 5 minutes from the scheduled time)

c) Early bus (buses departing more than –1 minutes before the scheduled time)

The distribution in figure 6.14 was generalised as shown in the figure 6.15 to calculate the average waiting time.

Figure 6.15. Generalised bus departure probability distribution in Southampton.



The probability of buses departing at different points with respect to the scheduled time for these three categories is illustrated in figure 6.15 and can be interpreted as follows:

- X-axis shows time in relation to the schedule point 'C' and Y-axes shows relative number of buses departing at that time.
- When a bus is assumed to be punctual, it can depart between points 'B' (-1 min. from schedule) and point 'D' (+5 min. from schedule). The probability of bus departing at any time interval between BD is the area between the intervals divided by area of the trapezium between BD.

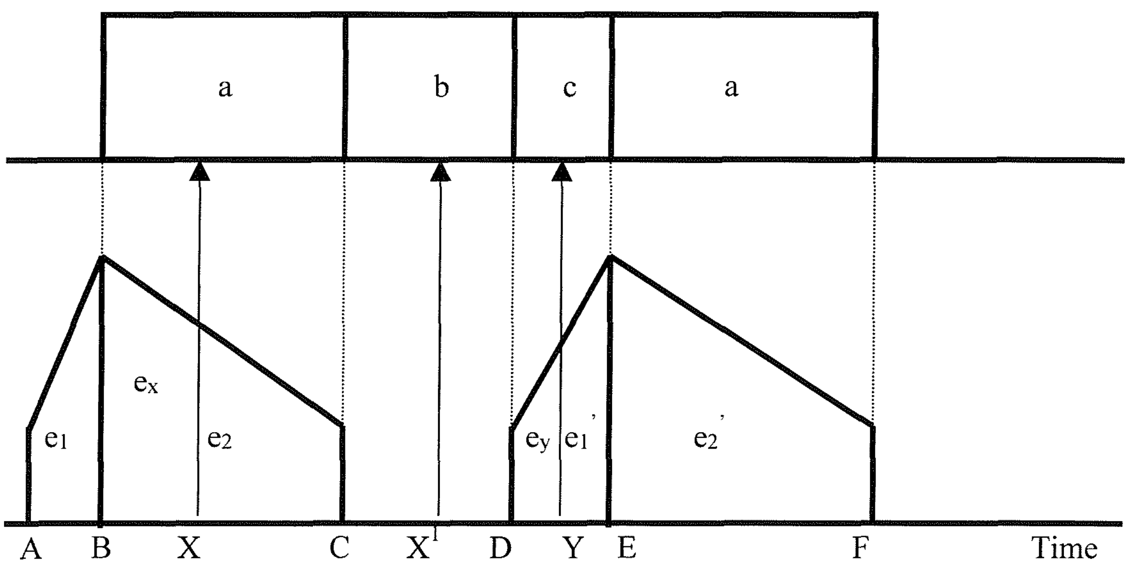
- When a bus is late it can depart between point 'D' (+5 minutes from schedule) and point 'E' (+10 minutes from schedule) and can depart with the same probability between any time intervals. The number departing later than 10 minutes was not significant and therefore this limit was assumed.
- When a bus is early it can depart between point A (-4 minutes from schedule, the earliest observed value) and point B (-1minutes from scheduled time). The probability of departing at between any time intervals between AB is the area between the intervals divided by the area of the trapezium between AB.

Using this *probability profile for bus departures, and a passenger arrival profile as an example*, calculation of the average waiting time for users arriving in the first 5 minutes interval of a ten minutes frequency service is explained in the following section.

Average waiting time for users arriving in the first 5 minutes interval of a 10 minutes frequency service (all buses on time): This section illustrates the calculation of average passenger waiting time using the concept of passenger and bus departure profiles as just described. The example taken is where buses are assumed to be punctual (i.e., they all depart between –1 and +5 minutes from their scheduled time). The expected passenger arrival profile is shown (top portion of the figure 6.16) for a 10 minutes frequency service, a uniform arrival rate is shown as the expected arrival percentage for each 5 minutes interval can be expected to be 50% (as shown in Table L, appendix B).

Figure 6.16. Passenger arrival / Bus departure profiles

Passenger arrival profile:



Vehicle departure distribution

Here,

B = Scheduled departure time for the first bus.

AB = 1 minute

BC = 5 minutes (first interval)

E = Scheduled departure time for the second bus.

CE = 5 minutes (Second Interval)

DE = 1 minute

EF = 5 minutes

The first bus can depart at 'A', 1 minute before scheduled time 'B' or depart at point 'C', +5 minutes from scheduled time and the second bus can depart at 'D', 1 minute before scheduled time or depart at point 'F', +5 minutes from scheduled time 'E' when the bus is assumed to be punctual.

'a', 'b' and 'c' are proportion of passengers arriving (assumed uniform arrival) within the time intervals BC, CD and DE respectively. That is (a + b + c) is the total passengers arriving between the scheduled time 'B' and 'E'. 'a' is the proportion of passengers arriving in the first 5 minutes interval.

From the vehicle departure probability distribution:
When the bus service is 'punctual' then, according to figure 6.15, if 2 buses depart at 'A' then 7 buses would depart at point 'B' and 2 buses would depart at point 'C'.

Therefore,
If 'e_1' (the area of the trapezium between point A and B) represents the probability of the first bus departing between 'A' and 'B'
'e_2' (area of the trapezium between point B and C) represents the probability of the first bus departing between 'B' and 'C'
Similarly the probability of the second vehicle departing between DE and EF, e_1' and e_2' will be same as e_1 and e_2 respectively.

The probability of vehicles departing within time interval 'A' to 'B' $= e_1 / (e_1 + e_2)$

$= \{1/2\,(2+7)*1\} \,/\, [(\{1/2\,(2+7)*1\} + \{1/2\,(2+7)*5\}]$

$= 1/6$

The probability of vehicles departing within time interval B to C

$= e_2 / (e_1 + e_2)$

$= 5/6$

Average waiting time (AWT) for passengers (a) arriving in the first 5 minutes interval:

For 1/6th of the time

The probability of the first bus departing between A and B is 1/6, therefore for 1/6th of the time the waiting time for passengers arriving in the first 5 minutes interval 'a' will depend on the departure time of second bus, which can depart between DF.

Passengers arriving at any point X between B and C will miss the first bus and the waiting time will be:

= BC +CD + Distance from point D to the cg (centre of gravity for area $(e_1' + e_2')$ for second bus) - X

As it varies from 0 to 5,

Total time $= \int_0^5 (BC + CD + cg - X)\, dx$

$= \int_0^5 (5 + 4 + 2.63 - X)\, dx$

AWT $= 9.13$ ....Case 1

For 5/6th of the time

The probability of the first bus departing between B and C is 5/6, therefore for 5/6th of the time the waiting time for passengers arriving in the first 5 minutes interval 'a' will depend on both the first bus and the second bus as:

Any passenger arriving at any point X between B and C will have a probability of $(e_2 - e_x)/e_2$ (Probability of bus departing after point X) of boarding the first bus and the waiting time will be: = cg of area $(e_2 - e_x)$ from point X, where 'e_x' is the area of trapezium between BX

However the probability of the passenger missing the bus = e_x/e_2 (probability of bus departing before point X) and the waiting time will be:

= XC + CD + cg of area $(e_1' + e_2')$ from point D ($e_1' = e_1$ and $e_2' = e_2$)

Therefore the waiting time for a passenger arriving at point X will be:

$= (e_2 - e_x)/e_2$ * cg of area $(e_2 - e_x)$ from point X + (e_x/e_2) * (XC + CD + cg of area $(e_1' + e_2')$ from point D)

As X varies from 0 to 5

Total waiting time for passengers arriving between B and C will be:

$$= \int_0^5 \left\{ (e_2 - e_x)/e_2 * \text{cg of area } (e_2 - e_x) \text{ from point X} \right\} + \left\{ (e_x/e_2) * (XC + CD + \text{cg of area } (e_1' + e_2') \text{ from point D}) \right\}$$

$$= \int_0^5 \left\{ \left[\{(\tfrac{1}{2}(7 - X + 2) * (5 - X)\} / \tfrac{1}{2}(7 + 2)*5 \right] * \{(2*2 + 7 - X)(5 - X)/(3 *(7 - X + 2)\} \right\} + \left\{ \{ (\tfrac{1}{2}(7 + 7 - X)) * X) / (\tfrac{1}{2}(7 + 2)*5)\} * \{(5 - X) + 4 + 2.63)\} \right\}$$

$= 23.52$

Average waiting time will therefore be:

$= 1/5 *$ total waiting time

$= 27.98/5$

$= 5.60$ ....Case 2

Therefore AWT for 'a'

$= 1/6^{th}$ of case 1 and $5/6^{th}$ of case 2

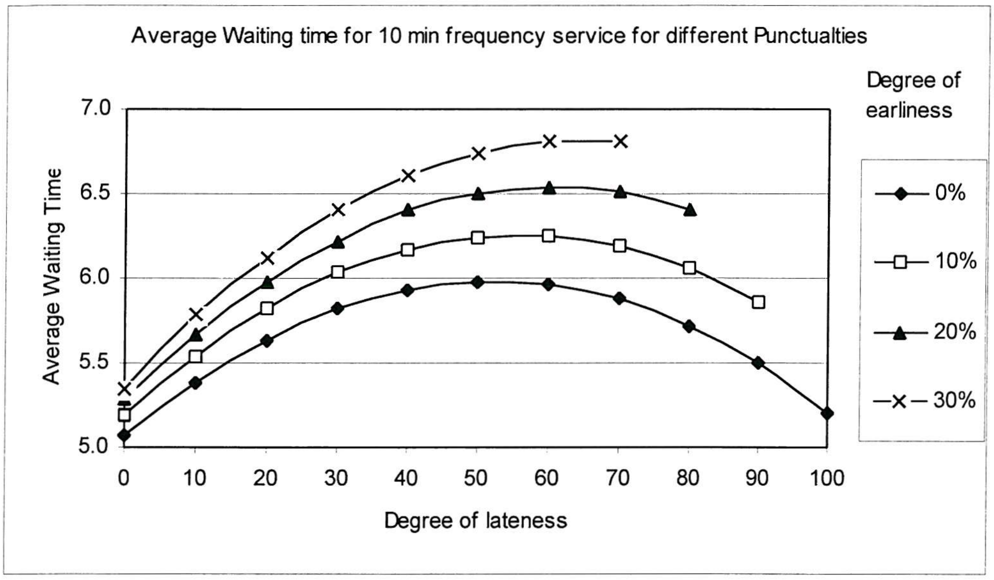
$= 1/6 * 9.13 + 5/6 * 5.6$

AWT $= 6.19$ ....*Case 3*

With similar logic the waiting time for users arriving in the second 5 minutes time interval can be calculated. An example for calculating waiting time for 10 minutes frequency service for different punctualities is elaborated in Appendix C. This process leads to a set of cases with values as calculated above (case 1 to case 3) for different scenarios. These values were entered in an excel spreadsheet, along with the relations for calculating passenger arrival profile (for low frequency services) to calculate AWT for any punctuality. This was carried out for 10, 15, 20 and 30 minutes frequency services. The average waiting time for these service frequencies are illustrated in figures, 6.17, 6.19, 6.21 and 6.22. Passenger arrival percentages for low frequency services were calculated using equations 1 and 5 from section 6.7.2.

Figure 6.17 applies to high frequency services, where equal proportions of users arrived in the first and second half of the headway. For a given degree of lateness, the average waiting time increased with the increase in degree of earliness. For a given degree of earliness, the average waiting time for passengers increased with the increase in degree of lateness.

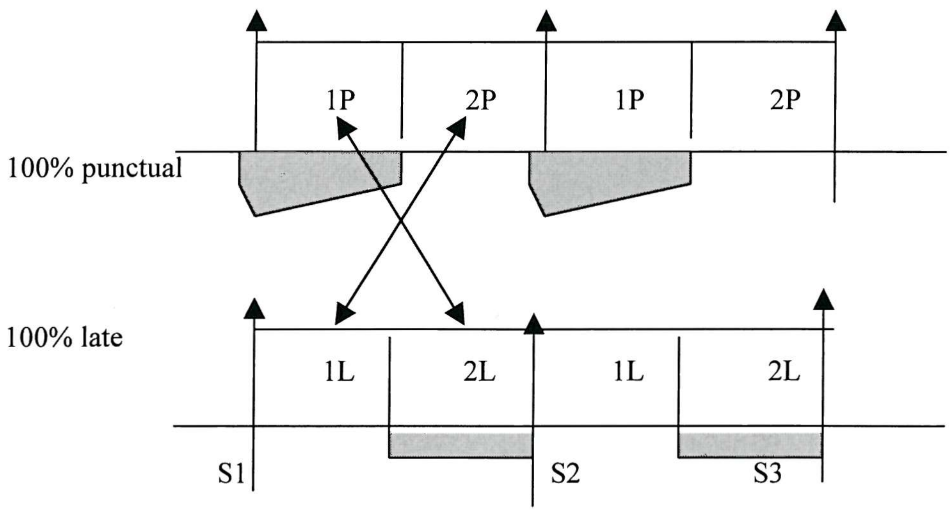
Figure 6.17 Average Waiting time for 10 minutes frequency services



Note:
Degree of lateness: percentage of buses departing 5 minutes after the scheduled time
Degree of earliness: percentage of buses departing more than 1 minute before the scheduled time

However the waiting time decreased when the degree of lateness exceeded 50 % until at 100% degree of lateness the value was nearly same as 100% punctual. This is due to the fact the frequency of service is 10 minutes, the arrival percentage for both 5 minutes interval are equal and the maximum lateness has been assumed as 10 minutes from the scheduled time. This is illustrated in figure 6.18.

Figure 6.18 Equivalence of waiting time in 10 minutes frequency service



Note: S1, S2 and S3 are scheduled departure time.
1P and 2P are users arriving in the first and second interval when bus service is 100% punctual, and 1L and 2L are users arriving in the first and second 5 minutes interval when the service is 100% late.
The bus departure distribution is shown by the shaded area below the passenger arrival profile.

Figure 6.18 illustrates how the total waiting time for users arriving in the first 5 minutes interval when the service is punctual is nearly the same as the waiting time for users arriving in the second 5 minutes interval when the bus is 100% late and vice versa. The total waiting time for 1P users is equivalent to total waiting time for 2L users and the total waiting time for 2P users is equivalent to total waiting time for 1L users. As 1P = 2P = 1L = 2L, the average waiting time would therefore be nearly same for both cases. The slight difference is due to the difference in bus departure probability distribution in the two cases. It should also be noted that the waiting time would be different for a different vehicle departure probability distribution.

It should be noted here that the result would be consistent with the waiting time calculated using the formula given by Jolliffe (1975) for bus stops with passengers arriving randomly. Here the waiting time is given as:

$$Waiting\ time = \mu\,(1 + \sigma^2 / \mu^2)\,/2,$$

where μ and σ are respectively mean headway and standard deviation of the time headways between the buses. When 0% or 100% of the buses are late the standard deviation of the time headways will be equal to zero and the waiting time will equal half the headway of the service.

Figure 6.19 Average Waiting time for 15 minutes frequency services

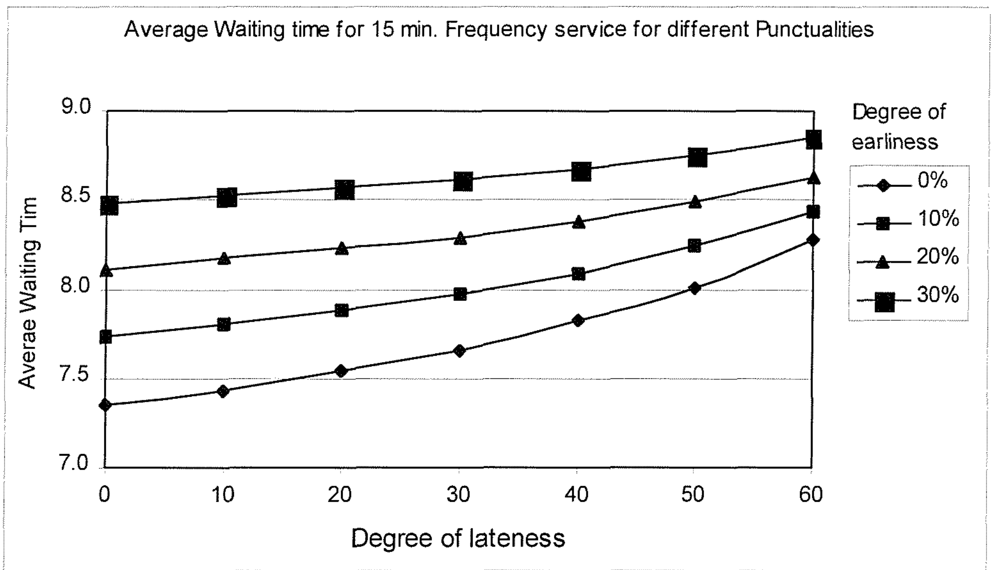
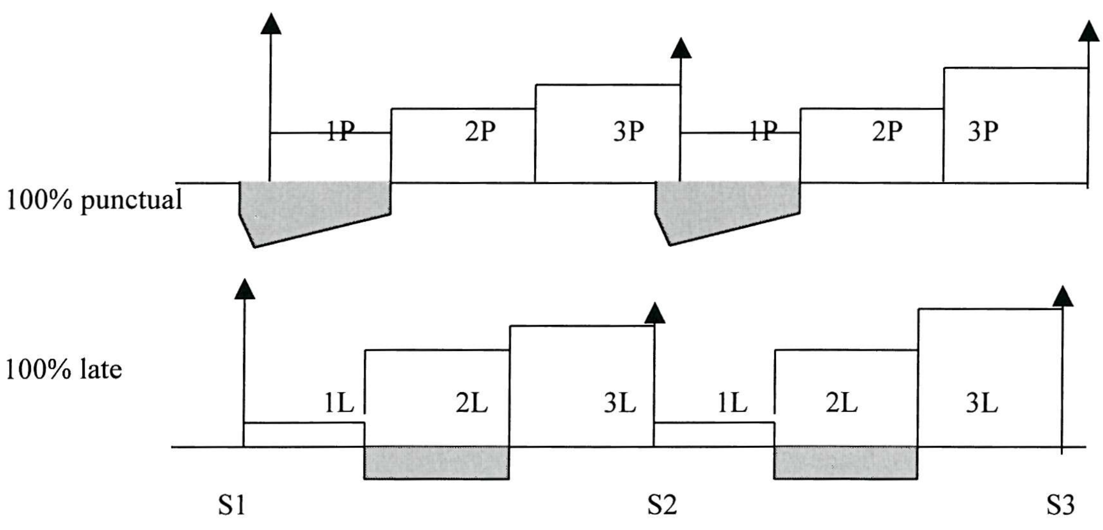


Figure 6.19 shows the change in waiting time for a lower frequency service of 15 minutes with the change in service punctualities. The waiting time is calculated for punctuality limits within which the relation between punctuality and arrival profile has been derived

(refer section 6.7.2) Unlike for high frequency services the waiting time does not decrease after 50% degree of lateness. This is illustrated in figure 6.20.

- The passenger arrival percentages for the last two intervals increases with the increase in degree of lateness but decreases in the first interval. 3L>3P and 2L> 2P and 1L< 1P.
- When the service is assumed to be late the bus departs in the second interval. The average waiting time for users arriving in the first and the second interval decrease slightly than when bus is punctual. As when the bus departure distribution overlaps the interval, depending on the point of the arrival of the passenger and departure of the bus, waiting time for some users will be low (if the bus departs after the user arrives) but could be high (if the bus departs before the user arrives).
- For all the users arriving in the third interval waiting time will always be higher when bus is late as the bus is departs 5 minutes late than when the service is on time. As the rate of increase in the proportion of users arriving in the third interval is higher than in the second interval (refer equation 1 and 5) the average waiting time for low frequency services does not decrease when the degree of lateness exceeds 50%.

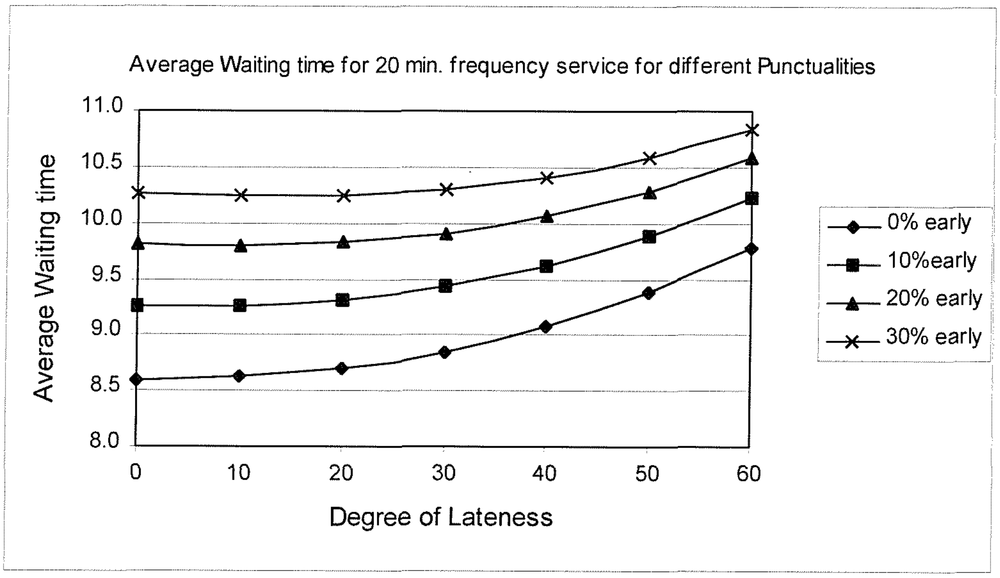
Figure 6.20 Variation of waiting time in 15 minutes frequency service



Note: S1, S2 and S3 are scheduled departure time.
1P, 2P and 3P are users arriving in the first and second interval when bus service is 100% punctual, and 1L, 2L and 3L are users arriving in the first, second and the 5 minutes interval when the service is 100% late.
The bus departure distribution is shown by the shaded area below the passenger arrival profile.

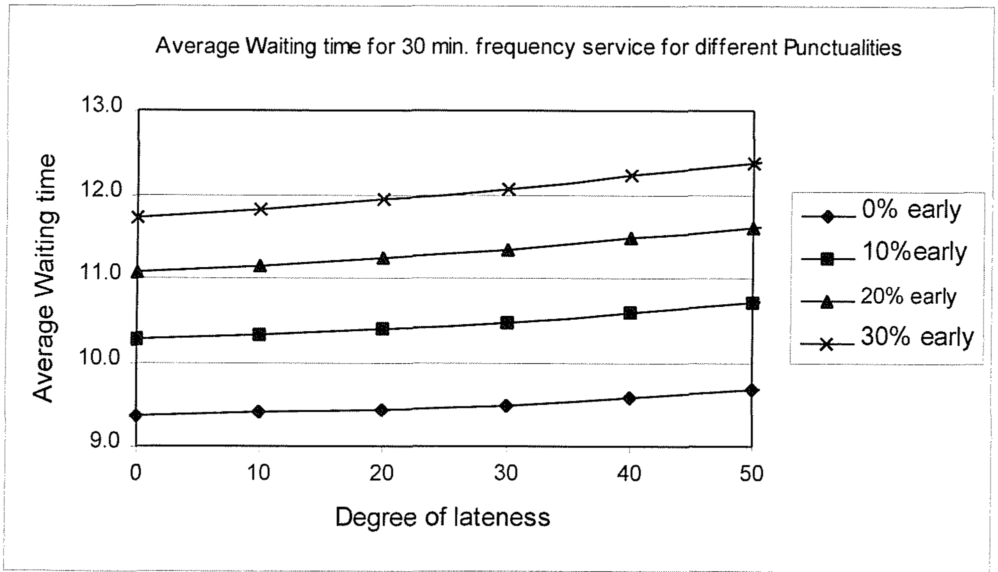
The average waiting time for 20 and 30 minutes frequency service is given in figures 6.21 and 6.22. In all the low frequency service, the degree of earliness increases waiting time more than degree of lateness as more users miss a particular bus and have to wait for the next bus to arrive. For example in a 15 minutes frequency service, an increase in degree of lateness from 0% to 30% (for 0% degree of earliness) increased the waiting time by 0.32 minutes but an increase in degree of earliness from 0% to 30% (for 0% degree of lateness) increased the waiting time by 1.13 minutes.

Figure 6.21 Average Waiting time for 20 minutes frequency services



The figures show that the increase in an average waiting time for same punctualities does not increase in a straight line as proposed by previous studies (O'Flaherty et. al., 1970 and Seddon et. al., 1974).

Figure 6.22 Average Waiting time for 30 minutes frequency services



The main aim of this exercise was to derive a waiting curve, which can be used in TRIPS modelling. Figure 6.23 shows the waiting curve for 100% punctual bus service, where the average waiting time has been calculated using the derived relations and observations (The value for 25 minutes frequency service was assumed to get a smooth curve).

Figure 6.23 Wait curve for 100% punctual bus service.

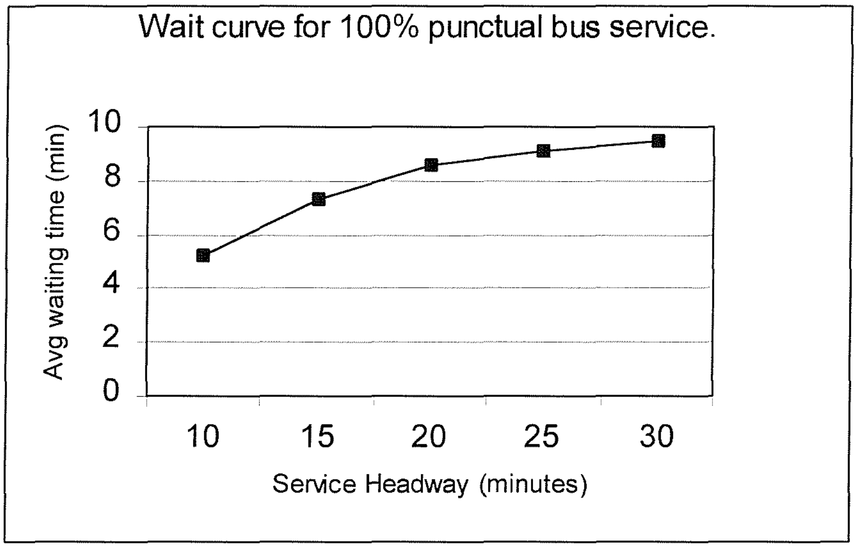


Figure 6.23 shows that the average waiting time for lower frequency services is lower than the default value of half the bus headway, which is often used in modelling, because many users time their arrival at bus stop according to the timetable and their perceived reliability/punctuality of the service. It should be noted here that the waiting curve derived is network specific and is based on limited data, however the method of calculating average waiting time would be applicable to any area served by scheduled based bus services

6.11. Conclusion:

A modelling framework (section 6.2) using two transport models TRIPS and SPLIT can be used to illustrate the main impacts, waiting time, change in journey time and optimal route choice of selected ITS measures. To illustrate these impacts on a transport network using transport modelling two surveys were carried out to collect the necessary data and derive the required relationships. This included the following:

1) Data required to build the TRIPS transport network (described in section 6.4) and the SPLIT transport network (described in section 6.5).

2) The derivation of a relationship (section 6.5.2.1) used in the SPLIT modelling to account for the change in boarding time (dwell time) with improved ticketing methods as:

*Dwell time = 5.9 + 6.59*number boarding + 3.16* number alighting*

3) Analysis of the difference between perceived and observed punctuality (section 6.7.3) giving the result that users perception of punctuality was on average 22% lower than the observed punctuality.

4) Analysis of the relationship between route choice and travel time (section 6.7.4) giving a scaling factor for use in TRIPS modelling to reflect change in route choice with differences in travel time where two or more services/route serve the same OD pair.

5) New analysis of waiting time: one of the main impacts of ITS measures, changes in waiting time can be modelled using different waiting curves in the TRIPS model as described in section 5.5. The waiting time at a bus stop was shown to depend on passenger arrival profile and bus departure profile, i.e., how passengers arrive with respect to bus departures.

An in depth analysis using the survey data was carried out to find out what factors affected passenger arrival profiles (section 6.7.2). This showed that passenger arrival profiles for high frequency services were independent of user category and arrive randomly over the service headway (section 6.7.2.1); the arrival profile for lower frequency services were independent of user category but depended on the punctuality of the bus service. Linear additive relationships were derived between arrival percentages in 5 minutes intervals and punctuality variables, including degree of lateness and degree of earliness were derived (section 6.7.2.1, step 3 and 5).

Factors affecting bus departure profiles include operational efficiency (how operators manage the service), variation in patronage (which affects the dwell time at bus stops) and network conditions (changes in congestion levels affects link journey time). For calculating waiting time for different punctualities (section 6.10), bus departure profiles were assumed in terms of degree of lateness (percentage of buses late), degree of earliness (percentage of buses that departed early) and on time (percentage of buses on time). A bus departure probability distribution was generated to show the average departure time of buses within these time windows.

Using the bus departure probability distribution and the relationships derived to calculate the passenger arrival profile distribution, a rigorous mathematical procedure (section 6.10) was developed to calculate the average waiting time for different frequency services to derive waiting curves, which can and have been used in the TRIPS model.

7. Illustration of Impacts of ITS Measures on a Transport Network

One of the objectives of this research has been to evaluate the impacts of selected ITS measures for buses in a transport network to illustrate the operational benefits. This chapter will present, analyse and discuss the results obtained from modelling the impacts of improved ticketing, passenger information and bus priority using ITS systems. The modelling framework described in section 6.2 incorporating two transport models and relationships derived from survey 2 were used for this purpose. Evaluation for various scenarios with both individual and combination of the ITS measures were carried out and is outlined in the following sections.

7.1. Different Ticketing Options:

An important potential impact of improved ticketing (as discussed in section 3.2.3) is the reduction in boarding time for passengers at bus stops. The total saving in the dwell time (and therefore in the running time of the bus) with this reduction in boarding time would be the decrease in boarding time per passenger multiplied by the number of passengers boarding the service. *However:*

- The time saved by a passenger would depend their boarding and alighting point. For example a user boarding at the start and alighting at the end of the service route would benefit more than a user boarding further down the line or alighting earlier.
- The increase in patronage or mode change could be influenced by the change in cost (which includes travel time) between an OD pair in a network. The time reduction (and hence cost) between an OD pair cost would depend on the amount of reduction in links joining the two zones.

These reasons led to the use of modelling to illustrate the impact of reduction in boarding time with improved ticketing for various scenarios. It should be noted here that one of the main points of convenience of Smartcards is that they can provide a seamless journey when moving between modes to make travelling more attractive.

7.1.1. Modelling Procedure:

The dwell time formula in SPLIT (referenced in section 5.6.3) has been used to reflect the change in boarding times with improved ticketing measures. The dwell time formula for buses with one entry door where users board the bus after all people alight is given in the following format (York, 1993):

*Dwell time = A + B*number boarding +C* number alighting,* Where,

A = Constant to account for bus to come to a halt and open door for use)

B = time for boarding

and C = time for alighting. Due to different conditions in Southampton the dwell time formula was derived (as detailed in section 6.5.2.1):

Dwell time = 5.9 +6.59* boarders + 3.16 *alighters (seconds)

For the illustrative modelling of different scenarios the boarding time (B) was reduced to 4 for travel cards and 3.2 seconds for smart cards (source: Halcrow, 1995). It should be noted here that dwell time could also be affected by driver behaviour in competing lines (more than one operator running a common line) and 'float' time used by the operators (section 6.5.2.1).

The outputs from SPLIT were used to calculate the inputs for the TRIPS public transport module (section 6.2) to analyse the impacts in the network as outlined in the framework in figure 6.1 and as detailed below. Outputs from SPLIT (typical output is shown in figure 7.1) were entered in an excel spreadsheet to work out the change with and without the measures which included:

a) The average journey time for each link - The average change in link time was calculated using the two sets of output from SPLIT, with and without the measure. The link times in the network file in public transport module of the TRIPS model were then reduced by the same amount.

b) The bus arrival time at each bus stop – Standard deviation from the scheduled departure time was calculated with and without the measures for the percentage change between the two values. Boarding penalty in TRIPS modelling was changed accordingly. In the modelling, the boarding penalty (refer section 5.5) has been used to reflect the variability of bus arrival time.

c) Waiting time at each bus stop – For schedule-based priority SPLIT uses average passenger arrival profiles for the service and the bus arrival times at a bus stop to calculate the average waiting time at that bus stop. Improved ticketing affects the bus arrival time (reduces the journey time) and would therefore change waiting times at bus stops. The percentage change in the waiting time was calculated for different frequency services and applied to the waiting curve (refer section 5.3.2.) in TRIPS to reflect the change in waiting time with improved ticketing.

Origin destination (OD) cost matrices were skimmed for zone-to-zone cost with and without the changes due to improved ticketing in the TRIPS model. Using elasticity values the change in patronage level were predicted for the change in travel cost between each origin and destination using the MVMODL program in TRIPS (refer section 5.5). It should be noted here that the patronage generated would increase the journey time (more passenger boarding would increase the dwell time) and a variable trip matrix procedure would be necessary for a better evaluation. However, this strand of research has not been pursued due to the limitation of the models used and a fixed matrix has been assumed.

Table 7.1 Typical SPLIT output:

Route = 11									
Bus stop no.	1	2	3	4	5	6	7	8	9
AV headway (sec)	1125	1125	1124	1124	1120	1118	1118	1118	1117
SD headway	245	246	247	249	259	262	263	265	265
AV occupancy (no)	20.6	21.3	21.8	23.1	23.5	23.6	17.9	15.3	12.8
AV journey T (sec)	0	88	128	223	280	335	478	619	670
Route = 20									
Bus stop no.	1	2	3	4	5	6	7	8	9
AV headway (sec)	0	0	0	1820	1823	1825	1826	1826	1826
SD headway	0	0	0	28	20	18	16	14	14
AV occupancy (no)	0	0	0	18.6	18.1	18.4	14.9	14	12.6
AV journey T (sec)	0	0	0	0	55	110	231	363	409
Route = 102									
Bus stop no.	1	2	3	4	5	6	7	8	9
AV headway (sec)	0	0	0	1800	1799	1798	1798	1798	0
SD headway	0	0	0	0	2	3	4	4	0
AV occupancy (no)	0	0	0	16.7	15.9	16.3	13	9	0
AV journey T (sec)	0	0	0	0	60	116	261	399	0
Avg passenger waiting times (secs)									
AVwt IC = 11 only	626	656	656	0	0	0	0	0	0
AVwt IC = 20 only	0	0	0	854	844	0	0	0	0
AVwt IC = 102 only	0	0	0	878	891	903	0	0	0
Bus arrival times at stops (secs)									
Times = 1	1889	1978	2020	2117	2187	2247	2389	2533	2585
Times = 2	2609	2696	2735	2829	2880	2934	3076	3217	3268
Times = 3	3809	3897	3937	4032	4080	4133	4273	4413	4464
Times = 4	5189	5277	5317	5412	5471	5528	5673	5815	5866
Times = 5	6389	6477	6517	6612	6665	6720	6862	7003	7054
Times = 6	0	0	0	2162	2210	2263	2381	2513	2559
Times = 7	0	0	0	3962	4022	4079	4202	4335	4381
Times = 8	0	0	0	5822	5874	5929	6049	6180	6226
Times = 9	0	0	0	7622	7680	7737	7859	7991	8037
Times = 10	0	0	0	2460	2522	2580	2726	2864	0
Times = 11	0	0	0	4260	4318	4374	4518	4656	0
Times = 12	0	0	0	6060	6119	6176	6320	6458	0
Times = 13	0	0	0	7860	7919	7975	8119	8257	0

Note: The '0' values for some of the bus stops are due to buses not stopping at those stops or no one boarding at those stops.

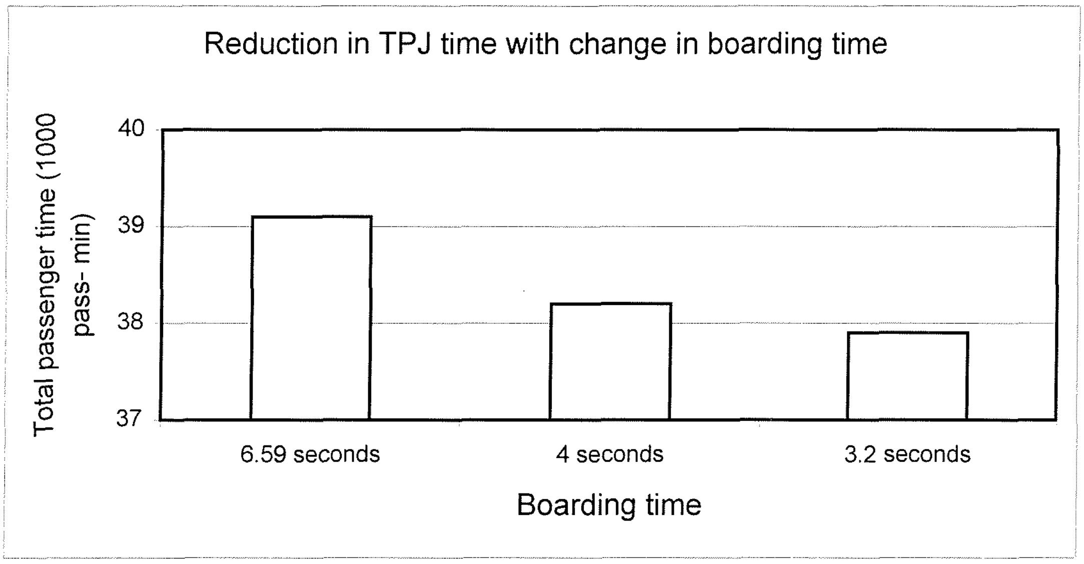
7.1.2 Scenarios with Improved Ticketing

Scenario 1: Boarding time reduced to 4 (Travel card) and 3.2 (Smart cards) seconds from the surveyed value of 6.59 seconds. The changes observed included:

1) The link times in the network file in TRIPS were reduced by the average change in times calculated from the SPLIT output. The change in total passenger journey time (Pass-

minutes), which includes in-vehicle time, waiting time (weight = 2), walk time and the user specified penalties is shown in figure 7.1. This time is therefore perceived time.

Figure 7.1 Change in total passenger journey time with improved boarding time



Note: Boarding time:

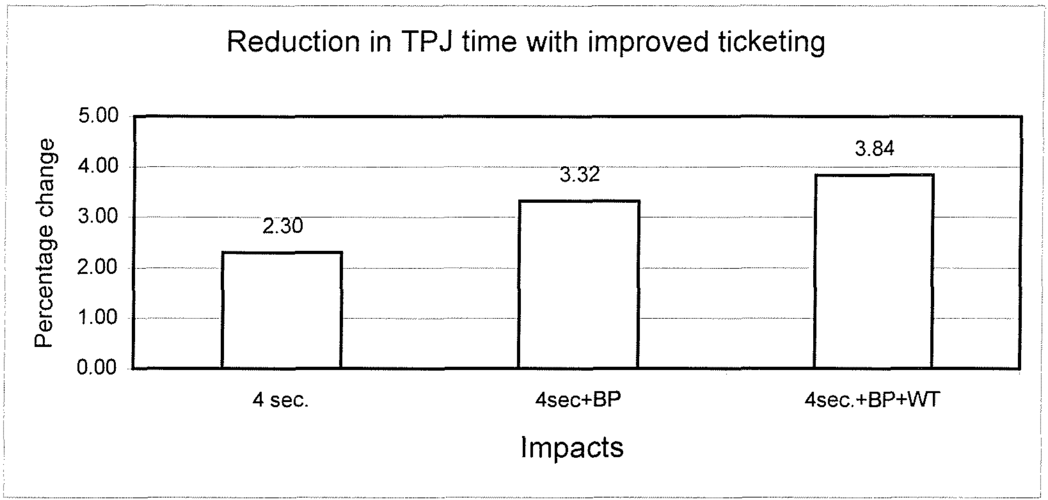
6.59 sec:	Actual Boarding time of 6.59sec/pass used in the modelling
4 sec:	Boarding time reduced to 4 sec/pass, only the change in link time from SPLIT outputs was used in TRIPS modelling to analyse the impact due to improved ticketing.
3.2 sec:	Boarding time reduced to 3.2 sec/pass, only the change in link time from SPLIT outputs was used in TRIPS modelling to analyse the impact due to improved ticketing.
TPJ time:	Total passenger journey time, which includes walking to and waiting at bus stop, in-vehicle time, walking from bus stop to destination and user specified penalties.

Figure 7.1 illustrates that with a reduction of 1 second in boarding time the total passenger journey time is reduced by 0.38 thousand passenger minutes, which is 1.0% reduction in journey time or on average 0.33 minutes for each passenger.

2.) Reduction in standard deviation from the scheduled time for services running late and increase for services running on time was also observed. This is expected as the decrease in journey time for services running late would bring the services closer to the scheduled time and could also result in punctual services becoming early (although the operators could change the schedule time for the service in this event).

In the modelled network on average the services were 10% early and 30% late. The result showed that on average the standard deviation from schedule time was reduced with improved ticketing. This is due to the fact that even when buses are termed punctual they can depart between –1 and +5 minutes of the scheduled time and most of the buses would depart after the exact scheduled time as shown in figure 6.17. The reduction in journey time would thus bring the departure time of most of the service closer to the scheduled time and reduce the deviation. Using the percentage reduction in the deviation from scheduled time the change in total journey time compared to the base case (boarding time = 6.59 seconds) is shown in the second column of figure 7.2

Figure 7.2 Change in total passenger journey time (TPJ time) with improved ticketing



Note: Impacts:

4 sec:	Boarding time reduced to 4 sec/pass, only the change in link time from SPLIT outputs was used in TRIPS modelling to analyse the impact due to improved ticketing.
4 sec + BP:	Boarding time reduced to 4 sec/pass, the change in link time and standard deviation from the scheduled time from SPLIT outputs were used in TRIPS modelling to analyse the impact due to improved ticketing.
4 + BP + WT:	Boarding time reduced to 4 sec/pass, the change in link time, standard deviation from the scheduled time and waiting time from SPLIT outputs were used in TRIPS modelling to analyse the impact due to improved ticketing.

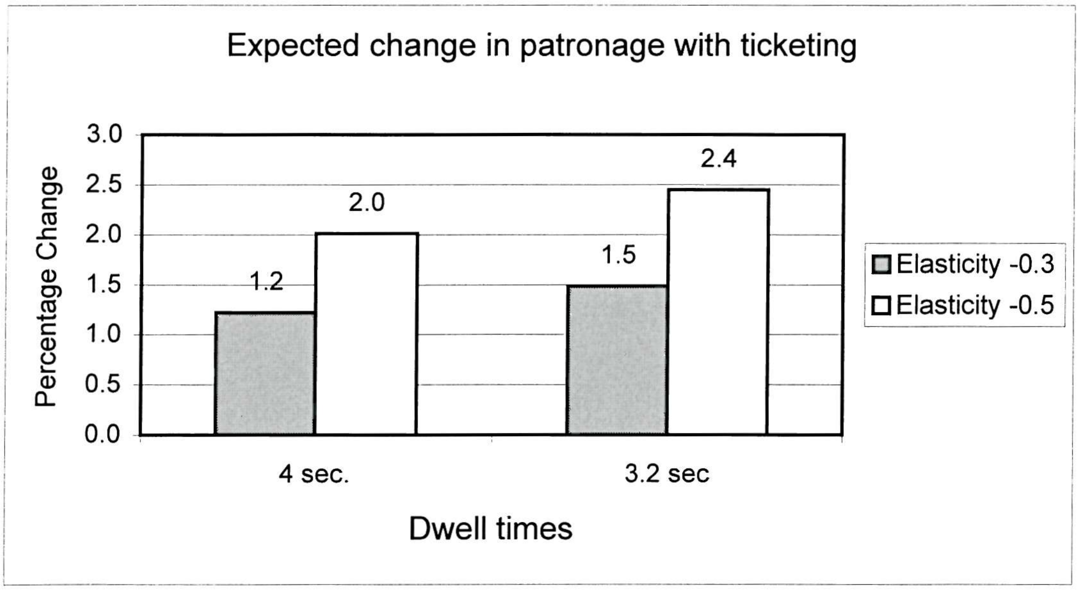
3.) The waiting time curves (section 5.1.2) in TRIPS were calculated from the graphs in section 6.10. With improved ticketing as buses arrive closer to the scheduled time (in this case, where most of the service arrives after the scheduled time as explained above) the average waiting time for the services were also reduced. The waiting time curves in the TRIPS model were reduced by the same percentage to account for this change. The further reduction in the total passenger journey time due to the effect on the waiting time at bus stops is shown in the last column of figure 7.2. Table 7.1 shows the change in total passenger journey time for different scenarios (i.e., different reductions in boarding time). The total journey time decreased from 39172 passenger minutes to a maximum of 37269 passenger minutes when boarding time is reduced to 3.2 sec/pass (assuming use of Smart card) due to the reductions in link travel time, boarding penalty and waiting time. This is a decrease of 4.90%, in other words a saving of 1.6 minutes per passenger trip can be expected with the use of Smart cards.

Table 7.2 Change in total passenger journey time (TPJ time) for different scenarios

Scenario	Change in (TPT)	Avg. time saved per passenger/trip
Boarding time change to 4 seconds		
i) Only the change in link time (LT) accounted	2.30%	0.79 min
ii) LT + change in standard deviation with scheduled time (BP) accounted	3.32%	1.14 min
iii) LT + SD + change in waiting time (WT) accounted	3.84%	1.31 min.
Boarding time change to 3.2 seconds		
i) Only the change in link time (LT) accounted	2.81%	0.96 min
ii) LT + change in standard deviation with scheduled time (BP) accounted	3.84%	1.31 min
iii) LT + SD + change in waiting time (WT) accounted	4.90%	1.57 min.
Approximate change with 1 second reduction in boarding time		
i) Only the change in link time (LT) accounted	0.85%	0.30 min
ii) LT + change in standard deviation with scheduled time (BP) accounted	1.20%	0.42 min
iii) LT + SD + change in waiting time (WT) accounted	1.46%	0.50 min

4.) Assuming elasticity -0.3 to -0.5 with change in journey time a change in patronage of up to 2.4% could be expected as illustrated in figure 7.3.

Figure 7.3 Expected increase in bus patronage with improved ticketing:



Note: Dwell time:

4 sec: Boarding time reduced to 4 sec/pass, the change in link time, standard deviation from the scheduled time and waiting time from SPLIT outputs were used in TRIPS modelling to analyse the impact due to improved ticketing.

3.2 sec: Boarding time reduced to 3.2 sec/pass, the change in link time, standard deviation from the scheduled time and waiting time from SPLIT outputs were used in TRIPS modelling to analyse the impact due to improved ticketing.

5.) Route choice - The degree of change in journey time between services serving same OD pair was not significant enough for any change in route choice. The output from

TRIPS for the two cases showing passengers boarding and alighting for each of the operating services showed no changes.

7.2. 'Differential' Bus Priority at Signal Controlled Junction using Selective Detection:

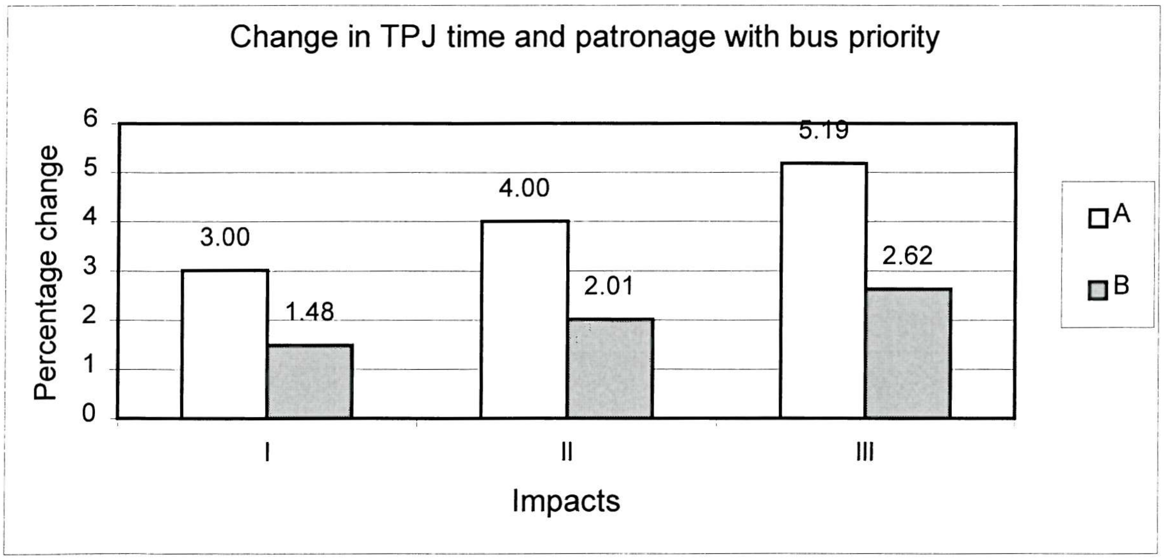
'Differential bus priority at signal controlled junction helps to reduce travel time by decreasing junction delays, improve regularity and punctuality to reduce waiting time at bus stops. The SPLIT model was used to calculate change in travel times, standard deviation of arrival time and in passenger waiting times for the network with and without differential bus priority at signal controlled junctions, as it would be expected to operate. The outputs from SPLITS were used to calculate the inputs for the TRIPS model (as detailed in section 7.1.1) to illustrate the impact on the whole network.

7.2.1. Scenarios with 'Differential' Bus Priority at Signal Controlled Junction

Scenario 2 - For actual network conditions

With actual network conditions (degree of saturation of non-priority links bus arrival times, etc.) an average saving of 8 secs/bus/junction was observed in the SPLIT modelling, which is comparable to other studies. The TRIPS model was used to get the total passenger travel times and the expected change in patronage using the same procedure as in the case of improved ticketing (scenario 1) and is illustrated in figure 7.4

Figure 7.4 Change in TPJ time and patronage with differential bus priority.



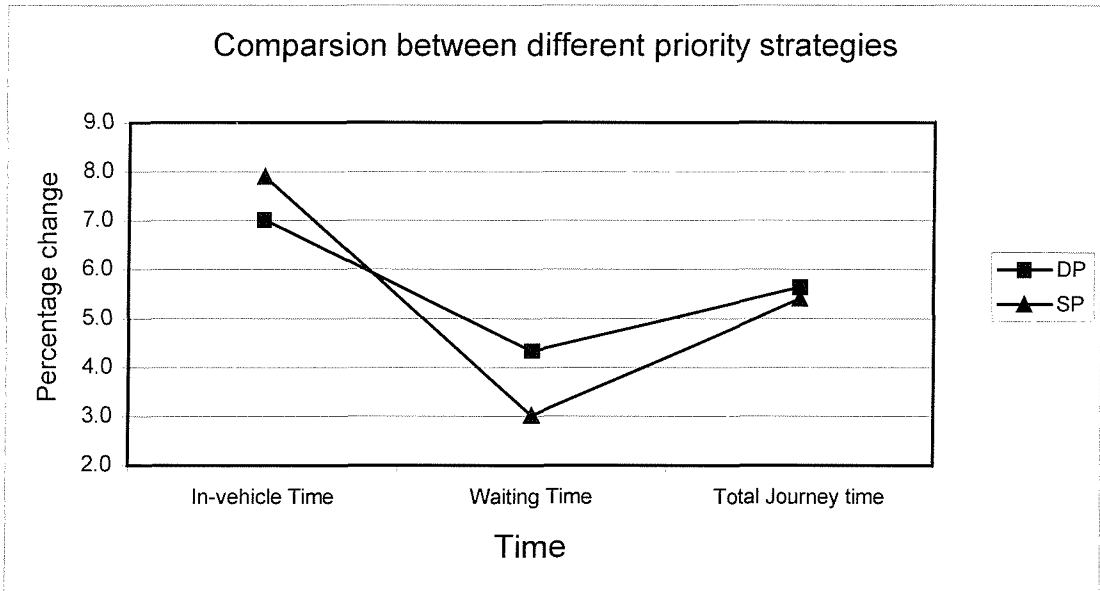
Note: Impacts:

I: Only the change in link time from SPLIT outputs was used in TRIPS modelling to analyse the impact due to improved ticketing.

II: The change in link time and standard deviation from the scheduled time from SPLIT outputs were used in TRIPS modelling to analyse the impact due to improved ticketing.
III: The change in link time, standard deviation from the scheduled time and waiting time from SPLIT outputs were used in TRIPS modelling to analyse the impact due to improved ticketing.
A - Change in total passenger time, B – Change in patronage for elasticity value -0.5

The reduction in total passenger journey time for actual case is 5.19 %, and expected increase in patronage is 2.62%. The average journey time per passenger per bus trip decreased from 34.2 to 32.4 minutes or a saving of 1.8minutes per passenger trip. The scale of change was nearly the same as the change resulting from reducing the boarding time to 3.2 seconds per passenger. The results show that the benefit due to the reduction in waiting time achieved from improvement in punctuality is 40% of the benefit due to the reduction in junction delay. This emphasises the importance of 'differential' selective bus priority modelled in this research, which can improve waiting time more as it can improve punctuality and regularity as shown in figure 7.5.

Figure 7.5 Change in in-vehicle time and waiting time at bus stops with different types of priority at signal-controlled junction



Note:
DP: Scenario with differential priority
SP: Scenario with strong priority, i.e., all buses getting priority

Figure 7.5 shows that as all buses get priority (Scenario SP) the change in in-vehicle time is higher (running time for all the buses will be reduced) but the total saving in time is lower due to smaller change in waiting time (early buses getting priority would increase the waiting time).

Scenario 3: *Changes due to differential bus priority for different network conditions*

The amount of time saved using bus priority at signal-controlled junction would depend on a number of factors. It would depend on network conditions, such as the amount of spare green available (which depends on the allowable minimum green for non priority stages), detector distance (where the bus is detected) from the signal and the degree of saturation of non-priority arms. It would also depend on the threshold levels (refer section 5.6.2) specified by the user and the level of service. For example if a service is entirely punctual and priority is related to punctuality, then buses would not require any priority and so no benefits would be accrued. Maximum benefits from priority would occur when all the buses are late/irregular and allowed priority. Results for different scenarios is given in figure 7.6 and 7.7.

Figure 7.6. Change in TPJ time with different bus punctuality

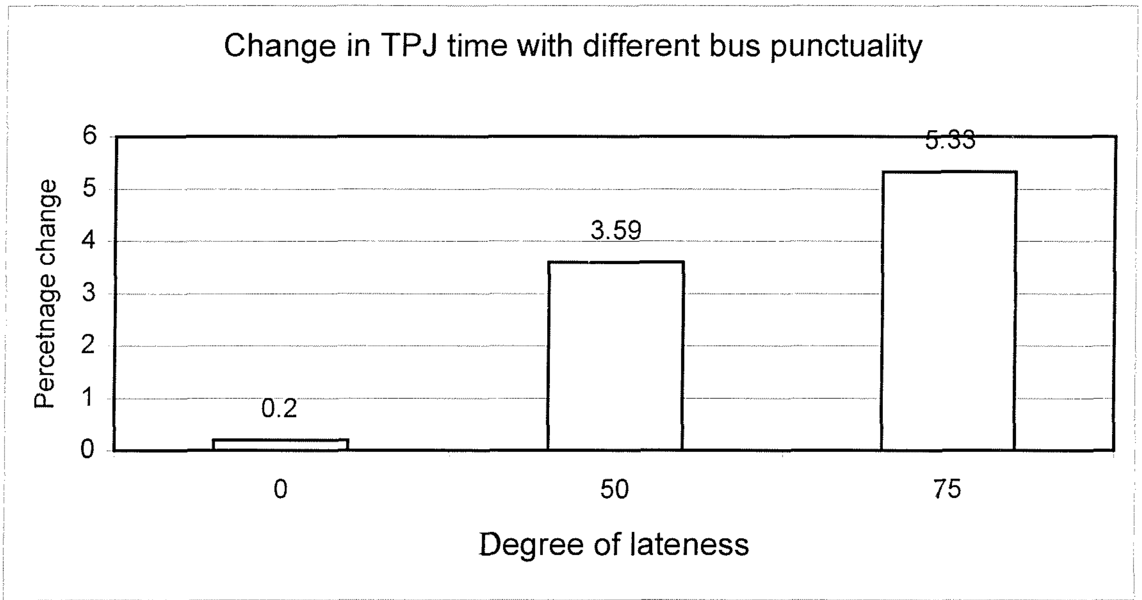
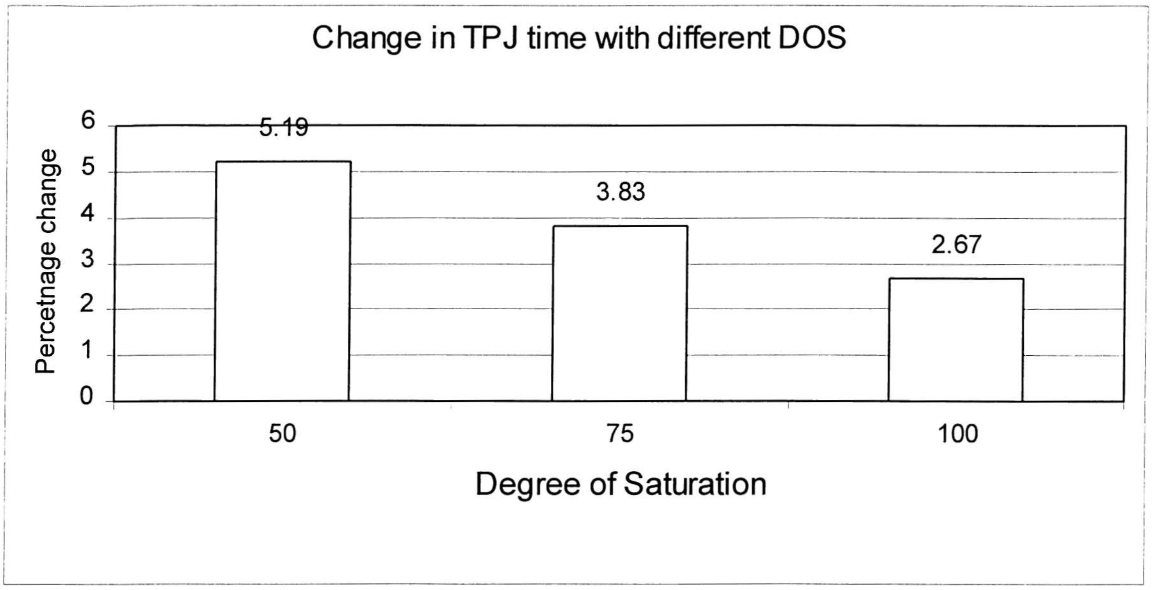


Figure 7.6 shows that as the punctuality of service deteriorates the benefit, or the saving in total passenger journey time increases. A small benefit at 0% degree of lateness was observed. This is due to the fact that even though the service starts on time, at some intermediate stops it starts to run late, i.e., the running time of the service is more than the scheduled time for the morning peak (modelled period).

Similarly figure 7.7 shows that an increase in the degree of saturation for the non-priority traffic stream reduces benefit for a set level of priority. Any increase in degree of saturation (DOS) in the non-priority links reduced the priority available and therefore the reduction in link times, standard deviation and waiting times were less.

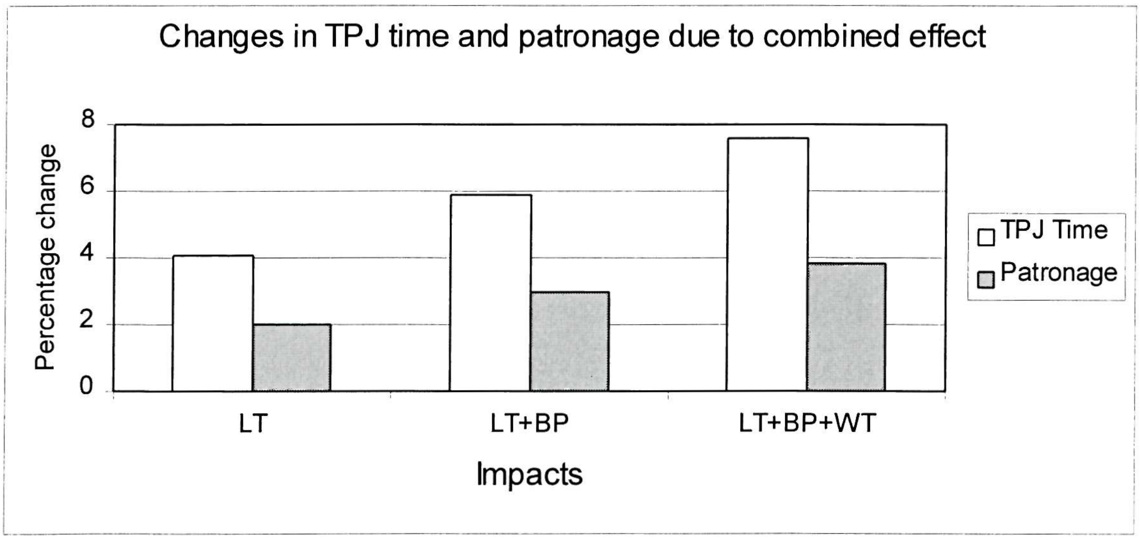
Figure 7.7. Change in TPJ time with different DOS in the non- priority traffic streams



The change in the link times were not high enough (maximum 176 seconds over the whole route for service 20) to bring about any change in route choice with bus priority measures.

Scenario 4: *Combined effect of improved ticketing and 'differential' bus priority at signal controlled junctions:* Results for the combined impact of ticketing (boarding time 4 seconds) and bus priority (actual network conditions) is illustrated in figure 7.8. The results showed a reduction of 7.59% in total passenger time. It is clear that it is not the sum of the two measures (refer figure 7.2 and 7.4, sum = 9.2%) when implemented separately. This is logical as the reduction in link times due to improved ticketing would bring the bus times closer to scheduled time and the level of priority given would be reduced.

Figure 7.8 Changes due to combine impacts of improved ticketing and bus priority:



Note: Impacts:

LT:	Only the change in *link time* from SPLIT outputs was used in TRIPS modelling to analyse the impact due to improved ticketing.
LT+BP:	The change in *link time* and *standard deviation from the scheduled time* from SPLIT outputs were used in TRIPS modelling to analyse the impact due to improved ticketing.
LT+BP+WT:	The change in *link time, standard deviation from the scheduled time and waiting time* from SPLIT outputs were used in TRIPS modelling to analyse the impact due to improved ticketing.
TPJ time:	Change in total passenger journey time
Patronage:	Change in patronage using elasticity value of –0.50

7.3. Passenger Information

Passenger information can change the waiting time by changing the passenger arrival profile (as described in section 3.2). A user may be able to arrive closer to the expected departure time if real time bus arrival time information is available or he/she may be able to make better use of the waiting time (e.g. by leaving the bus stop when waiting time is high and coming back later). Information can also help to reduce the higher perception of waiting time by reducing the uncertainty of bus arrival and help users choose optimal routes/services.

7.3.1. Modelling Impacts of Pre trip Information

a) Firstly pre-trip information systems can help users to arrive closer to the departure time, i.e. time their arrival with respect to expected arrival times than bus schedule, which could be earlier or later than the actual arrival time. In the at-stop survey conducted (refer section 6.6) users who knew the scheduled time stated that they try to arrive at the bus stops within 3-5 minutes of the scheduled time. Therefore, assuming that users generally time their arrivals reasonably the average waiting time would not exceed 5 minutes for users having access to the information as they can time their arrival with the expected bus arrival time. In modelling the impact of pre-trip information on waiting time this value of waiting time has been assumed for users (assumed proportion) with access to information.

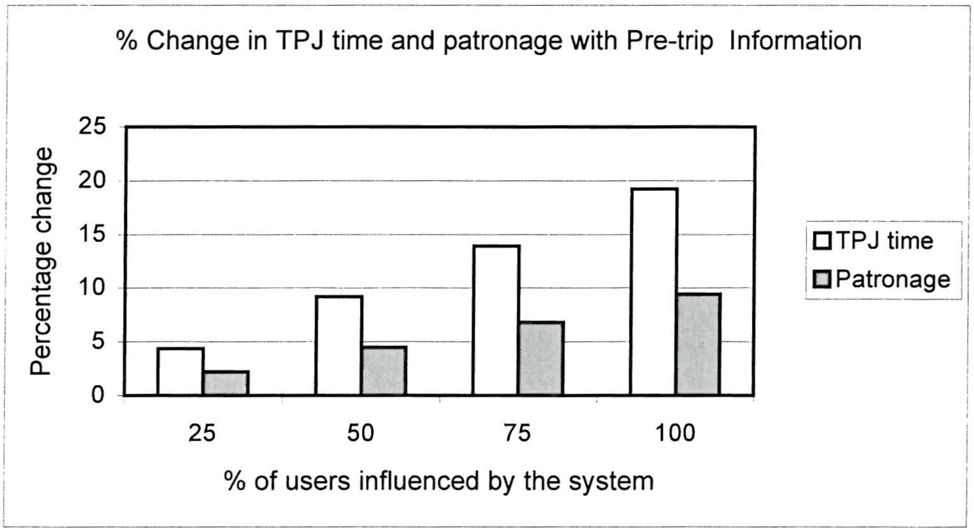
b) Secondly the variability of bus times (deviation from scheduled time, referenced in section 5.5) would be zero if the information were precise (If buses arrive as informed, users would plan their trip according to this new informed schedule) thus reducing the boarding penalty to zero. However evidence from literature review (Brown, 1997) suggest that on average the systems are accurate to within 3 minutes. This value is used as boarding penalty for the proportion of users having access to information.

c) The third effect is on wait time weight as the uncertainty of bus arrival time is reduced for the informed proportion of the users. The reduction used is 22%, the average value (the perceived value lies between 6 and 38%) by which users perceive punctuality lower than the observed one (refer section 6.7.3).

To analyse the impacts discussed above the percentage of users having access and using the information is required. Assumptions were made for the following scenarios:

Scenario 5: *Changes due to pre-trip information.* In an ideal condition where all users have access to the real time pre-trip information the average waiting time would then be 5 minutes for all services. The boarding penalty will be 3 minutes and the reduction in wait time weight will be 22%. Similarly assuming 25%, 50% and 75% have access to the information the resulting impact is shown in figure 7.9.

Figure 7.9 Changes due to impacts of Pre-trip Information

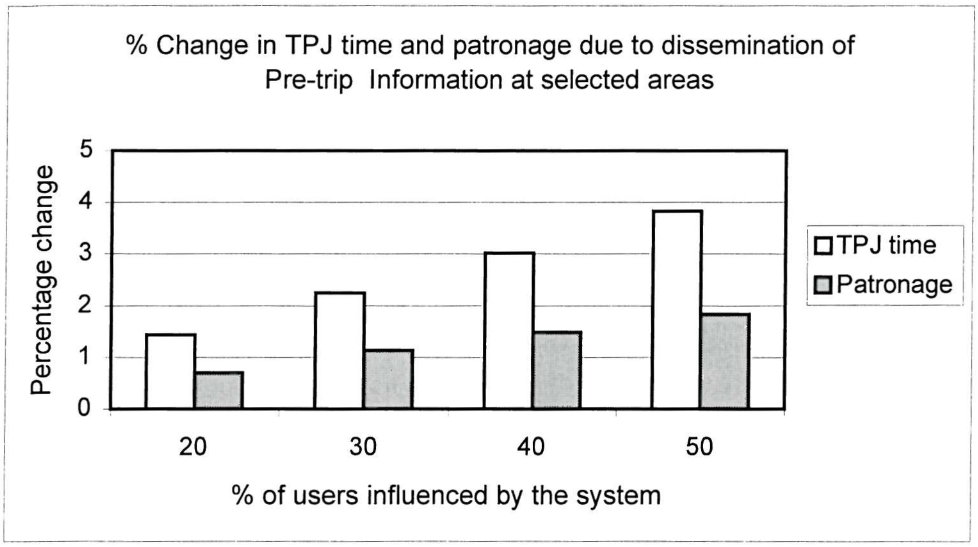


The change in total passenger journey time assuming 100% of users access pre-trip information is 19.22%. However, a more probable change would be nearer 25% users accessing the service. This still could bring about a change of 4.35%, which is identical to the change brought about by change in ticketing and bus priority.

Scenario 6: *Changes due to Pre-trip information being available only at specific areas*

Pre trip information for short urban trips could be more viable where information is disseminated easily like display boards in city/centres or major demand centres where a significant proportion of users can easily access the information. Assuming different proportions of users having access (20 to 50%) to the information at such places, the impact is shown in figure 7.10.

Figure 7.10: Changes due to pre-trip Information dissemination at specific locations



Change in total passenger journey time (TPJ time) and patronage level is less than half (for e.g., 3.83 for 50% users influenced by the system to 9.21% in the previous scenario) compared to the same proportion of users having access to the information in scenario 5. This is due to the fact that passenger volume towards City Centre was higher than the other way around in the modelled period (morning peak).

7.3.2. Modelling Impacts of At-stop Information

The main impacts of real time bus arrival information at bus stops will be:

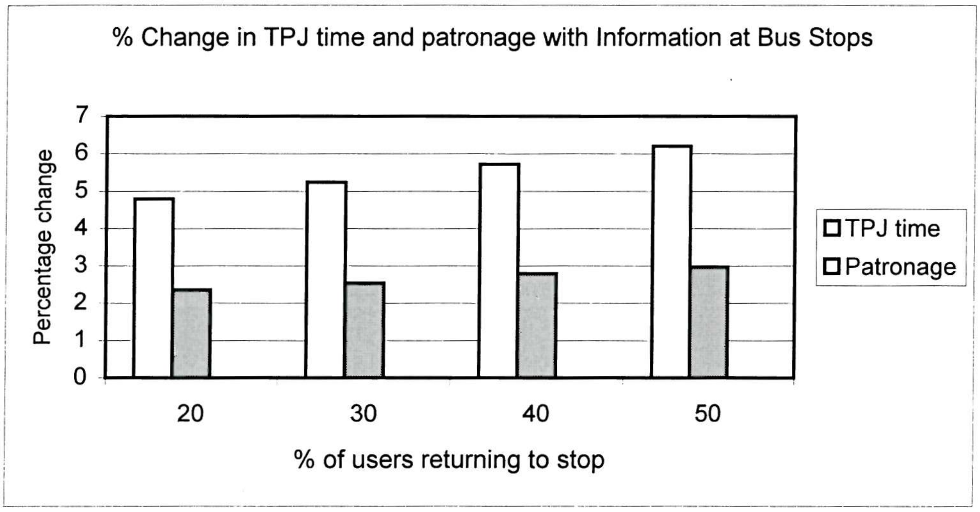
a) A reduction in the perceived value of waiting time due to the reduction of uncertainty of bus arrival times (section 5.5)
b) A change in passenger arrival profile (refer section 6.8). This is where users opt to use the waiting time for other purposes and come back closer to the actual arrival times to reduce waiting time.

Scenario 7: *Changes due to information at bus stops.*

In this case the wait time weight for all users will be reduced as all the users have access to the information. Previous studies indicate that (section 6.8) about 24% prefer to leave the stop if the waiting time is 10 minutes and 36% for 20 minutes. Here assuming a range of 20 to 50% users behave likewise, the change in travel time is shown in figure 7.11. The waiting time of the proportion of users leaving the bus stop and returning later has been assumed to be 4 minutes assuming that they return to the stop within 3 to 5 minutes of the bus departure time as stated in survey 2.

The graph shows a high percentage of change in total passenger journey time and corresponding patronage in comparison to pre-trip information. This is due to the assumption that all users have access to information, which reduces the waiting time weight. The change in total journey time due to physical reduction in waiting time is only 0.8% for at stop information. The higher value observed is due to the assumed reduction of 22% in wait time weight for all users.

Figure 7.11. Changes in TPJ time and patronage with real time information at bus stops.

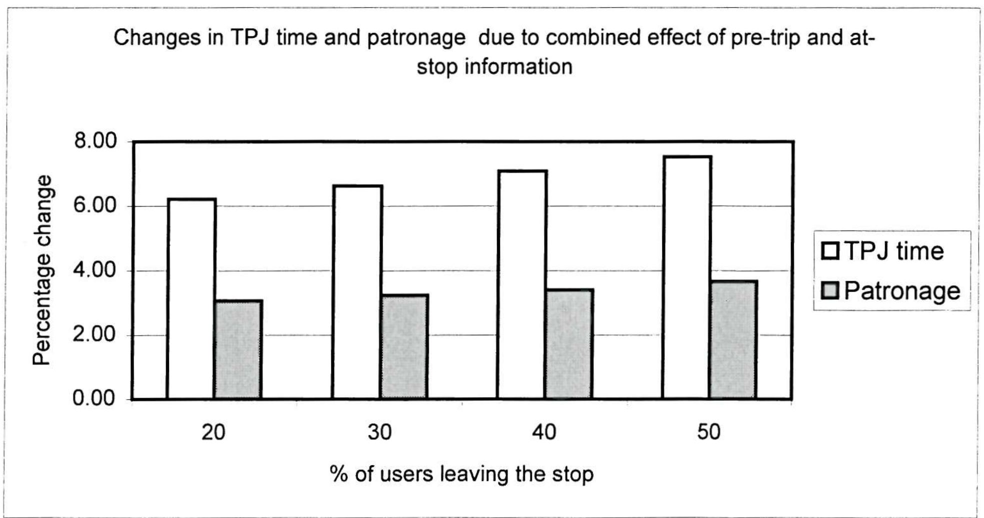


7.3.3 Modelling Combined Impacts of the ITS Measures

Scenario 8: *Combine effect of pre-trip and at stop passenger information*

The result shown in figure 7.12 is for 30% of passengers using services from major stops influenced by the pre-trip information for different proportion of users choosing to leave the stop when waiting time is high.

Figure 7.12. Changes due to combined effect of pre-trip and at-stop information:



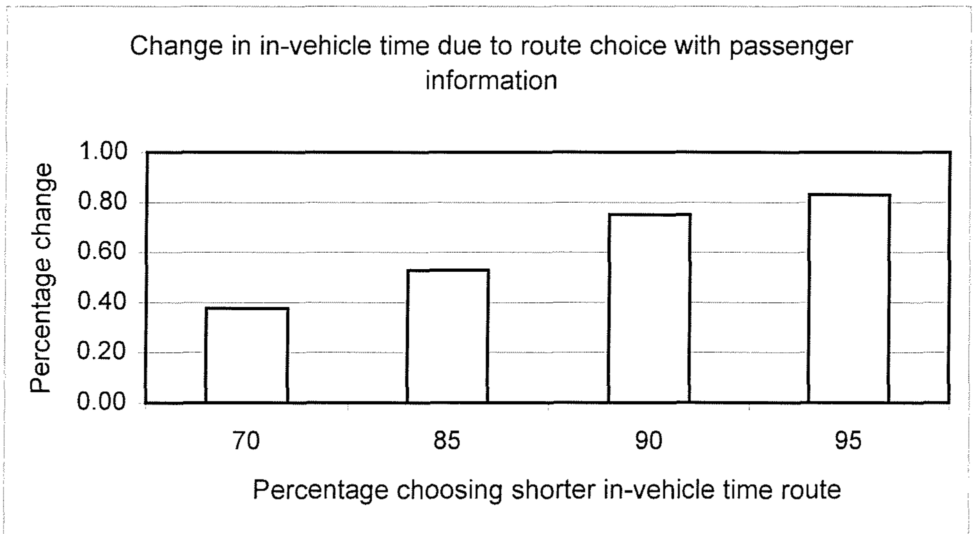
The combined value is less than the additive value of individual changes of the systems as both the measures have impact on the wait time weights, which is accounted for only once.

Scenario 9: *Influence of information on Route Choice*

From the survey (described in section 6.7.4) a definite bias towards the use of shorter in-vehicle time route over the longer one was observed. With pre-trip information users can choose the shorter in-vehicle time route to reduce their journey time. Users may prefer to wait for a service, which is quicker than to board the first bus that arrives at the bus stop when provided with real time bus arrival information at bus stops.

The TRIPS model can be calibrated for the shift in route choice depending on the in-vehicle journey time. The model had been calibrated (using a 'scaling' parameter value of 0.25) so that 70% of users choose the shorter in-vehicle time route when the in-vehicle time difference is 4 minutes (as described in section 6.7). The proportion of users choosing the shorter in-vehicle time route can be changed changing this 'scaling' parameter value. For example 85%, 90% and 100% of the users would choose the shorter in-vehicle time route (total journey time difference is 4 minutes) when the 'scaling' parameter is changed to 0.5, 0.75 and 1.0 respectively. The scale of change in in-vehicle time for different parameter values is shown in figure 7.13.

Figure 7.13. Change in in-vehicle time due to route choice with information.

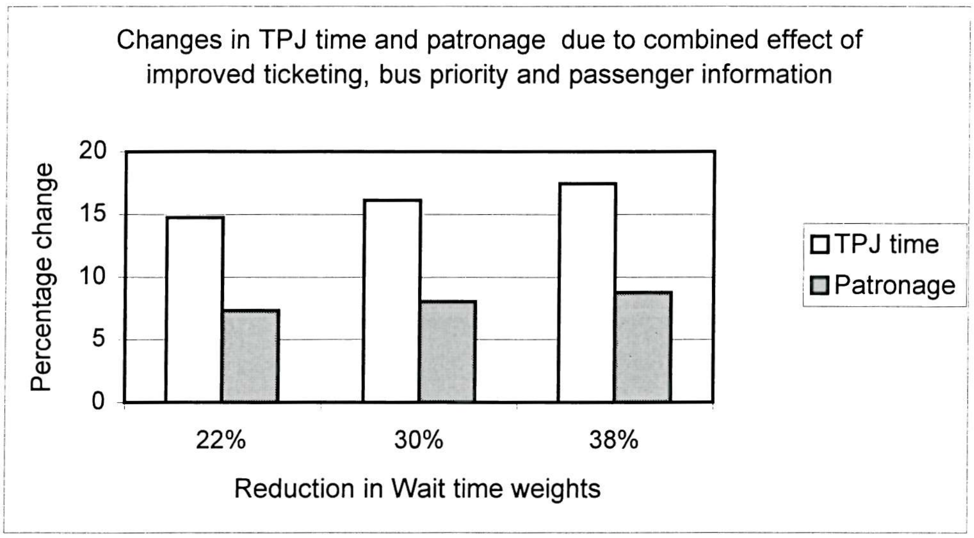


The result shows a small change in in-vehicle time. This was expected, as the possibility of alternative routes in the size of the modelled network is limited. The change in the value would depend on the public transport network condition and the volume of users. The higher the difference in journey times between alternatives, the choice of alternate services available and the affected user volume, the higher the change in in-vehicle time.

Scenario 10: *Combined effect of improved ticketing, 'differential' bus priority at signal controlled junction and passenger information*

The combined effect of impacts due to improved ticketing, 'differential bus priority at signal controlled junction and passenger information is shown in figure 7.14. The change in total passenger journey time for the actual network condition is 14.7 %. In this scenario it has been assumed that 25% of the users using services from major stops are affected by pre-trip information and 20% of users opting to return with information at bus stops. The boarding time is reduced to 4 seconds per passenger. The change is additive here, i.e., the combined impact of all measures is equivalent to the combined impact of improved ticketing and 'differential' bus priority plus the combined impact of information.

Figure 7.14 Change in in-vehicle time due to combined effect of improved ticketing, 'differential' bus priority at signal controlled junction and passenger information



This is due to the fact that the overlapping impacts between these two cases are the change in waiting time and boarding penalty. However, in the first case the reduction in waiting time is due to the services being more regular or coming closer to the scheduled time but in the second case the reduction in waiting time is due to users choosing to arrive closer to the bus arrival times. As these are mutually exclusive the impact is additive.

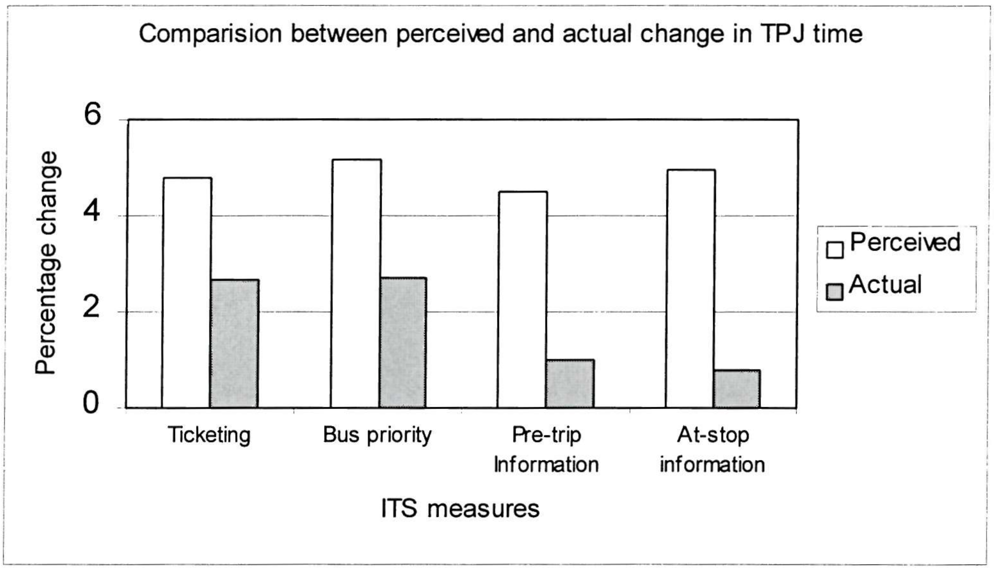
Similarly the reduction in boarding penalty in the first case is assumed to be due to the change in bus arrival variability and in the second case due to a proportion of users having pre trip information. As they are mutually exclusive the impact is additive.

7.4. Discussion

Perceived and Actual change

The change in total passenger journey time shown in the above presentation for all scenarios is perceived changes, as the potential for mode change and/or patronage change (illustrated above) depends on this perceived change. The scale of actual reduction in total passenger journey time for the most probable scenarios compared to the base case (actual network condition) is illustrated in figure 7.15.

Figure 7.15 Comparison between perceived and actual change in TPJ time



Note:
ITS measures –
Ticketing – Boarding time reduced to 3.2 seconds, i.e., assuming use of Smart cards for actual network conditions
Bus priority – Differential bus priority using selective detection for actual network conditions
Pre-trip information – Assuming 25% of users are influenced by pre-trip information for actual network conditions
At- stop information – Assuming 20% of users leave the stop to return later for actual network conditions

The perceived change is higher as the waiting time was assumed to be twice the in-vehicle time and hence any change in waiting time would consequently show a bigger change. The figure also illustrates the small change in actual TPJ time with passenger information, i.e., the change due to information is mainly due to perceived change in waiting time (lower wait time weights).

Comparative impacts

Figure 7.15 also illustrates the similar perceived impacts for the actual network conditions for all the ITS systems. It should however be noted that unlike improved ticketing or passenger information, bus priority measures would have dis-benefits to non-priority traffic which could outweigh the total network benefit. However, this could also have a higher effect on the relative cost difference between private and public transport to encourage more mode shift and increase (or retain) patronage. Within the context of most urban areas already having some form of UTC systems, the cost implication for bus priority at signal controlled junction could also be lower than changing the whole ticketing system for the operators and could more likely be implemented. However it should be noted that improved ticketing has other benefits (helps to reduce fraud, collect data for management and helps in multi-modal trips) and hence the choice between the two measures would depend on end requirements.

The potential benefit for operators from passenger information would be the potential increase in (or retention of) revenue due to increase in (retention of) patronage or mode change. These measure have less potential compared to improved ticketing and bus priority at signal controlled junction in terms of actual time saved by the users and saving in operating cost due to decrease in vehicle running times for the operators. However the potential of these measures to improve the perceived saving (which affects mode change and patronage) with these systems are higher. For example if 50% of users have access to pre-trip information the perceived change in TPJ time would be 9.21% which is higher than the combined effect of improved ticketing and bus priority at signal controlled junction.

Effect of service and network condition

Impacts of ITS measures vary with service condition. If the service were punctual/regular the impact of these measure would be different. 'Differential' bus priority at signal-controlled junction would not be needed if the services were always punctual/regular. Improved ticketing and passenger information too would have lesser impact. On the other hand if the service were less punctual/regular the measure would all have higher impact. However providing information about poor service could affect patronage adversely with users opting to use other modes, walk or suppress the trip.

It would therefore be ideal first to provide the best possible punctuality through measures such as more efficient management by bus operators, traffic demand management and segregation. In such areas (served by punctual/regular services), improved ticketing and bus priority at signal controlled junction could be used to minimise the journey time by reducing the boarding time and junction delays and then re-setting the scheduled time to have 'perfect' punctuality/regularity. However even in these 'ideal' conditions varying traffic conditions in a transport network will still inevitably affect the bus service, which could then benefit with 'differential' bus priority at signal controlled junctions and passenger information.

Limitation:

a) Variable trip matrix - The evaluation in this research has been carried out using a fixed trip matrix. The potential of these measures to affect the patronage level and mode change could require variable trip matrix modelling for a more thorough evaluation. For example, with improved ticketing the saving in journey time is due to reduction in boarding time, but with increased patronage the journey time would increase to offset the saving in time. An iterative method to achieve equilibrium would be required to get more exact values.

b) Route choice - It should be noted that the users choice of route with information would not only depend on in-vehicle time as illustrated in scenario 9. With information, users can choose the best option available. In other words they can choose a service to reduce their overall journey time, which can either be a reduction in waiting time (e.g., by taking the first bus which could offer a longer in-vehicle time but reduced wait time) or wait for second bus (as the reduction in in-vehicle time would compensate for the longer waiting times). Any modelling for route choice would therefore require simulating spatial real time passenger and vehicle arrival times and behavioural responses of the users. For example users can also choose a particular bus service, as it would be more suited to their schedule even though the overall journey time is longer.

It should further be noted that the users choice of route also depends on their schedule (the longer journey time service may better cater to their schedule), time of the day (e.g. at night time, lone female users may opt to choose the first bus for safety) and weather or environment may not be pleasant for waiting.

c) Valuation of time – The benefits in the illustration have been shown in terms of time saved. However it should be noted that for any economic evaluation the time saved by different measures could have different values. For example, waiting time saved with pre-trip information could be valued more as it may be utilised more effectively than the waiting time saved by users with at-stop information (leaving the bus stop when informed bus will be late and returning later), as users may not have the option to utilise it effectively (or have the need).

d) Data collected – The amount of data collected for both surveys (1 and 2) have been limited due to limitation in resources. Therefore though no adverse event/function were noted during the data collection period it might not reflect the real street scenario or behaviour. However this research is more targeted at developing a practical framework to present the benefits of ITS measures to help in decision-making.

7.5. Conclusion:

The change in total passenger journey time (perceived) for all the ITS measures in isolation were around 5% (figure 7.15) for the most likely cases (assuming likely impacts with passenger information and actual network conditions for all measures). The actual change in travel time with improved ticketing and differential bus priority at signal-controlled junction was around 2.7%, which was comparatively higher than actual saving with passenger information. However the potential of passenger information to affect perceived cost (time) with higher proportion of users having access to information is higher.

The perceived saving in travel time due to reduction in link travel time with improved ticketing was 3%. The rest of the saving was due to the change in waiting time and journey time variability due to the decrease in travel time. The impact on waiting time and journey variability would be less if the scheduled time were changed to reflect this decrease. The potential change in patronage (with saving in journey time with improved ticketing) affects the final journey times and savings. The requirement to model a variable trip matrix is therefore more important in this case.

The impact of bus priority depends on network, traffic conditions (e.g., signal stages, degree of saturation in non-priority stages) and on service quality (e.g., punctuality). Sensitivity analysis showed that as the punctuality of service decreases the saving in total passenger journey time increases with a very small benefit for punctual/regular buses illustrating the importance of more efficient operation and demand management. Similarly increase in the degree of saturation for the non-priority traffic stream showed reduction in the benefit level of priority illustrating the requirement for a more integrated approach to enhancing public transport.

Benefits could accrue in situation where buses start on time but is delayed further downstream due to traffic conditions. Improvement in waiting time at stops consisted 25% of the benefits accrued emphasising the importance of 'differential' priority modelled in this research, which helps improve waiting time by making the service more punctual and/or regular.

The total benefit when all the measures are applied was a change in total passenger journey time (perceived) of 14.73%; a reduction of 5 minutes in the journey time. This could increase patronage by 7.34% (elasticity –0.5%) and could have potential mode change. This change in patronage could influence congestion levels and dwell times at bus stops, i.e., a variable trip matrix evaluation would be more appropriate to illustrate the impacts.

No change in route choice was observed with improved ticketing and 'differential' bus priority at signal-controlled junction as the change in route travel times were not significant enough to affect any change. The limitation of the models used did not allow simulation of spatial real time passenger and vehicle arrival times and behavioural responses of the users. However sensitivity analysis by increasing the percentage of users (to 95% from the observed 70%) choosing shorter route when the travel time between alternate routes differ by 4 minutes showed a change of 0.8% in total passenger journey time. This is due to the limited opportunity of choice in the modelled network.

The modelling framework had limitations due to inherent limitations of the models used. For example SPLIT could only model linear networks and cannot cope with overlapping routes, route choice and conflicting priorities and TRIPS did not implicitly model behavioural responses. However the framework provides a methodology to illustrate the scale of impact for different scenarios and provides a base for pre-implementation evaluation of the ITS measures in bus service.

8. Conclusions and Recommendations

The specific objectives of this research have been to:

1. Review the methods used for enhancing public transport systems, namely bus services in an urban area and the evidence of the use of Intelligent Transport Systems to enhance these methods.
2. Identify the role of modelling in the evaluation of ITS applications for public transport.
3. Outline the requirements for effective modelling of ITS measures.
4. Illustrate the impacts and benefits of selected ITS measures in a public transport network using appropriate modelling techniques and case studies.

8.1. Role of ITS Measure in Enhancing Bus Services

Bus patronage is influenced by a variety of measures, ranging from policy matters such as land use, parking policies and partnership between the parties involved to traffic demand measures such as bus priority and improvements in bus service quality. One of the main reasons cited for not using bus is its poor quality of service. This can be improved in many ways including improving regularity/punctuality of the service, journey times, waiting conditions, information provided, vehicle condition, bus stops, fare structure, staff attitude, marketing, access and frequency of bus service.

This research has shown that ITS measures in various forms can *to achieve one or more of the requirements needed to improve bus service quality*. For example, bus priority at signal controlled junctions, improved ticketing and automatic enforcement of bus lanes can help to improve service regularity and punctuality; while passenger information can improve user perception and reduce waiting times at bus stops and interchanges. DRT Systems can help users to have improved access to public transport.

ITS measures can *also complement other measures used for enhancing bus services*. For example the barrier of uncertainty of timing and reliability in integrated transportation can be improved with better and reliable information and automatic ticketing methods can solve the complexity of fare structure in a deregulated public transport environment. Automatic bus lane enforcement could decrease the amount of violation to make bus lanes more effective. Bus priority measures like 'pre-signal' can have particular benefits at junctions where buses are required to change lane from a near side bus lane.

Integration of measures can also be beneficial. For example, integrating advanced traffic control with physical bus priority measures can allow effective congestion management and queue relocation to protect buses. ITS measures can also be used where traditional measures are not feasible. For example bus priority at signal controlled where bus lanes are not feasible. DRTS can help to alleviate the problem of providing regular bus services where demand is too low to be economical.

8.2. Role of Modelling in the Evaluation of ITS Applications for Public Transport

Appropriate evaluation techniques are essential to evaluate the impact of ITS benefits, both pre-implementation and post implementation to provide a decision tool for decision makers.

Various methods can be used for post implementation evaluation but they are often limited in their scope. For example, before and after measurements would give a measure of tangible benefits of certain ITS measures but it can be difficult to account for changes in external conditions like traffic and network variability, policy changes, etc; reliable before measurements may not be available or could be impractical when large networks are involved. Post implementation attitudinal surveys could form a basis of showing how the schemes are perceived in a subjective manner. Whilst such evaluation can be essential, the focus of this thesis has been on pre-implementation evaluation.

Various techniques can also be used as pre-implementation evaluation methods which includes:

Results from previous studies can be used as a guide where relevant. However there are often significant differences between applications and differences in operating context so that the result may not provide a firm basis for future implementation in a new location. This approach also cannot be used to test a wide range of scenarios, over the whole network and for long term evolution.

Analytical Methods can be used to evaluate some impacts of some ITS measures. For example, bus delays savings through the implementation of green extensions may be estimated at isolated junctions according to signal timings and bus detection location. However this method is again limited in scope and application.

Stated preference surveys can be used to target sample population to identify user perception, requirements and probable response to schemes before their implementation.

Whilst valuable, these surveys have limitation in their scope for predicting network impacts.

Network modelling can be used as a tool to predict network wide impacts of transport initiatives, which can support systems design and optimisation as well as allow sensitivity testing to explore operational features and impacts. Within the context of modelling ITS impacts current modelling is limited in simulating behavioural responses in a dynamic integrated multi-modal transport network.

8.3. Requirements for Effective Modelling of impacts of ITS Measures

For effective modelling of ITS measures, it is first necessary to assess the likely impacts of interest, and hence, the functions and outputs required for the model. The provision of ITS measures in public transport could bring about behavioural changes in the users and influence the traffic in the network with potential implications in trip generation, trip distribution, mode choices and assignment. The model may therefore need to address one or more of the following issues: reproduction of user behaviour, passenger modelling, integrated demand and supply modelling, integrated multi modal modelling and system representation depending on the ITS application(s).

ITS measures could induce short and long term behavioural changes in response to the ITS measure, for example change in passenger arrival profile, optimum route selection and improved attitudes towards the service with perceived and real change in the level of service to encourage improved patronage and therefore *reproduction of user beha*viour could be an essential requirement. This gives rise to the second requirement of modelling impacts of ITS measures, *passenger modelling* to illustrate the impact on users with ITS measures.

The potential of ITS measures to influence patronage with a better level of service and user to make informed choices on mode, destination and time of travel with information would require the model to address a dynamic condition with *integrated demand and supply modelling*. The dynamic condition of a traffic network affects the working of some of the ITS measures; for example the level of priority may be limited by the dis-benefits allowable for non-priority traffic and compliance to automatic enforcement may depend on congestion. An *integrated multi modal modelling* may be required to address these dynamic and on street interaction between car and buses. *Modelling of systems* for some measures, like bus priority at signal-controlled junction, provides a way to evaluate the technical feasibility and working of the system itself and as their impact is dependent on control measures only the *modelling of the system* itself would give results comparable to field observations

The review has shown that some models can represent some ITS measures and impacts, but there is no integrated modelling framework/package available which is comprehensive. This research has therefore outlined the requirements for such modelling and has investigated specific ITS applications, adopting the most suitable models currently available.

8.4. Illustrating the Impacts and Benefits of Selected ITS Measures

Network modelling in this thesis has concentrated on illustrating the main impacts of ITS measures, which are increasingly being used, and where modelling is an appropriate evaluation tool. These measures have included passenger information, bus priority at signal-controlled junction and automatic ticketing. The key impacts of waiting and journey time changes and optimal route choice can improve the level of service of buses, which is the main reasons cited by users for less patronage. The parameters affecting the impacts are different for different ITS measures. The requirements to model these parameters resulted in developing a general modelling procedure using two separate models, evidenced impacts and surveys to collect relevant data and derive the required relationships.

8.4.1. Survey Findings and Relationships

From the passenger and bus operational surveys across Southampton, it was concluded that:

User profile: Bus services in an urban area are patronised by a significant proportion of regular and frequent users over the day with a fair knowledge about schedules. Female users were higher for all periods of the day compared to male users. Compared to morning and evening peak a relatively higher proportion of higher age group users were observed in the off peak period.

User perception: Users on average perceived punctuality to be 22% worse than observed.

Slack time: The stated preference of users for 'slack time' to arrive at a bus stop was 3- 5 minutes before the scheduled bus departure. This increased slightly where buses were perceived to be often early. However in reality, users with such stated preference arrived between 0 to 10 minutes early.

Passenger arrival profiles: Data analysis showed that passenger arrival profiles at bus stops for high frequency services (i.e., more than 4 buses/hour) were independent of user category (different journey purpose and user profile represented by different peak periods) and that passengers arrive randomly. Analysis of survey data showed that in a 10 minutes frequency service 50% of the users can be expected to arrive in each 5 minute interval.

The passenger arrival profile for lower frequency services was independent of user category but depended on the punctuality of the bus service. Linear additive relationships were derived between arrival percentages in 5 minute intervals of the service headways and the punctuality variables, degree of lateness and degree of earliness. These relationships showed that, with a higher degree of lateness, more users come in the last two 5 minutes interval and with higher degree of earliness less users come in those intervals.

The calculation showed that for high frequency services the average waiting time is governed by regularity, i.e., if the service is regular the average waiting time would be the minimum or half the headway. For lower frequency services the average waiting time was affected by the punctuality of the service and is affected more by earliness than by lateness

Route choice: Users showed preference for the shorter in-vehicle route after a certain threshold value.

8.4.2. Findings from Modelling

From the modelling results using the integrated TRIPS and SPLIT framework, the following conclusions were drawn:

Individually, ITS measures reduced the total passenger journey time (perceived door-to-door time, i.e., including walk time to/from origin/destination from bus stops) by around 5% for the most likely cases. The actual change in travel time (door-to-door time) with improved ticketing and differential bus priority at signal-controlled junction was around 2.7%, which was comparatively higher than actual saving with passenger information.

The advantage of automatic ticketing over other measures is its potential to achieve similar/higher impact/benefit without any adverse effect on other traffic plus other benefits, which includes reduction in fraud, data collection and multi-modal/multi purpose use. On the other hand, the advantage of bus priority strategies like differential bus priority at signals is its scope for targeting buses most in need of priority. The potential of passenger information to reduce perceived cost (time) when higher proportion of users having access to information is substantially high. This could therefore have more bearing on increasing patronage and mode change.

The change in total travel time for individual ITS measure is often less than the typical average savings with traditional methods like bus lanes, but comparable savings might be expected for combined implementation. It should however be noted that there is no dis-benefit to car users with measures like improved ticketing and passenger information and considerably less for selective bus priority measures compared to such traditional methods.

8.5 Limitations:

The research has been focussed on operational benefit, namely saving in journey time with selected ITS measures in a bus network, which could lead to economic, social and environmental benefits. Assumptions on impacts of ITS used to illustrate the benefit have not always been rigorously proven, for example percentage of passengers leaving the bus stops with when informed in real time that the waiting time is high or the influence on arrival profiles with pre-trip information.

Limitation of the models used did not allow modelling variable trip matrix where change in patronage level could affect the impacts or simulate spatial real time passenger and vehicle arrival time and behavioural responses of the user to model route choice with passenger `information. The data collected have been limited due to resources available and could be too site specific and the resulting relationships and waiting time curve may not be transferable, however the process would still be useful for other data sets.

8.6 Recommendations:

The main recommendations from this study are that:

- Current modelling, whilst useful, has revealed limitations in a number of areas in their structure and functions. Therefore there is a need for developing enhanced, integrated modelling tools, which can simulate temporal and dynamic behavioural responses of users to these measures and the potential impact these responses can have in demand and supply of both public and private trips.

- There is also a need for better behavioural data which can be used in modelling, some of which are:
    - User responses to real time information in route/mode choice, arriving pattern and waiting at bus stops.
    - Perception of change for example ease in transfer at interchanges and waiting time with information and seamless journeys in multi-modal/operator services with integrated ticketing.
    - Attitude towards these measures.
- There is therefore a need to monitor implemented measures and use before and after data for feedback to validate models.
- Actual waiting time makes up about one third of the total travel time in a bus trip. Users perceiving this time as twice the in-vehicle time emphasises the importance of decreasing this time to make bus travel more attractive. This merits further research in analysing effective methods to disseminate information to maximum proportion of users and the extent of its effect on passenger arrival profiles.
- Conventional methods of enhancing bus service could play a major role for the ITS measures to have optimal effect. For example, improving travel time with bus priority could be offset by poor fleet management or driver behaviour (speeding in some section and waiting at other stops) and providing information about a poor service could adversely affect patronage. In other words an integrated approach using both conventional and ITS measures could provide best results.

It could therefore be ideal first to improve the service in the first phase by means of more efficient management by operators, demand (traffic) management or segregation. In second phase minimise the journey time using improved ticketing and bus priority at signal controlled junction and then re-set the scheduled time to have 'perfect' punctuality/regularity. In the third phase use differential bus priority and passenger information to offset the impact due to varying traffic condition in a transport network.

APPENDIX A

Review of Transport Models

1) Four Stage Transport Models

EMME/2

EMME/2 is a 'state-of-the-art' multi-modal transportation planning system based on the four stage model system, which offers the users a wide ranging sets of tools for demand modelling, network analysis and evaluation across all the models. It can be used as a classical four-step model to multi-modal assignment with direct demand function as well as trip chains (INRO, 1993). EMME/2 uses Evans' partial linear approximation algorithm to solve the combined distribution, mode choice and assignment model (Metaxatos et al., 1995).

The network data set consists of modes, nodes, links, turnings and transit lines. Since all modes are integrated into one consistent network, it is possible to model the interaction between the sharing modes.

The standard EMME/2 public transport assignment assumes costs on the public transport network are fixed and therefore does not allow for congestion effects due to limited vehicle capacity. It is based on the concept of optimal strategies. A strategy (Speiss et. al., 1989) is an assumed rule followed by passengers to reach their destination. It allows the passengers to take the first of alternative PT services to call at the stop (therefore incorporating a degree of multi-routing). The optimal strategy is that which minimises total expected time or cost. It includes sensitivity to fare structures and crowding but is not implicitly modelled. Recently it has been extended to take account of passenger congestion, leading to the formulation of a transit equilibrium assignment identical to Wardrop equilibrium highway assignment models using Frank -Wolfe decent algorithm.

The principal difference between EMME/2 and other transportation studies is it is a database system of storing, manipulating and examining data for the user to develop and manipulate than to perform pre - specified tasks. (Bolland et. al., 1992)

EmandS

While EMME/2 (Bolland et al., 1992) allows the user to specify junction delay functions for turning movements it cannot dynamically adjust these to take account of traffic conflicts. In congested situation this would have significant impact. The SATURN packages in EmandS carries out detailed junction simulation in which iterative re-assignment on basis of flow delay curves produced by simulation is used. The linking of the two models result in a detailed junction modelling integrated with a multi- modal package.

It is possible to apply it to networks, which has been subjected to either SATURN or EMME/2. Following the final run of SATURN simulation the link and turn flows, turning proportions, queues and delays are transferred to EMME/2 for assignment thus creating an assignment and simulation loop and the final results are manipulated and display through EMME/2. In effect it is using the assignment model of EMME/2 for the successive use of assignment and simulation in SATURN and test results show that there is a high degree of correlation with results where modelling is carried out with SATURN alone (Bolland et al., 1992).

TRIPS

TRIPS (MVA, 1995) is an integrated transportation model package which represents the state-of-art for modelling based on the classic model structure using aggregate and zonal data. It has a flexible structure allowing independent use of elements such as highway assignment while also being suited to a more comprehensive approach. Its trip generation, trip distribution and modal split components are based on conventional methods (multiple linear regression, gravity model, growth factoring, logit model). It also provides matrix estimation model, which can take advantage of a variety of data sources including trip ends, link counts, license plates etc.

The public transport module of TRIPS is a multi - modal stochastic user equilibration assignment model which predicts user controlled multi route paths between zones, journey time matrices, transit and walk links, interchanges and impact of different fare systems and congestion by line and links. It allows the user to have a great deal of control over the parameters and to choose and develop the level of detail of the model (MVA, 1996). It is capable of addressing complex issues such as:

- Realistic representation of passenger route choices using multi routing path algorithm (logit curve) to find all reasonable routes for each O-D pair and assign trips to the best path.
- It models passenger trips and all the components of generalised costs can be user specified to reflect behavioural changes.

- It can also model impact of different fares system and effect of crowding on route choice.

The public transport module of TRIPS is detailed in section 5.4.

2. Disaggregate Transport Models.

Dutch National Model system

Dutch National Model system (Gunn & Ben-Akiva, 1993 in Chaterjee 1999.) is a good example of the practical application of disaggregates modelling principles. It is designed to be a system of models to predict long term developments in travel by all land based travel modes under various explicit hypothesis about developments in national socio-economic structures, land use patterns and transport policy scenarios (increased fuel taxes, vehicle purchase taxes, improvement of public transport, etc.,). Relevant major innovations in the system include:

- Modular structure, each module based on model structures compatible with national individual (and household) decision making, and calibrated using disaggregate data for individuals and households;
- Forecast year populations and simulated in detail prior to any travel demand prediction, using local planning data. Uses 'prototypical' sample of households (1000 households from existing data source).
- Addresses the problem of the change of attitudes towards the ownership and use of private vehicles (e.g. between the older generations and the younger) by incorporating predictions based on aggregate driving license ownership;
- Addresses an exceptionally comprehensive set of travel related decisions, including driving license acquisition, car ownership, tour frequency, mode choice, destination choice, departure time and route choice;
- Trip related choices are allowed to interact through equilibration over route choice, departure time, mode and destination choice;

SATURN

SATURN (Simulation and Assignment of Traffic to Urban Road Networks) is a suite of traffic network analysis program for four basic functions -

- A combined traffic simulation and assignment model for the analysis of traffic management scheme over relatively localised network.
- As a conventional traffic assignment model for the analysis of much larger network
- Simulation model of individual junction

- A network database and analysis system.

As a combined simulation and assignment model, SATURN is most suitable for analysis of relatively minor network changes such as the introduction of one-way streets, changes to junction controls, bus only streets in other words traffic management measures where detailed analysis of traffic behaviour at junctions is required. However it can also be used as a conventional assignment model (Willumsen – 1993)

Network is made of unidirectional links with a detailed treatment of junctions. Though not a multi - modal network bus routes can be entered explicitly and multiple user class assignment is also possible. It looks at bus services as sharing road space and not as alternative mode connecting origins and destinations and providing interchange facilities. SATURN provides most features of a standard assignment package such as generalised cost, all-or-nothing, Wardrop equilibrium, Burrell multiple route assignment, etc. It is also possible to set up 'split-level networks' enabling existing networks to be modelled immediately as pure buffer networks with junction simulation being introduced in stages. Dividing the period of interest into shorter time intervals treats effects on route choice due to the dynamic nature of queue building. Each time interval is then treated as a steady state assignment problem.

SATED program in the model allows for the interactive simulation and editing of individual junctions, so that the user is able to vary parameters such as flows, saturation flows, signal setting to simulate one node in isolation. It can also be used for the analysis of network based data which need not be in any way related to traffic assignment problems. For example, data relating to accident rates per link may be input and analysed, or the last dates of road resurfacing stored.

It has a graphical interface for output and editing to calibrate the network on a node-by-node basis. It is closely linked with ME2 model (matrix estimation from maximum entropy), which enables O-D trip matrices to be estimated directly from traffic counts. For demand responsive modelling a new module SATEASY, has been introduces to allow for trip generation/suppression using elasticity concepts. This module allows trips to be suppressed as a function of travel time. It does not however reflect what these diverted or suppressed trips do. A SATURN to URECA interface module (SURI) to assist in economic evaluation of schemes is also available.

SATCHMO

SATCHMO (Saturn Travel Choice Model) is a multi-modal transport package to complement SATURN providing the facilities required to model behavioural responses by the trip makers. (Arzeki et al., 1992) There are three groups of modelling issues that SATCHMO has been designed to address.

- Interaction between road schemes and public transport changes in the performance of PT and car movements and their respective impact on mode choice.
- Estimation of non - users benefits
- Elastic demand modelling using variable trip matrices.

It is designed to handle the full complexity of public transport networks along with an integrated network with the private transportation. The choice between private and public transport modes is always a part of more flexible mode choice formulation.

In addition to route and mode choice dis-utility associated with choice of departure time, destination and trip frequency is incorporated into consistent formulation. It can model all range of highway related schemes and represent different user class and vehicles. The structure of the package is divided into three main components (Willumsen et. al., 1993).

1. Public transport modules.

It builds a multi - modal public transport network. The services are described in terms of their unit capacities, frequencies and travel times. Operating speed can be related to highway speeds through coefficients to account for bus performances and stop times. Route choice is on the basis of generalised cost, which can be user specified, in the predicted multi - paths. It performs path skimming for the relative attractiveness of each mode and service. Trip loading onto the networks is achieved by allowing for the relative attractiveness of each mode and service. Fares can be handled as a part of route/mode choice or separately in a fare matrix for integrated system.

2. Demand and Choice models -

The main program SACHAS performs simultaneous travel choice and assignment using modified Frank - Wolfe algorithm. It offers joint choice and assignment within an equilibrium framework with significant advantages of consistency and efficient convergence (Arzeki et al 1992) It considers travel choice as part of a general (nested) logit formulation which is very general and allows the user to handle a wide range of responses.

SACHD1 program has been developed to cope with incremental and classic distribution and mode choice model outside an explicit equilibration network. (Abraham et al 1992)

3. Graphic Modules

Graphic facilities in SATURN have been enhanced using user interface and new features for public transport. It can be used for building and editing both private and public transport networks using digitiser or mouse inputs.

SATCHMO complements SATURN through the provision of public transport and demand modelling capabilities, and so offer a comprehensive modelling tool capable of handling:

- Detailed local congestion and traffic schemes and their implications on route, time of day, mode and destination choice;
- Strategic transport modelling using buffer networks and advanced public transport and travel choice models;
- Combination of the above.

However limitations noted (Burden, 1999) by users include:

- It has no PT interchange and capacity restraint.
- Use of All or nothing assignment on PT modes causes complete flipping of assignment
- The outputs and analysis package for PT is poor
- It is rooted to DOS platform and hence is not user friendly.
- There is very little SATCHMO support or development

3. Land Use Models.

TRANUS

An example of land use model is TRANUS. It is an integrated land use and transport model (www.modelistica.com/tranus/index.html), which can be applied at an urban or regional scale. The program suite has double purpose: firstly, the simulation of the probable effects of applying particular land use and transport policies and projects, and secondly the evaluation of these affects from social, economic, financial and energy points of view. It can also be used as a stand-alone transport model.It uses a multidimensional path search method and in effect can be viewed as a model of the options available to users when travelling from an origin to a destination. Once all the paths have been found, iterative calculation are carried out to get generalised costs and aggregated over all modes to obtain the average monetary and composite cost of travel from an origin to a destination for a given user category.

Trip generation determines the number of trips from an origin to destination by a particular transport category, as an elastic function of corresponding composite cost. Trips for each category are distributed by means of a MNL (logit) model in which utility function is determined by the composite cost of travel by mode.

Trips by mode must be assigned to different paths connecting origins to destinations by that mode. Since each path implies a particular sequence of operators and transfers, trips are simultaneously assigned to operators, as well as to links of the network. This is carried out by another MNL model, which includes both diminishing marginal perception of utilities and overlapping, and where the utility function is determined by the composite cost of each path.

In the final stage of the iterative process a capacity restriction procedure is performed, whereby travel speeds are reduced and waiting times are increased in every link for each operator as a function of demand/capacity ratios. Waiting times take into consideration the frequency of transit systems as well a possible delay due to congestion and the demand/capacity ratio in the vehicle themselves. The user specifies a convergence criteria and the model is said to have converged if in the current iteration volumes, speeds and waiting time have changed with respect to the previous iteration values below the convergence criterion in all links of the network.

MEPLAN:

MEPLAN (Chaterjee, 1999) is an integrated land use/transport model suite designed for practical application to a wide range of planning studies. A typical MEPLAN model has characteristics such that:

- The demand for travel at each point in time is mainly a function of the economic interactions between activities.
- The change in accessibility between places due to changes in the supply of transport and the congestion of the transport system influence the location of changes over time.
- Both the transport and land use systems are modelled as markets where the interaction between demand and supply works through prices for land and for transport.

There are four main components in the model:

1. A land use mode (LUS) estimates the spatial pattern of rents, densities of occupation and of location of households, firms and floor space. It estimates the pattern of movements by purpose between zones and contains the trip distribution stage of the traditional four-stage process.
2. An interface between land use and transport (FRED) converts the generalised costs of travel estimated by the transport model into costs and disutility for use in the land use model. Conversely, it takes outputs from the land use model and calculates per hour trip matrices (generation stage of the four-stage process).
3. The transport model (TAS) splits the trip matrices by mode (modal split) and assigns vehicles and persons to the road and rail networks. Capacity restraint is applied to both road and rail.
4. There is an evaluation package EVAL. This draws output from the land use and transport models typically for a base run and a policy run and compares the two sets of results. Land use information includes inter-zonal trades and zonal production and consumption characteristics including costs and prices. Outputs from the transport module include link loads, flows between zone pairs by mode and type, average trip costs, times and revenues.

Experience from the use of the model suggests larger zone sizes than for transport models are appropriate. For the purpose of detailed network design it needs to be interfaced with a local area traffic model.

4. *Activity -travel Models*

VISEM:

VISEM (Fellendorf et al., 1995) is a tool to estimate and forecast mode specific origin destination matrices (O-D tables). The two basic ideas of VISEM are the classification of the population into behaviourally homogeneous groups and the generation of trip chains derived from activity chains. Disaggregate household survey data is classified into clusters of behaviourally homogeneous groups to eliminate computationally burdens as well as to ease calibration.

VISEM includes a set of models in one system. The most important ones are

Daily mobility patterns: Behaviourally homogeneous groups are classified by their specific travel behaviour accounting for age, employment and car ownership. A heuristic procedure is applied to transform the empirical mobility of travel diaries to a reduced set of selected activity chains for the groups to avoid long computation time and low probability chains. Group specific probability for each trip chain is calculated to derive daily mobility pattern.

Trip chains: The choice of destination zone depends on the separation (e.g. distance, travel time) between origin and destination zone and on the sensitivity of each activity to separation. This sensitivity to separation is specified in the parameters of the deterrence function for each activity and each group. By choosing destinations the destination choice sub-model generates numerous trips from each activity chains: thus the results of trip distribution are a complete trip matrix and the total number of trip chains.

Nested *logit mode choice:* VISEM applies a behaviour-oriented approach, which considers three aspects in mode choice:

- The socio economic situation, specially car availability of the decisive persons (by population group)
- Different attributes of the transport mode alternatives (via an utility function),
- Choice restraints within a trip chain (as there are defined exchangeable and not exchangeable modes).

This problem of decision is represented by a multinomial LOGIT model, which states the probability of mode choice for any given trip chain.

VISEM calculates time of day matrices based upon time patterns, which represent the temporal distribution of activities during the day. This model replaces the first three steps of the classical four-stage model in an integrated manner.

ELASIS model system

This model system uses trip chaining as part of a conventional modelling approach (Chaterjee, 1999). The main features of the trip-chaining model are as follows:

- Primary destination approach - every tour is assumed to have primary activity with other travel choices conditioned to primary ones.
- Tour includes conventional round trips, chain tours including a further intermediate trip, double round trips which accounts for 95% of trips.
- This model was calibrated from a single day travel diaries completed by 2000 residents of Salerno.
- Demand system has a sequential approach and uses a nested logit sub-models.
- The traffic assignment model uses a stochastic user equilibrium approach. Traffic is assigned according to a probit model.

AMOS

AMOS (Kitamura et al., 1995) comprises five main components and a reporting routine. It takes an observed *baseline daily travel pattern* of an individual generates an adaptation option using *Response option generator*, (e.g., change commute travel mode) that may be adopted by an individual when faced with different circumstances, adjust the baseline pattern (e.g. re-sequence activities or select new destination) to produce a modified activity travel pattern using *Activity travel pattern modifier;* evaluates the utility of the modified pattern; based on a satisficing rule (*Evaluation routine)*, accepts one of the modified patterns so far generated and (*using acceptance routine)* terminates the search, or continues to search for alternative.

5. Dynamic Models

CONTRAM

CONTRAM is an assignment models which calculates time varying traffic flows, queues and delays in a network from a set of time varying demands on the assumption that drivers are familiar with traffic conditions and choose routes which minimise their journey time or cost. It gives the flow, delays and queues for each link of the network, travel times and route for selected vehicles for different intervals of time, which enables a range of economic and environmental impact to be assessed (TRL, 1989). It assigns fixed routes to model public transportation. There have been numerous developments in CONTRAM in the context of modelling ITS measure in private transportation.

CONTRAM developments:

CONTRAMI (Breheret, et al., 1990) specifies driver response to incidents by link number, reduction in capacity and duration. The decision logic is that motorist use normal optimal routes until they encounter an unexpected queue, which exceeds the threshold level specified and then re route (at the junction upstream of the occupied link), depending on their willingness to divert, and the attractiveness of the alternative (expressed in terms of extra cruise time). They may then divert from their alternate route, but only a limited number of times.

MGCONTRM (Robinson et. al., 1994)) is being used to develop practical VMS strategies and to produce on line recommendations for operators. The user can specify that the motorists passing VMS either use fixed diversion routes as specified by user, or allow free re-routing at the VMS; the proportion of traffic diverting (representing the effective strength of the message); and the timing of the display relative to the incident.

RGCONTRAM (McDonald et al., 1995) has been developed at the University of Southampton to model traffic information operations. The emphasis in RGCONTRAM has been on single day modelling (that is traffic conditions on a specific day rather than normal day) with enhanced traffic incident and driver behaviour sub-models. It operates on an equilibrium model or a once through non-equilibrium simulation where the dynamic processes dominates and preclude the use of an equilibrium approach.
Simulation models like MIDAS, INTEGRATION, DYNASMART also uses the concept of dynamic changes in traffic demand and supply.

6. Micro-Simulation Models

DYNASMART is a descriptive analysis tool for the evaluation of information supply strategies, traffic control measures, and route assignment at network level (Hu et al 1995). The model is designed around a flexible structure that provides a sensitivity to a wide range of traffic control measures for both intersections and freeways, capability to model traffic disruptions as a result of incidents, and representation of several user classes, physical facilities, different information availability status, and different behavioural rules. It integrates macroscopic traffic flow models, path processing methodologies, behavioural rules (bounded rational), and information availability status into a single simulation assignment framework.

One of its principal features that allow it to interface with activity based models is its explicit representation of individual trip making decisions, particularly for path selection decision, both at the trip origin and en route.

DRACULA (Liu et al., 1995) uses a framework of micro-simulation of drivers, vehicles and system parameters in order to model the day to day evolution of a traffic network to examine how flow evolve over a typical pattern of days; aggregate measures are then obtained over the full number of days simulated. The framework consists of separate demand and supply model.

FLEXSYT II is a commercially available, event-based microscopic model that has been developed in the Netherlands. Its most innovative feature is the possibility to use a special traffic control programming language with which it is possible to simulate any type of control. Different modes of transport can be modelled including buses, walking, bicycles, cars and lorries. The model has been applied in studies of all kind of traffic management measures and control strategies including public transport priority, ramp metering and toll gates (Taale and Scheerder, 2000). The model is however only suitable for small-scale networks and difficulty in model validation have been observed by Taale et. al. (2000).

HUTSIM (Helsinki University of Technology Simulation) is a microscopic simulation model that was specifically developed for traffic signal simulation. HUTSIM has been developed by the Helsinki University of Technology, Laboratory of Transportation Engineering since 1989. The flexible and versatile object-oriented modelling has made HUTSIM easy to adapt for various simulation studies. It's rule-based vehicles dynamics produces a consistent and stable driving behaviour in any traffic situation with only a set of a few rules for speed control, lane changing and gap acceptance. HUTSIM also offers multi-modal capabilities like pedestrian traffic and public transport simulation. One of its main feature the possibility of connecting it directly to traffic signal controllers to evaluate real control strategies like bus priority (Kosenen, 1999).

INTEGRATION analyses traffic flows in terms of vehicles as individual entities (Berkum et al., 1996). This microscopic approach permits a traffic flow representation, which is common to all networks and also permits a continuous dynamic queuing based traffic assignment. The strength of this model is it combines simulation and dynamic assignment. Vehicles are shown individually during simulation, which allows for a detailed analysis of traffic process. The interaction of individual vehicles along the links is modelled using speed flow relationship, lane changing and car following logic and detailed techniques to determine vehicle emissions and different driver classes to represent different route choice behaviour and utilisation of dedicated lanes.

MIDAS (Goulias et. al., 1992,) combines dynamic simulation of population with dynamic models of travel behaviour. The two main components both operate at the household level. The first component is a micro simulator of the household socio-economics and demographics. The output from this component is used in a dynamic model system of mobility predicting weekly levels of car ownership, trip generation, modal split, car trip distance and transit trip distance. The sub models within the system are probabilistic and have been calibrated using panel data.

PARAMICS (Parallel Microscopic Simulation) includes a sophisticated microscopic car following and lane changing model, dynamic and intelligent routing and can model dome ITS measures (Druitt, 1998). An interface to other common macroscopic data formats and real time traffic input data sources is also provided. The movement of individual vehicles is governed by three interacting models representing vehicle following, gap acceptance and lane changing. It claims to account for public transport and its interaction with other modes at bus stops and through bus priority measures.

PARAMICS-CM (Mc Arthur, 1995) augments the basic PARAMICS simulator by modelling

- Advanced driver information - Information (positions of ATT elements) is superimposed on highway network, with three data structures, sets of events, effects and resulting route updates.
- Dynamic route determination supporting re-routeing - The routeing module (Router) determines the shortest paths between trip origin and destination producing a route table in which, from any node, the journey cost to destination is tabulated for each exit
- And the behavioural response of the drivers - a rule language has been established for driver response to incidents being used in VMS evaluation reflect the result of the CEC DRIVE project QUO VADIS (Bonsall et al, 1994) where PC based route choice simulators were used to identify driver responses to a variety of situations.

STEER (Ghali et al., 1995) is a multi-model micro simulation, assignment, control model. It is designed to allow the effects on users to be estimated using a congestion model and also help in design in road pricing, urban traffic control and route guidance systems. STEER has three basic parts: A event based network loading procedure, dynamic route assignment using time slices and a control procedure which resets the signal according to a user specified traffic control policy.

TRAF-NETSIM is a member of 'NETSIM' family of simulation models, which includes CORSIM, developed by the Federal Highway Administration (FHWA). This model (Hugosson et. al., 1997) provides a detailed evaluation of proposed improvements in a signalised network. The model can model signal-controlled intersection and interaction between cars and buses explicitly. It applies interval-based simulation to describe traffic operations where each vehicle is a distinct moving object that is moved every second.

Vehicles are moved according to car following logic, responding to traffic control devices and other demands such as stopping buses to pick up passengers at bus stops.

7. Timetable Based Models

Public transport assignments have been using frequency based networks which does not use exact vehicle arrival or interchange times to effectively model hidden waiting time consistently or to apply capacity restraints within each vehicle. Furthermore with timetable based models, it is possible to distribute fares to every vehicle making it possible to predict economic feasibility of new lines and/ or new fare structures (Pedersen, 1999).

TPSchedule (Pedersen, 1999) is a schedule based stochastic model, The model transforms the public transport network to a calculation network called 'dual' network to calculate transfer times and apply standard shortest path algorithms. Dual network consist of three level:

- Infrastructure (modes, roads, junctions)
- Line (spatial description)
- Departure (time description of lines)

The model then uses Dijkstra type of algorithm to find shortest path and conventional MSA loadings. It had been shown that the use of distributed coefficient in utility functions (Nielson 1999 in Pedersen 1999) enables a public transport assignment model to describe passenger behaviour convincingly than SUE as it allows for different persons to have different perceptions and preferences using error components. A principal asset of this model is the calculation of hidden waiting time, which is the difference between a desired departure time and the timetable.

A large-scale stochastic timetable based transit assignment model for route and sub mode choice proposed by Nielsen et al., (1999). The model uses the whole timetable of a network for a more precise description of travel times and accounts for transfer time, capacity of each vehicle, number of transfers, time of departure and hidden waiting times. It uses income groups and an error component for joint route and sub-mode choices to explain the systematic differences within one group. It also takes into account the temporal behavioural variation using lognormal or normal distribution to that of income.

APPENDIX B

Table 1. Validation of TRIPS model

Stops	Observed		TRIPS value		difference	difference		
	Boarding	Alighting	Boarding	Alighting	B(diff)	A(diff)	$B(diff)^2$	$A(diff)^2$
75	5	0	4.85	0	0.15	0.00	0.02	0.00
83	4	1	4.04	0.85	-0.04	0.15	0.00	0.02
84	1	0	0.01	0	0.99	0.00	0.98	0.00
85	178	0	131.97	0.08	46.03	-0.08	2118.76	0.01
109	0	0	0.84	0	-0.84	0.00	0.71	0.00
108	7	1	5.09	1	1.91	0.00	3.65	0.00
106	0	3	0.02	0	-0.02	3.00	0.00	9.00
104	0	0	1.31	2.31	-1.31	-2.31	1.72	5.34
102	0	0	0	0	0.00	0.00	0.00	0.00
103	0	0	0	0	0.00	0.00	0.00	0.00
123	7	8	10.77	33.84	-3.77	-25.84	14.21	667.71
126	16	70	14.87	45.55	1.13	24.45	1.28	597.80
265	19	99	13.83	46.24	5.17	52.76	26.73	2783.62
141	2	6	2.28	0.66	-0.28	5.34	0.08	28.52
143	0	0	0	0	0.00	0.00	0.00	0.00
152	5	5	7	7	-2.00	-2.00	4.00	4.00
164	0	0	0	0	0.00	0.00	0.00	0.00
166	12	17	13.94	19.45	-1.94	-2.45	3.76	6.00
185	9	9	11.37	6.45	-2.37	2.55	5.62	6.50
192	3	0	2.18	1.38	0.82	-1.38	0.67	1.90
198	0	0	3.84	0	-3.84	0.00	14.75	0.00
206	2	4	2.73	4.55	-0.73	-0.55	0.53	0.30
217	10	6	9.53	5.18	0.47	0.82	0.22	0.67
224	5	7	9.29	5.27	-4.29	1.73	18.40	2.99
238	0	0	0	1.03	0.00	-1.03	0.00	1.06
248	0	4	0	4	0.00	0.00	0.00	0.00
255	9	7	6.93	7	2.07	0.00	4.28	0.00
258	0	17	0	14	0.00	3.00	0.00	9.00
251	0	28	0	50.85	0.00	-22.85	0.00	522.12
				Sum	37.31	35.31	2220.37	4646.57
				Average	1.29	1.22		
s_d^2 =	77.58	164.41	s_d =	8.81	12.82	t =	0.79	0.51

Value of t calculated is less than table value (2.05) at 28 df and 5% significance level, therefore there is no significant difference between the observed and model outputs

Table 2. Validation of SPLIT model

Split Value	Observed value for service 101		
x_1	x_2	x_1-x_2	$(x_1-x_2)^2$
18	21	-3	9
21	16	5	25
82	82	0	0
56	57	-1	1
38	32	6	36
216	184	32	1024
64	25	39	1521
63	64	-1	1
46	33	13	169
34	30	4	16
23	19	4	16
80	82	-2	4
71	77	-6	36
95	114	-19	361
64	89	-25	625
60	55	5	25
57	65	-8	64
80	72	8	64
	Sum	51	3997
	Average	2.68	210.37
s_d^2	214.45	s_d	14.64
t	0.80		

Value of t calculated is less than table value (2.101) at 18 df and 5% significance level, therefore there is no significant difference between the observed and model outputs

Table A. Relation between observed punctuality and arrival % in the last 5minutes, all stops

	OP x	AP y	$(x)^2$	$(y)^2$	xy	$(x-x_{avg})$	$(y-y_{avg})$	$(x-x_{avg}) * (y-y_{avg})$	$(x-x_{avg})^2$	$(y-y_{avg})^2$
	52	67	2704	4489	3484	-14.62	19.5	-285.09	213.74	380.25
	67	48	4489	2304	3216	0.38	0.5	0.19	0.14	0.25
	73	63	5329	3969	4599	6.38	15.5	98.89	40.70	240.25
	80	50	6400	2500	4000	13.38	2.5	33.45	179.02	6.25
	33	67	1089	4489	2211	-33.62	19.5	-655.59	1130.30	380.25
	80	56	6400	3136	4480	13.38	8.5	113.73	179.02	72.25
	100	45	10000	2025	4500	33.38	-2.5	-83.45	1114.22	6.25
	13	55	169	3025	715	-53.62	7.5	-402.15	2875.10	56.25
	67	56	4489	3136	3752	0.38	8.5	3.23	0.14	72.25
	100	48	10000	2304	4800	33.38	0.5	16.69	1114.22	0.25
	60	50	3600	2500	3000	-6.62	2.5	-16.55	43.82	6.25
	70	46	4900	2116	3220	3.38	-1.5	-5.07	11.42	2.25
	71	30	5041	900	2130	4.38	-17.5	-76.65	19.18	306.25
	62	43	3844	1849	2666	-4.62	-4.5	20.79	21.34	20.25
	70	40	4900	1600	2800	3.38	-7.5	-25.35	11.42	56.25
	70	49	4900	2401	3430	3.38	1.5	5.07	11.42	2.25
	83	45	6889	2025	3735	16.38	-2.5	-40.95	268.30	6.25
	56	48	3136	2304	2688	-10.62	0.5	-5.31	112.78	0.25
	40	51	1600	2601	2040	-26.62	3.5	-93.17	708.62	12.25
	75	45	5625	2025	3375	8.38	-2.5	-20.95	70.22	6.25
	50	30	2500	900	1500	-16.62	-17.5	290.85	276.22	306.25
	59	30	3481	900	1770	-7.62	-17.5	133.35	58.06	306.25
	78	38	6084	1444	2964	11.38	-9.5	-108.11	129.50	90.25
	73	38	5329	1444	2774	6.38	-9.5	-60.61	40.70	90.25
	70	51	4900	2601	3570	3.38	3.5	11.83	11.42	12.25
	80	45	6400	2025	3600	13.38	-2.5	-33.45	179.02	6.25
Sum	1732	1234	124198	61012	81019	-0.12	-1	-1184.38	8820.15	2444.50
Averag	66.62	47.5								
	b=	$[(\Sigma xy - 1/n(\Sigma x * \Sigma y)] / [(\Sigma x^2 - 1/n(\Sigma x)^2]$					se2=	95.23		
	b=	-0.1343					sb2=	0.01		
	a=	avgY -b*avgX					sb=	0.10		
		56.407					t=	-1.29	R=	-0.26

The table value of t for 24degree of freedom and 5 % significance level, - 2.064 is less than calculated value, which means the regression coefficient does not play a significant role in determining arrival and as correlation coefficient is not close to 1, the correlation is not significant.

Note : OP = Observed Punctuality, PP = Perceived punctuality, AP = Arrival percentage,
P = Punctuality, AP = Arrival percentage for all tables in this Appendix

Table B. Relation between OP and AP in the last 5 minutes for high frequency service

	OP x	AP y	$(x)^2$	$(y)^2$	xy	$(x-x_{avg})$	$(y-y_{avg})$	$(x-x_{avg}) * (y-y_{avg})$	$(x-x_{avg})^2$	$(y-y_{avg})^2$
	52	67	2704	4489	3484	-14.50	12.40	-179.80	210.25	153.76
	67	48	4489	2304	3216	0.50	-6.60	-3.30	0.25	43.56
	73	63	5329	3969	4599	6.50	8.40	54.60	42.25	70.56
	80	50	6400	2500	4000	13.50	-4.60	-62.10	182.25	21.16
	33	67	1089	4489	2211	-33.50	12.40	-415.40	1122.25	153.76
	80	56	6400	3136	4480	13.50	1.40	18.90	182.25	1.96
	100	45	10000	2025	4500	33.50	-9.60	-321.60	1122.25	92.16
	13	46	169	2116	598	-53.50	-8.60	460.10	2862.25	73.96
	67	56	4489	3136	3752	0.50	1.40	0.70	0.25	1.96
	100	48	10000	2304	4800	33.50	-6.60	-221.10	1122.25	43.56
Sum	665	546	51069	30468	35640	0.00	0.00	-669.00	6846.50	656.40
Avg	66.5	54.6								
	b=	$[(\Sigma xy - 1/n(\Sigma x * \Sigma y)] / [(\Sigma x^2 - 1/n(\Sigma x)^2]$					se2=	73.88		
	b=	-0.098					sb2=	0.01		
	a=	avgY -b*avgX					sb=	0.10		
		61.098					t=	-0.94	R=	-0.32

The table value of t for 8 degree of freedom and 5 % significance level, - 2.305 is less than calculated value, which means the regression coefficient does not play a significant role in determining arrival and as correlation coefficient is not close to 1, the correlation is not significant.

Table C. Relation between PP and AP in the last 5 minutes for high frequency service

	PP	AP								
	x	y	$(x)^2$	$(y)^2$	xy	$(x-x_{avg})$	$(y-y_{avg})$	$(x-x_{avg}) * (y-y_{avg})$	$(x-x_{avg})^2$	$(y-y_{avg})^2$
	39	67	1521	4489	2613	-15.90	9.50	-151.05	252.81	90.25
	49	63	2401	3969	3087	-5.90	5.50	-32.45	34.81	30.25
	52	50	2704	2500	2600	-2.90	-7.50	21.75	8.41	56.25
	60	56	3600	3136	3360	5.10	-1.50	-7.65	26.01	2.25
	74	45	5476	2025	3330	19.10	-12.50	-238.75	364.81	156.25
	17	55	289	3025	935	-37.90	-2.50	94.75	1436.41	6.25
	68	56	4624	3136	3808	13.10	-1.50	-19.65	171.61	2.25
	80	68	6400	4624	5440	25.10	10.50	263.55	630.01	110.25
Sum	439	460	27015	26904	25173	-0.20	0.00	-69.50	2924.88	454.00
Avg	54.9	57.5								
	b=	$[(\Sigma xy - 1/n (\Sigma x * \Sigma y)] / [(\Sigma x^2 - 1/n(\Sigma x)^2]$					se2=	75.39		
	b=	-0.024					sb2=	0.03		
	a=	avgY -b*avgX					sb=	0.16		
		58.804					t=	-0.15	R=	-0.06

The table value of t for 6 degree of freedom and 5 % significance level, - 2.447 is less than calculated value, which means the regression coefficient does not play a significant role in determining arrival and as correlation coefficient is not close to 1, the correlation is not significant.

Table D. Relation between OP and AP in the last 5 minutes for low frequency service

	OP	AP								
	x	y	$(x)^2$	$(y)^2$	xy	$(x-x_{avg})$	$(y-y_{avg})$	$(x-x_{avg}) * (y-y_{avg})$	$(x-x_{avg})^2$	$(y-y_{avg})^2$
	60	50	3600	2500	3000	-6.69	7.56	-50.58	44.76	57.15
	70	46	4900	2116	3220	3.31	3.56	11.78	10.96	12.67
	71	30	5041	900	2130	4.31	-12.44	-53.62	18.58	154.75
	62	43	3844	1849	2666	-4.69	0.56	-2.63	22.00	0.31
	70	40	4900	1600	2800	3.31	-2.44	-8.08	10.96	5.95
	70	49	4900	2401	3430	3.31	6.56	21.71	10.96	43.03
	83	45	6889	2025	3735	16.31	2.56	41.75	266.02	6.55
	56	48	3136	2304	2688	-10.69	5.56	-59.44	114.28	30.91
	40	51	1600	2601	2040	-26.69	8.56	-228.47	712.36	73.27
	75	45	5625	2025	3375	8.31	2.56	21.27	69.06	6.55
	50	30	2500	900	1500	-16.69	-12.44	207.62	278.56	154.75
	59	30	3481	900	1770	-7.69	-12.44	95.66	59.14	154.75
	78	38	6084	1444	2964	11.31	-4.44	-50.22	127.92	19.71
	73	38	5329	1444	2774	6.31	-4.44	-28.02	39.82	19.71
	70	51	4900	2601	3570	3.31	8.56	28.33	10.96	73.27
	80	45	6400	2025	3600	13.31	2.56	34.07	177.16	6.55
Sum	1067	679	73129	29635	45262	-0.04	-0.04	-18.81	1973.44	819.94
Avg	66.688	42.438								
	b=	$[(\Sigma xy - 1/n (\Sigma x * \Sigma y)] / [(\Sigma x^2 - 1/n(\Sigma x)^2]$					se2=	58.55		
	b=	-0.010					sb2=	0.03		
	a=	avgY -b*avgX					sb=	0.17		
		43.073					t=	-0.06	R=	-0.01

The table value of t for 14 degree of freedom and 5 % significance level, - 2.145 is less than calculated value, which means the regression coefficient does not play a significant role in determining arrival and as correlation coefficient is not close to 1, the correlation is not significant.

Table E. Relation between degree of earliness and degree of lateness

	Latenes x	Earliness y	$(x)^2$	$(y)^2$	xy	$(x-x_{avg})$	$(y-y_{avg})$	$(x-x_{avg}) * (y-y_{avg})$	$(x-x_{avg})^2$	$(y-y_{avg})^2$
	35	13	1225	169	455	11.62	3.00	34.86	135.02	9.00
	13	20	169	400	260	-10.38	10.00	-103.80	107.74	100.00
	27	0	729	0	0	3.62	-10.00	-36.20	13.10	100.00
	12	8	144	64	96	-11.38	-2.00	22.76	129.50	4.00
	0	67	0	4489	0	-23.38	57.00	-1332.66	546.62	3249.00
	20	0	400	0	0	-3.38	-10.00	33.80	11.42	100.00
	0	0	0	0	0	-23.38	-10.00	233.80	546.62	100.00
	74	13	5476	169	962	50.62	3.00	151.86	2562.38	9.00
	33	0	1089	0	0	9.62	-10.00	-96.20	92.54	100.00
	0	0	0	0	0	-23.38	-10.00	233.80	546.62	100.00
	40	0	1600	0	0	16.62	-10.00	-166.20	276.22	100.00
	30	0	900	0	0	6.62	-10.00	-66.20	43.82	100.00
	16	13	256	169	208	-7.38	3.00	-22.14	54.46	9.00
	30	8	900	64	240	6.62	-2.00	-13.24	43.82	4.00
	20	10	400	100	200	-3.38	0.00	0.00	11.42	0.00
	30	0	900	0	0	6.62	-10.00	-66.20	43.82	100.00
	10	7	100	49	70	-13.38	-3.00	40.14	179.02	9.00
	30	14	900	196	420	6.62	4.00	26.48	43.82	16.00
	47	13	2209	169	611	23.62	3.00	70.86	557.90	9.00
	13	12	169	144	156	-10.38	2.00	-20.76	107.74	4.00
	23	27	529	729	621	-0.38	17.00	-6.46	0.14	289.00
	20	21	400	441	420	-3.38	11.00	-37.18	11.42	121.00
	15	7	225	49	105	-8.38	-3.00	25.14	70.22	9.00
	20	7	400	49	140	-3.38	-3.00	10.14	11.42	9.00
	30	0	900	0	0	6.62	-10.00	-66.20	43.82	100.00
	20	0	400	0	0	-3.38	-10.00	33.80	11.42	100.00
Sum	608	260	20420	7450	4964	0.12	0.00	-1116.00	6202.15	4850.00
Avg	23.38	10.0								
	b=	$[(\Sigma xy - 1/n (\Sigma x*\Sigma y)] / [(\Sigma x^2 - 1/n(\Sigma x)^2]$					se2=	193.72		
	b=	-0.180					sb2=	0.03		
	a=	avgY -b*avgX					sb=	0.18		
		14.208					t=	-1.02	R=	-0.20

The table value of t for 24degree of freedom and 5 % significance level, - 2.064 is less than calculated value, which means the regression coefficient is not significant and as correlation coefficient is not close to 1, the correlation is not significant.

Table F. Multiple regression analysis, all frequency between observed punctuality factors and arrival %

	arrival %	%late	%early						
	Y	x_1	x_{2-}	Y^2	$(x_1)^2$	$(x_2)^2$	$(x_1 * x_2)$	$(Y* x_1)$	$(Y* x_2)$
	67	35	13	4489	1225	169	455	2345	871
	48	13	20	2304	169	400	260	624	960
	63	27	0	3969	729	0	0	1701	0
	50	12	8	2500	144	64	96	600	400
	67	0	67	4489	0	4489	0	0	4489
	56	20	0	3136	400	0	0	1120	0
	45	0	0	2025	0	0	0	0	0
	55	74	13	3025	5476	169	962	4070	715
	56	33	0	3136	1089	0	0	1848	0
	48	0	0	2304	0	0	0	0	0
	50	40	0	2500	1600	0	0	2000	0
	46	30	0	2116	900	0	0	1380	0
	30	16	13	900	256	169	208	480	390
	43	30	8	1849	900	64	240	1290	344
	40	20	10	1600	400	100	200	800	400
	49	30	0	2401	900	0	0	1470	0
	45	10	7	2025	100	49	70	450	315
	48	30	14	2304	900	196	420	1440	672
	51	47	13	2601	2209	169	611	2397	663
	45	13	12	2025	169	144	156	585	540
	30	23	27	900	529	729	621	690	810
	30	20	21	900	400	441	420	600	630
	38	15	7	1444	225	49	105	570	266
	38	20	7	1444	400	49	140	760	266
	51	30	0	2601	900	0	0	1530	0
	45	20	0	2025	400	0	0	900	0
Sum	1234	608	260	61012	20420	7450	4964	29650	12731
Average	47.46	23.38	10						
		$(\Sigma v_i)^2$	$(\Sigma u_{1i})^2$	$(\Sigma u_{2i})^2$	$(\Sigma(u_{1i} * u_{2i}))$	$(\Sigma(u_{1i} * v_i))$	$(\Sigma(u_{2i} * v_i))$		
		2444.46	6202.15	4850.00	-1116.00	793.38	391.00		
	Coefficient	b_1	0.15	t test					
	Coefficient	b_2	0.11		s^2_E	2476.06			
		R^2	0.07	elements	c_{11}	0.00017			
	MCC	R	0.26	inverse	c_{12}	-0.00004			
				matrix	c_{22}	0.00021			
				Variance of $b_1 = s_{b1}$ =		0.65	Variance of $b_2 = s_{b2}$ =		0.71
				test statistic t =		0.23	test statistic t =		0.18

MCC (multiple correlation coefficient) is not close to 1, which shows that the linear regression equation is not a good fit and both t value at 23 d.f. and 5% significance level is 2.069 is greater than the calculated values the physical interpretation is that a unit increase in degree of lateness or earliness does not make a significant change in arrival precentage.

Table G. Multiple regression analysis, High frequency between observed punctuality factors and arrival %

	Y	x_1	x_{2-}	Y^2	$(x_1)^2$	$(x_2)^2$	$(x_1 * x_2)$	$(Y* x_1)$	$(Y* x_2)$
	67	35	13	4489	1225	169	455	2345	871
	48	13	20	2304	169	400	260	624	960
	63	27	0	3969	729	0	0	1701	0
	50	12	8	2500	144	64	96	600	400
	67	0	67	4489	0	4489	0	0	4489
	56	20	0	3136	400	0	0	1120	0
	45	0	0	2025	0	0	0	0	0
	55	74	13	3025	5476	169	962	4070	715
	56	33	0	3136	1089	0	0	1848	0
	48	0	0	2304	0	0	0	0	0
Sum	555	214	121	31377	9232	5291	1773	12308	7435
Average	55.5	21.4	12.1						
		$(\Sigma v_i)^2$	$(\Sigma u_{1i})^2$	$(\Sigma u_{2i})^2$	$(\Sigma(u_{1i} * u_{2i}))$	$(\Sigma(u_{1i} * v_i))$	$(\Sigma(u_{2i} * v_i))$		
		574.50	4652.40	3826.90	-816.40	431.00	719.50		
	Coefficient	b_1	0.13	t test					
	Coefficient	b_2	0.22		s^2_E	2831.76			
		R^2	0.37	elements	c_{11}	0.00022			
	MCC	R	0.61	inverse	c_{12}	-0.00005			
				matrix	c_{22}	0.00026			
				Variance of $b_1 = s_{b1}$ =		0.80	Variance of $b_2 = s_{b2}$ =		0.86
				test statistic t =		0.16	test statistic t =		0.27

MCC (multiple correlation coefficient) is not close to 1, which shows that the linear regression equation is not a good fit and both t value at 7d.f. and 5% significance level is 2.365 is greater than the calculated values the physical interpretation is that a unit increase in degree of lateness or earliness does not make a significant change in arrival precentage.

Table H. Multiple regression analysis, Low frequency between observed punctuality factors and arrival %

	Y	x_1	x_{2-}	Y^2	$(x_1)^2$	$(x_2)^2$	$(x_1 * x_2)$	$(Y * x_1)$	$(Y * x_2)$
	50	40	0	2500	1600	0	0	2000	0
	46	30	0	2116	900	0	0	1380	0
	30	16	13	900	256	169	208	480	390
	43	30	8	1849	900	64	240	1290	344
	40	20	10	1600	400	100	200	800	400
	49	30	0	2401	900	0	0	1470	0
	45	10	7	2025	100	49	70	450	315
	48	30	14	2304	900	196	420	1440	672
	51	47	13	2601	2209	169	611	2397	663
	45	13	12	2025	169	144	156	585	540
	30	23	27	900	529	729	621	690	810
	30	20	21	900	400	441	420	600	630
	38	15	7	1444	225	49	105	570	266
	38	20	7	1444	400	49	140	760	266
	51	30	0	2601	900	0	0	1530	0
	45	20	0	2025	400	0	0	900	0
Sum	679	394	139	29635	11188	2159	3191	17342	5296
Average	42.44	24.63	8.69						
		$(\Sigma v_i)^2$	$(\Sigma u_{1i})^2$	$(\Sigma u_{2i})^2$	$(\Sigma(u_{1i} * u_{2i}))$	$(\Sigma(u_{1i} * v_i))$	$(\Sigma(u_{2i} * v_i))$		
		819.94	1485.75	951.44	-231.88	621.63	-602.81		
	Coefficient	b_1	0.33	t test					
	Coefficient	b_2	-0.55		s^2_E	779.39			
		R^2	0.66	elements	c_{11}	0.0007			
	MCC	R	0.81	inverse	c_{12}	-0.0002			
				matrix	c_{22}	0.0011			
				Variance of $b_1 = s_{b1}$ =		0.74	Variance of $b_2 = s_{b2}$ =		0.91
				test statistic t =		0.45	test statistic t =		-0.75

MCC (multiple correlation coefficient) is close to 1 and shows that the linear regression equation is a good fit and t value at 13d.f. and 5% significance level is 2.106 is greater than calculated value of 0.45 and -2.106 is less than the calculated value of -0.75, the physical interpretation is that a unit increase in degree of lateness or earliness does not make a significant change in arrival precentage.

Regression Equation =	Y = (Yavg + b1 (x1 +x1avg) + b2 (x2 – x2avg)	
	Y= 39.07 - 0.55*Earliness +0.33 Lateness	Equation 1

Table I. Multiple regression analysis, Low frequency between perceived punctuality factors and arrival %

	Y	x_1	x_{2-}	Y^2	$(x_1)^2$	$(x_2)^2$	$(x_1 * x_2)$	$(Y * x_1)$	$(Y * x_2)$
	50	50	0	2500	2500	0	0	2500	0
	46	40	10	2116	1600	100	400	1840	460
	30	30	20	900	900	400	600	900	600
	43	45	15	1849	2025	225	675	1935	645
	40	30	15	1600	900	225	450	1200	600
	49	40	10	2401	1600	100	400	1960	490
	45	30	10	2025	900	100	300	1350	450
	48	45	20	2304	2025	400	900	2160	960
	51	41	20	2601	1681	400	820	2091	1020
	45	30	15	2025	900	225	450	1350	675
	30	30	30	900	900	900	900	900	900
	30	40	30	900	1600	900	1200	1200	900
	38	35	17	1444	1225	289	595	1330	646
	38	40	15	1444	1600	225	600	1520	570
	51	35	0	2601	1225	0	0	1785	0
	45	40	10	2025	1600	100	400	1800	450
Sum	679	601	237	29635	23181	4589	8690	25821	9366
Average	42.44	37.56	14.81						
		$(\Sigma v_i)^2$	$(\Sigma u_{1i})^2$	$(\Sigma u_{2i})^2$	$(\Sigma(u_{1i} * u_{2i}))$	$(\Sigma(u_{1i} * v_i))$	$(\Sigma(u_{2i} * v_i))$		
		819.94	605.94	1078.44	-212.31	316.06	-691.69		
	Coefficient	b_1	0.32	t test					
	Coefficient	b_2	-0.58		s^2_E	886.73			
		R^2	0.61	elements	c_{11}	0.0018			
	MCC	R	0.78	inverse	c_{12}	-0.0003			
				matrix	c_{22}	0.0009			
				Variance of $b_1 = s_{b1}$ =		1.25	Variance of $b_2 = s_{b2}$ =		0.91
				test statistic t =		0.25	test statistic t =		-0.46

MCC (multiple correlation coefficient) is close to 1 and shows that the linear regression equation is a good fit and t value at 13d.f. and 5% significance level is 2.106 is greater than calculated value of 0.25 and -2.106 is less than the calculated valueof -0.46, the physical interpretation is that a unit increase in degree of lateness/earliness does not affect arrival % significantly

Regression Equation =	Y = (Yavg + b1 (x1 +x1avg) + b2 (x2 – x2avg)	
	Y= 39.01 - 0.58*Earliness +0.32 Lateness	Equation 2

Table J. Difference between arrival percentage for different peaks for high frequency service

	First Interval Morning vs. Off Peak				Second interval Morning vs. Off Peak				First Interval Morning vs. Evening				Second interval Morning vs. Evening			
	x_1	x_2	$(x_1)^2$	$(x_{2-})^2$	x_1	x_2	$(x_1)^2$	$(x_{2-})^2$	x_1	x_2	$(x_1)^2$	$(x_{2-})^2$	x_1	x_2	$(x_1)^2$	$(x_{2-})^2$
	35	44	1225	1936	65	56	4225	3136	35	36	1225	1296	65	64	4225	4096
	42	55	1764	3025	58	45	3364	2025	42	52	1764	2704	58	48	3364	2304
	36	30	1296	900	63	70	3969	4900	36	45	1296	2025	63	55	3969	3025
	50	34	2500	1156	50	66	2500	4356	50	60	2500	3600	50	40	2500	1600
	33	52	1089	2704	67	48	4489	2304	33		1089	0	67		4489	0
Sum	196	215	7874	9721	303	285	18547	16721	196	193	7874	9625	303	207	18547	11025
Avg	39.2	43			60.6	57			39.2	48.3			60.6	51.8		
	s_1^2	47.7	9.54			46.3	9.26			47.7	9.54			46.3	9.26	
	s_2^2	119	23.8			119	23.8			104	26.0625			104	26.0625	
	t	-0.6581	t*	2.776		0.6261	t*	2.776	t	-1.64	t*	3.09		1.61	t*	3.09214

In all cases the absolute calculated value of t is less than the table value, t* which shows that there is no significant difference between the two sample population at 5% significance level

Table K. Difference between arrival profiles for two 5 minutes intervals in high frequency service

	1st	2nd	Diff	$(Diff)^2$
	33	67	34	1156
	52	48	-4	16
	36	63	27	729
	50	50	0	0
	33	67	34	1156
	44	56	12	144
	55	45	-10	100
	45	55	10	100
	44	56	12	144
	52	48	-4	16
	36	64	28	784
	52	48	-4	16
	45	55	10	100
	60	40	-20	400
Sum			125	4861
Avg			8.928571	
	sd^2	288.071		
	sd	16.9727		
	t	1.96832		

Value of t calculated is less than table value of 2.16, therefore there is no significant difference at 5% significance level

Table L. Expected arrival percentage in each interval for high frequency

	1st	2nd	$(1^{st})^2$	$(2^{nd})^2$
	33	67	1089	4489
	52	48	2704	2304
	36	63	1296	3969
	50	50	2500	2500
	33	67	1089	4489
	44	56	1936	3136
	55	45	3025	2025
	45	55	2025	3025
	44	56	1936	3136
	52	48	2704	2304
	36	64	1296	4096
	52	48	2704	2304
	45	55	2025	3025
	60	40	3600	1600
Sum	637	762	29929	42402
Avg	45.5	54.4286	2137.8	3028.7
		s^2	73	71.3
		s	8.5	8.4
		t	-2.0	2.0

Calculated value of t is less than the table value of t (2.16)at 5% significance level and 13 d.f. which means that the expected arrival percentage for both intervals is 50%

Table M. Random Arrivals, 10 minute frequency service

Arrival %		OF		Prob	Exp	Z
0 to10	1	0	0	0.0044	0.132	0.132
11to 20	2	0	0	0.0239	0.7168	0.71676
21to 30	3	1	3	0.0649	1.946	0.45988
31to 40	4	7	28	0.1174	3.5223	3.43376
41to 50	5	8	40	0.1594	4.7815	2.16646
51to 60	6	7	42	0.1731	5.1927	0.62904
61to 70	7	6	42	0.1566	4.6994	0.35997
71to 80	8	1	8	0.1215	3.6454	1.9197
81to 90	9	0	0	0.0825	2.4743	2.4743
91 to100	10	0	0	0.0498	1.4928	1.49283
Sum		30	163			13.7847
Avg			5.43333			

As the calculated value is less than Chi square value at 8 deg.freedom (15.51), the arrivals fits a Poissons distribution

Table N. arrival percentage in the last 5 minutes with punctuality for different periods of day(low Frequency)

Morning

arrival	%late	%early							
Y	x1	x2-	Y2	(x1)2	(x2)2	(x1* x2)	(Y* x1)	(Y* x2)	
50	40	0	2500	1600	0	0	2000	0	
49	30	0	2401	900	0	0	1470	0	
45	10	7	2025	100	49	70	450	315	
48	30	14	2304	900	196	420	1440	672	
38	15	7	1444	225	49	105	570	266	
38	20	7	1444	400	49	140	760	266	
43	30	8	1849	900	64	240	1290	344	
40	20	10	1600	400	100	200	800	400	
30	20	21	900	400	441	420	600	630	
381	215	74	16467	5825	948	1595	9380	2893	
42.33	23.89	8.22							
	$(\Sigma v_i)^2$	$(\Sigma u_{1i})^2$	$(\Sigma u_{2i})^2$	$(\Sigma(u_{1i} * u_{2i}))$	$(\Sigma(u_{1i} * v_i)$	$(\Sigma(u_{2i} * v_i))$			
	338.0	688.9	339.6	-172.8	278.3	-239.7			

Coeff	b_1	0.3	t test				
Coeff	b_2	-0.57		s^2_E	1040.5		
	R^2	0.62	elements	c_{11}	0.002		
MCC	R	0.79	inverse	c_{12}	-0.001		
			matrix	c_{22}	0.003		
			Variance of $b_1 = s_{b1}$ =		1.32	Variance of $b_2 = s_{b2}$ =	1.75
			test statistic t =		0.20	test statistic t =	-0.44

Off Peak

arrival	%late	%early							
Y	x1	x2-	Y2	(x1)2	(x2)2	(x1* x	(Y* x1)	(Y* x2)	
46	30	0	2116	900	0	0	1380	0	
30	16	13	900	256	169	208	480	390	
51	47	13	2601	2209	169	611	2397	663	
45	13	12	2025	169	144	156	585	540	
30	23	27	900	529	729	621	690	810	
51	30	0	2601	900	0	0	1530	0	
45	20	0	2025	400	0	0	900	0	
298	179	65	13168	5363	1211	1596	7962	2403	
42.571	25.571	9.2857							
	$(\Sigma v_i)^2$	$(\Sigma u_{1i})^2$	$(\Sigma u_{2i})^2$	$(\Sigma(u_{1i} * u_{2i}))$	$(\Sigma(u_{1i} * v_i$	$(\Sigma(u_{2i} * v_i))$			
	481.71	785.71	607.429	-66.1	341.7	-364.1			

Coeff	b_1	0.39	t test				
Coeff	b_2	-0.56		s^2_E	999.23		
	R^2	0.70	elements	c_{11}	0.001		
MCC	R	0.83	inverse	c_{12}	0.000		
			matrix	c_{22}	0.0016		
			Variance of $b_1 = s_{b1}$ =		1.13	Variance of $b_2 = s_{b2}$ =	1.28
			test statistic t =		0.34	test statistic t =	-0.49

MCC (multiple correlation coefficient) is close to 1 and shows that the linear regression equation is a good fit. The physical interpretation of t values is that a unit increase in degree of lateness/earliness does not make a significant change in arrival %

Regression Y = (Yavg + b1 (x1 +x1avg) + b2 (x2 – x2avg)	Regression Y = (Yavg + b1 (x1 +x1avg) + b2 (x2 – x2avg)
Y= 39.8 - 0.57*Earliness +0.30 Lateness Equation 3	Y= 37.8 - 0.56*Earliness +0.39 Lateness Equation 4

Table O. Difference in arrival profile within day for low frequency service

Equation		3	4			1			2			5	6		
Earline	Latenes	Mor	Off	Diff	$(Diff)^2$	overall	Diff	$(Diff)^2$	perce	Diff	$(Diff)^2$	OP	PP	Diff	$(Diff)^2$
20	0	28.4	26.6	1.8	3.24	28.07	0.33	0.1089	27.4	1.0	1.0	24.5	23.6	-0.9	0.8
20	10	31.4	30.5	0.9	0.81	31.37	0.03	0.0009	30.6	0.8	0.6	25.8	25.7	-0.1	0.0
20	20	34.4	34.4	0	0	34.67	-0.27	0.0729	33.8	0.6	0.3	27.1	27.8	0.7	0.5
20	30	37.4	38.3	-0.9	0.81	37.97	-0.57	0.3249	37.0	0.4	0.2	28.4	29.9	1.5	2.3
20	40	40.4	42.2	-1.8	3.24	41.27	-0.87	0.7569	40.2	0.2	0.0	29.7	32.0	2.3	5.3
20	50	43.4	46.1	-2.7	7.29	44.57	-1.17	1.3689	43.4	0.0	0.0	31.0	34.1	3.1	9.6
20	60	46.4	50	-3.6	12.96	47.87	-1.47	2.1609	46.6	-0.2	0.0	32.3	36.2	3.9	15.2
			Sum	-6.3	28.35	Sum	-3.99	4.7943	Sum	2.73	2.18		Sum	10.5	33.7
			Avg	-0.9		Avg	-0.57		Avg	0.39			Avg	1.5	
			sd^2		3.78	sd^2		0.42	sd^2		0.19		sd^2		2.99
			sd		1.944222	sd		0.6481	sd		0.43		sd		1.73
			t		-1.22	t		-2.33	t		2.39		t		2.30

Value of t calculated is more than table value of - 2.447 or less than 2.447,there is no significant difference at 5% significance level between the values calculated using equation, 1,2,3 and 4 and between equation 5 and 6

Table P. Difference between arrival percentage for 15 minutes frequency service between the last two intervals

	1st	2nd		
	x	y	Diff	$(Diff)^2$
	46	50	4	16
	24	30	6	36
	38	46	8	64
	31	40	9	81
	28	46	18	324
	40	40	0	0
Sum			45	521
Avg			7.5	
	sd^2	36.7		
	sd	6.058052		
	t	3.03		

Value of t calculated is more than table value of 2.57, therefore there is no significant difference at 5% significance level

Table Q, Difference between arrival percentage for 20 minutes frequency service between the last two intervals

First and Second Interval

	x	y	Diff	$(Diff)^2$
	35	49	14	196
	36	45	9	81
	32	48	16	256
	35	51	16	256
	40	45	5	25
	30	30	0	0
	30	30	0	0
Sum			60	814
Avg			8.57143	
		sd^2	49.9524	
		sd	7.0677	
		t	3.21	

Third and second Interval

	x	y	Diff	$(Diff)^2$
	16	35	19	361
	17	36	19	361
	17	32	15	225
	9	35	26	676
	15	40	25	625
	34	30	-4	16
	32	30	-2	4
Sum			98	2268
Avg			14	
		sd^2	149.33	
		sd	12.22	
		t	3.03	

Value of t calculated is more than table value of 2.447, for both cases, therefore there is no significant difference at 5% significance level

Table R Multiple regression analysis, Low frequency between observed punctuality factors and arrival %

	arriva	%late	%early						
	Y	x1	x2-	Y2	(x1)2	(x2)2	(x1* x2)	(Y* x1)	(Y* x2)
	46	40	0	2116	1600	0	0	1840	0
	38	30	0	1444	900	0	0	1140	0
	24	16	13	576	256	169	208	384	312
	34	30	8	1156	900	64	240	1020	272
	30	20	10	900	400	100	200	600	300
	35	30	0	1225	900	0	0	1050	0
	36	10	7	1296	100	49	70	360	252
	32	30	14	1024	900	196	420	960	448
	35	47	13	1225	2209	169	611	1645	455
	40	13	12	1600	169	144	156	520	480
	30	23	27	900	529	729	621	690	810
	30	20	21	900	400	441	420	600	630
	36	15	7	1296	225	49	105	540	252
	33	20	7	1089	400	49	140	660	231
	36	30	0	1296	900	0	0	1080	0
	32	20	0	1024	400	0	0	640	0
Sum	547	394	139	19067	11188	2159	3191	13729	4442
Average	34.19	24.6	8.69						
		$(\Sigma v_i)^2$	$(\Sigma u_{1i})^2$	$(\Sigma u_{2i})^2$	$(\Sigma(u_{1i}* u_{2i}$	$(\Sigma(u_{1i} *v_i)$	$(\Sigma(u_{2i} *v_i))$		
		366	1486	951	-231.88	259.13	-310.1		
	Coeffic	b_1	0.13	t test					
	Coeffic	b_2	-0.3		s^2_E	542.68			
		R^2	0.63	elements of	c_{11}	0.001			
	MCC	R	0.79	inverse	c_{12}	0.000			
				matrix	c_{22}	0.001			
				Variance of $b_1 = s_{b1}$ =		0.62	Variance of $b_2 = s_{b2}$ =		0.76
				test statistic t =		0.21	test statistic t =		-0.48

MCC (multiple correlation coefficient) is close to 1 and shows that the linear regression equation is a good fit and t value at 13d.f. and 5% significance level is 2.106 is greater than calculated value of 0.79 and -2.106 is less than the calculated value of -0.48, the physical interpretation is that a unit increase in degree of lateness or earliness does not make a significant change in arrival precentage.

Regression Equation = Y = (Yavg + b1 (x1 +x1avg) + b2 (x2 – x2avg)
Y= 33.5 - 0.30*Earliness +0.13 Lateness Equation 5

Table S Multiple regression analysis, Low frequency between perceived punctuality factors and arrival %

arriva	%late	%early						
Y	x1	x2-	Y2	(x1)2	(x2)2	(x1* x2)	(Y* x1)	(Y* x2)
46	50	0	2116	2500	0	0	2300	0
38	40	10	1444	1600	100	400	1520	380
24	30	20	576	900	400	600	720	480
34	45	15	1156	2025	225	675	1530	510
30	30	15	900	900	225	450	900	450
35	40	10	1225	1600	100	400	1400	350
36	30	10	1296	900	100	300	1080	360
32	45	20	1024	2025	400	900	1440	640
35	41	20	1225	1681	400	820	1435	700
40	30	15	1600	900	225	450	1200	600
30	30	30	900	900	900	900	900	900
30	40	30	900	1600	900	1200	1200	900
36	35	17	1296	1225	289	595	1260	612
33	40	15	1089	1600	225	600	1320	495
36	35	0	1296	1225	0	0	1260	0
32	40	10	1024	1600	100	400	1280	320
547	601	237	19067	23181	4589	8690	20745	7697
34.188	37.563	14.8125						
	$(\Sigma v_i)^2$	$(\Sigma u_{1i})^2$	$(\Sigma u_{2i})^2$	$(\Sigma(u_{1i}* u_{2i}$	$(\Sigma(u_{1i} *v_i)$	$(\Sigma(u_{2i} *v_i))$		
	366	606	1078	-212	198	-405		
Coeffic	b_1	0.21	t test					
Coeffic	b_2	-0.33		s^2_E	756.99			
	R^2	0.48	elements of	c_{11}	0.0018			
MCC	R	0.70	inverse	c_{12}	0.000			
			matrix	c_{22}	0.0009			
			Variance of $b_1 = s_{b1}$ =		1.16	Variance of $b_2 = s_{b2}$ =		0.84
			test statistic t =		0.18	test statistic t =		-0.29

MCC (multiple correlation coefficient) is close to 1 and shows that the linear regression equation is a good fit and t value at 13d.f. and 5% significance level is 2.106 is greater than calculated value of 0.84 and -2.106 is less than the calculated value of -0.29, the physical interpretation is that a unit increase in degree of lateness or earliness does not make a significant change in arrival precentage.

Regression Equation = Y = (Yavg + b1 (x1 +x1avg) + b2 (x2 – x2avg)
Y= 31.2 - 0.33*Earliness +0.21 Lateness Equation 6

Table T Difference between calculated and observed arrival percentage with same punctuality

First interval

obs	cal	Diff	(Diff)2
4	9	5	25
16	14	-2	4
46	31	-15	225
23	20	-3	9
30	27	-3	9
16	14	-2	4
19	24	5	25
20	17	-3	9
14	9	-5	25
15	24	9	81
40	23	-17	289
40	24	-16	256
26	22	-4	16
29	20	-9	81
13	14	1	1
23	18	-5	25
	d sum	-64	1084
	davg	-4	
	sd2	55.2	
	sd	7.43	
	t	-2.0	

Second interval

obs	cal	Diff	(Diff)2
46	39	-7	49
38	37	-1	1
30	32	2	4
34	35	1	1
30	33	3	9
35	37	2	4
36	37	1	1
35	42	7	49
38	44	6	36
40	39	-1	1
45	45	0	0
30	42	12	144
36	38	2	4
33	38	5	25
36	37	1	1
32	36	4	16
	d sum	37	345
	davg	2.31	
	sd2	17.30	
	sd	4.16	
	t	2.08	

Third interval

obs	cal	Diff	(Diff)2
50	52	2	4
46	49	3	9
30	37	7	49
43	45	2	4
40	40	0	0
49	49	0	0
45	39	-6	36
48	41	-7	49
51	47	-4	16
45	37	-8	64
30	32	2	4
30	34	4	16
38	40	2	4
38	42	4	16
51	49	-2	4
45	46	1	1
	d sum	0	276
	davg	0	
	sd2	18.4	
	sd	4.2895	
	t	0.00	

For all three case the table value of t at 5% significance level 2.2 is more than calculated value and therefore there is no significant difference between the two values

Table U, Relation between observed (O) and perceived (P) Punctuality

P	O	Diff	(Diff)2
40	40	0	0
45	50	5	25
60	64	4	16
35	50	15	225
50	60	10	100
50	50	0	0
50	71	21	441
60	53	-7	49
59	33	-26	676
35	67	32	1024
70	57	-13	169
50	80	30	900
55	65	10	100
50	60	10	100
40	50	10	100
50	60	10	100
87	100	13	169
90	100	10	100
80	87	7	49
85	92	7	49
85	90	5	25
100	100	0	0
85	93	8	64
75	86	11	121
80	87	7	49
85	88	3	9
65	73	8	64
70	79	9	81
83	93	10	100
85	100	15	225
90	100	10	100
100	100	0	0
	d su	123	1205
	davg	3.84	
	sd2	23.62	
	sd	4.86	
	t	4.3	

As table value of t at 5% significance level 2.0, is less than calculated value the perceived value is significantly lower than the observed value

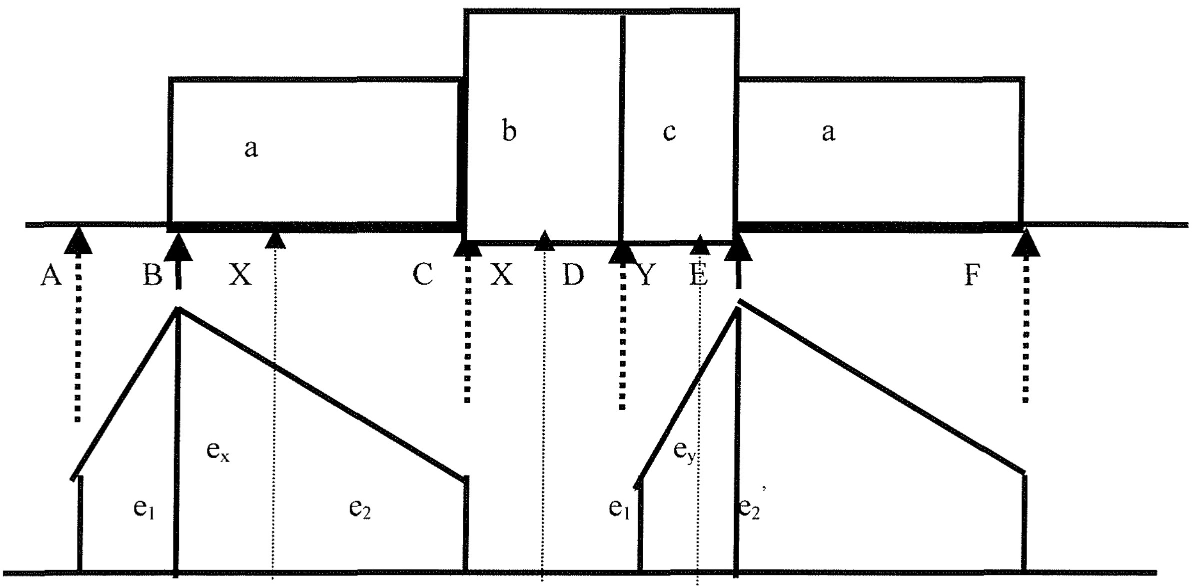
APPENDIX C

Calculation of Average Waiting Time at bus stops

Average waiting time (AWT) for 10 minutes frequency services:

Case I. When all the buses are on time.

Passenger arrival profile:



Vehicle departure profile

Here,

B = Scheduled departure time for the first bus.

AB = 1 minute

BC = 5 minutes (first interval)

E = Scheduled departure time for the second bus.

CE = 5 minutes (Second Interval)

DE = 1 minute

EF = 5 minutes

The expected passenger arrival profile is shown (top portion of the figure 6.18) for a 10 minutes frequency service, a uniform arrival rate is shown as there was no difference in arrival percentage for the first and second 5 minutes interval (as show in section 6.7.2.1).

The first bus can depart at 'A', 1 minute before scheduled time 'B' or depart at point 'C', +5 minutes from scheduled time and the second bus can depart at 'D', 1 minute before scheduled time or depart at point 'F', +5 minutes from scheduled time 'E' when the bus is assumed to be punctual.

'a', 'b' and 'c' are proportion of passengers arriving (assumed uniform arrival) within the time intervals BC, CD and DE respectively. That is (a + b + c) is the total passengers arriving between the scheduled time 'B' and 'E'. 'a' is the proportion of passengers arriving in the first 5 minutes interval.

From the vehicle departure probability distribution:
When the bus service is 'punctual' then, according to figure 6.17, if 2 buses depart at 'A' then 7 buses would depart at point 'B' and 2 buses would depart at point 'C'.

Therefore,
If 'e_1' (the area of the trapezium between point A and B) represents the probability of the first bus departing between 'A' and 'B'
'e_2' (area of the trapezium between point B and C) represents the probability of the first bus departing between 'B' and 'C'

Similarly the probability of the second vehicle departing between DE and EF, e_1' and e_2' respectively will be same as e_1 and e_2.

The probability of vehicles departing within time interval 'A' to 'B' $=e_1/(e_1+e_2)$

$=\{1/2\,(2+7)*1\} \,/\, [(\{1/2\,(2+7)*1\} + \{1/2\,(2+7)*5\}]$

$= 1/6$

The probability of vehicles departing within time interval B to C

$=e_2/(e_1+e_2)$

$= 5/6$

Average waiting time (AWT) for passengers (a) arriving in the first 5 minutes interval:

<u>For 1/6^th^ of the time</u>

The probability of the first bus departing between A and B is 1/6, therefore for $1/6^{th}$ of the time the waiting time for passengers arriving in the first 5 minutes interval 'a' will depend on the departure time of second bus, which can depart between DF.

Passengers arriving at any point X between B and C will miss the first bus and the waiting time will be:

= BC +CD + Distance from point D to the cg (centre of gravity for area ($e_1' + e_2'$) for second bus) - X

As it varies from 0 to 5,

Total time = $\int_0^5$ (BC +CD + cg – X) dx

= $\int_0^5$ (5 + 4 + 2.63 – X) dx

AWT = 9.13 ....Case 1

<u>For 5/6th of the time</u>

The probability of the first bus departing between B and C is 5/6, therefore for 5/6th of the time the waiting time for passengers arriving in the first 5 minutes interval 'a' will depend on both the first bus and the second bus as:

Any passenger arriving at any point X between B and C will have a probability of ($e_2 - e_x$)/e_2 (Probability of bus departing after point X) of boarding the first bus and the waiting time will be:

= cg of area ($e_2 - e_x$) from point X, where 'e_x' is the area of trapezium between BX

However the probability of the passenger missing the bus = e_x/e_2 (probability of bus departing before point X) and the waiting time will be:

= XC + CD + cg of area ($e_1' + e_2'$) from point D ($e_1' = e_1$ and $e_2' = e_2$)

Therefore the waiting time for a passenger arriving at point X will be:

= ($e_2 - e_x$)/e_2 * cg of area ($e_2 - e_x$) from point X + (e_x/e_2) * (XC + CD + cg of area ($e_1' + e_2'$) from point D)

As X varies from 0 to 5

Total waiting time for passengers arriving between B and C will be:

= $\int_0^5$ { ($e_2 - e_x$)/e_2 * cg of area ($e_2 - e_x$) from point X } + { (e_x/e_2) * (XC + CD + cg of area ($e_1' + e_2'$) from point D) }

= $\int_0^5$ {[{(½ (7 - X + 2) * (5 - X)} / ½ (7 + 2)*5] * {(2*2 + 7- X)(5 – X)/ (3 *(7 - X +

2)}} + {{ (½ (7 + 7 - X)) * X) / (½ (7 + 2)*5)} * {(5 – X) + 4 + 2.63)}}

= 23.52

Average waiting time will therefore be:

= 1/5 * total waiting time

= 27.98/5

= 5.60 ....Case 2

Therefore AWT for 'a'

= 1/6th of case 1 and 5/6th of case 2

= 1/6 * 9.13 + 5/6 * 5.6

AWT = 6.19 ....Case 3

Average waiting time (AWT) for passengers (b) arriving between CD:

For any passenger arriving at any point 'X^1' between 'C' and 'D' will miss the first bus. The waiting time will depend on the departure time of the second bus and will be:

CD - X^1 + cg of area ($e_1 + e_2$) from point D

As X^1 varies from 0 to 4

Total time = $\int_0^4$ (CD – X^1 + cg of area ($e_1' + e_2'$) from point D) dx^1

= $\int_0^4 (4 + 2.63 - X^1)\, dx^1$

= 18.52

Average waiting time will therefore be:

= 1/4 * total waiting time

= 18.52/4

= 4.63 .... Case 4

Average waiting time (AWT) for passengers (c) arriving between DE:

Any passenger arriving at any point 'Y' between DE will miss the first bus and the waiting time will depend on the departure time of second and the third bus.

As the bus arrival probability distribution is same, for 5/6th of the time the second bus will arrive between EF,

The probability of any passenger arriving at point 'Y' from D boarding the second bus is 5/6 and the waiting time will be:

= DE – Y + cg of area e_2' from point E and as 'Y' varies from 0 to 1,

Total time = $\int_0^1$ (DE – Y + cg of area e_2' from point E) dy

$= \int^1_0 ((1 - Y) + 2.04)\ dy$

$= \int^1_0 (3.04 - Y)\ dy$

$= 2.54$

AWT $= 2.54$ .... Case 5

For 1/6th of the time second bus will arrive between D and E.

Part of the waiting time will depend on the arrival time of second bus and other part on the arrival time of the third bus (same as case 2) as:

Any passenger arriving at any point 'Y' between DE will have a probability of $(e_1' - e_y)/e_1'$ (probability of bus arriving after point 'Y') of boarding the second bus and waiting time will be: = cg of area $(e_1' - e_y)$ from point Y ('e_y' = area of trapezium between point 'D' and 'Y')

However the probability of passenger missing the bus = e_y/e_1' (probability of bus arriving before point Y) and the waiting time will depend on the arrival time of the third bus (assume it arrives between GI (equivalent to DF) and arrival distribution will be same as along the time interval DF. The waiting time will then be:

= DE -Y + EF +FG + cg of area $(e_1' + e_2')$ from point G

Therefore the waiting time for a passenger arriving at point Y will be:

= $(e_1' - e_y)/e_1'$* cg of area $(e_1' - e_y)$ from point Y + (e_y/e_1') * (YE + EF +FG + cg of area $(e_1' + e_2')$ from point G)

As 'Y' varies from 0 to 1

Total waiting time for passengers arriving between 'D' and 'E' (proportion c) will be:

= $\int^1_0 \{(e_1' - e_y)/e_1'$* cg of area $(e_1' - e_y)$ from point Y$\} + \{(e_y/e_1')$ * (YE + EF +FG + cg of area $(e_1' + e_2')$ from point G)$\}$ dy

$= \int^1_0 \left[\left\{\left[\{½ (7 + 2 + 5Y) * (1-Y)\} / ½ (7 + 2)\right] * \{(2*7 + 2 + 5Y)(1 - 5)/ (3 *(7 + 5Y + 2))\}\right\} + \left\{\{½ (7 - 5Y + 2) * Y) / (½ (7 + 2)\} * \{(1 - Y) + 5 + 4 + 2.63)\}\right\}\right] dy$

$= 4.91$

AWT $= 4.02$ .... Case 6

Therefore for 'c' AWT

= 5/6th of case 5 and 1/6th of case 6

$= 5/6 * 2.54 + 1/6 * 4.91$

= 2.98 **……………………Case 7**

AWT for whole assuming uniform passenger arrival over the whole period will be:

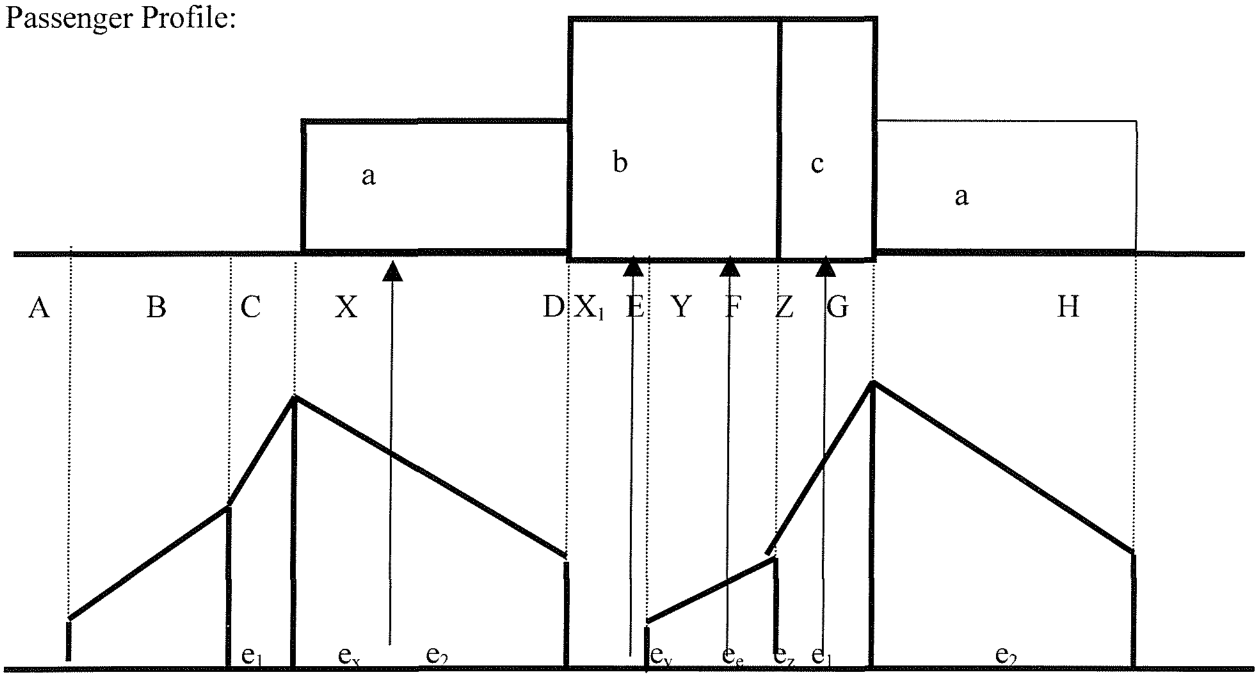
= (BC * case 3 + CD * case 4 + DE * case 7)/ BE

= (5 * 6.19 + 4 * 4.63 + 2.98)/10

= 5.25 minutes

Case II. When 10% of buses are early.

Passenger Profile:



Vehicle departure distribution

Here,

C = Scheduled departure time for the first bus,
AB = 3 minutes (buses depart within this time interval when they depart early)
BC = 1 minute
CD = 5 minutes (first interval)
DG = 5 minutes (second interval)
EF = 3 minutes
G = Scheduled departure time for the second bus
FG = 1 minutes

Buses depart between BD and FG when on time and depart between AB and DF when early.

Average waiting time (AWT) for passengers (a) arriving in the first 5 minutes interval:

90% of the time when the first bus depart on time

For 1/6th of the time when the first bus depart between BC wait time depends on the departure time of the second bus, which for 90% of time will depart on time.

AWT for this case will be same as case 1, = 9.13

For 10% of time when second bus is early, i.e., departs between DE, the wait time for any passenger arriving at point X from C will be:

= CD –X + DE + cg of area e_e from point E

= 5+1+1.91 – X

AWT = $1/5 \int_0^5 (7.91 - X)\, dx$

= 5.41 .... Case 10

AWT for 1/6th of time when the first bus is on time

= 10% of 5.41 + 90% of 9.13

= 8.76 .... Case 11

<u>For 5/6th of the time</u> (when the first bus departs between CD),

90% of the time when the second bus is on time the waiting time will depend on the arrival time of the first bus and on the arrival time of the second bus as in case 2: = 5.60

10% of the time when the second bus is early the wait time for any passenger arriving at point X will be:

= $(e_2 - e_x)/e_2$ * cg of area $(e_2 - e_x)$ from point X + (e_x/e_2) * (DE + cg of area e_e from pt. E)

As X varies from 0 to 5 the total waiting time for passengers arriving between CD will be:

$$= \int_0^5 \Big\{ \Big[\{(½ (7 - X + 2) * (5 - X)\} / ½ (7 + 2)*5 \Big] * \{(2*2 + 7- X)(5 - X)/ (3 *(7 - X + 2)\} \Big\} + \Big\{ \{ (½ (7 + 7 - X)) * X) / (½ (7 + 2)*5)\} * \{(5 - X) + 1 + 1.9\} \Big\}$$

=16.95

Average waiting time will therefore be

= 3.39 ....Case 12

AWT = 90% of case 2 and 10% of case 12

= 0.9 * 5.6 + 0.1 * 3.39

= 5.38 ....Case 13

Therefore for 90% of the time when the first bus is on time AWT for 'a' will be:

= 1/6 * case 11 + 5/6 * case 13

= 5.94 ....Case 14

For 10% of the time the first bus departs early, i.e., it departs between A and B

AWT for 'a' will be determined by the arrival time of second bus which,

For 90% time will arrive between FH, therefore AWT will be same as case 1,

= 9.13

For 10% of time second bus will arrive between EF the waiting time for any passenger arriving at point X will be:

= CD + DE + cg of area e_e from point E – X

Total time = $\int_0^5 (5 + 1 + 1.91 - X)\, dx$

AWT = 5.41 ....Case 15

Therefore for 10 % when the first bus is early AWT for 'a' will be:

= 90% of case 1 and 10% of case 15

= 8.76 .... Case 16

AWT for 'a' will therefore be:

= 90% of case 14 and 10% of case 16

= 6.22 .... Case 17

Average waiting time (AWT) for passengers (b) arriving between DF:

When 90% of the time the first bus arrives on time, i.e., between B and C or 10% early i.e., arriving between A and B,

The waiting time for any passenger arriving at X_1 depends on the arrival time of the second bus and third bus, which for 90% of time will be on time and so AWT will be same as case 4 = 4.63

When the second bus is early, for 10%, of the time the AWT will depend on the arrival time of second and the third bus.

For passenger arriving between DE, or 1/4th (DE/DF) proportion of the passengers the waiting time will depend solely on the arrival of second bus, which will arrive between EF.

For any passenger arriving at point X_1 from D the waiting time will be:

= DE + cg of area e_e from point E – X_1

AWT = $1/1 \int_0^1 (1 + 1.91 - X_1)\, dx_1$

= 2.41 .... Case 18

For passenger arriving between EF, or 3/4th proportion of the passenger the waiting time will depend on arrival time of second and third bus.

Any passenger arriving at any point Y between E and F will have a probability of (e_{e} –

e_y)/e_e (Probability of bus departing after point Y) of boarding the first bus and the waiting time will be:

= cg of area ($e_e - e_y$) from point Y, where 'e_y' is the area of trapezium between YF and 'e_e' is the area of trapezium between EF

Total waiting time $= \int^3_0 \{(e_e - e_y / e_e)^* \text{ cg of } e_e - e_y\}$

$= \{½ (0.2 + 0.6Y + 2)(3 - Y)\} / \{½ (0.2 + 2) *3\} * \{2*(2 + 0.2 + 0.6Y)(3-Y)\} / \{3 (0.2 + 0.6Y + 2)\}$

= 2.11 ....Case 19

However the probability of the passenger missing the bus = e_y/e_e (probability of bus departing before point Y) and the waiting time will depend on the departure of the third bus:

For 90% of the time the third bus will be on time, i.e., between KM (same as FG and BD). The waiting time will be:

= YF+ FG + GH + HI + cg of area (e_1+ e_2) from point J

Total $= \int^3_0 \{e_y/e_e$ * (YF+ FG + GH + HI + IJ+ cg of area ($e_1 + e_2$) from point J)$\}dy$

$= \int^3_0 [\{½ (0.2 + 0.6Y + 0.2)(3 - Y)\} / \{½ (0.2 + 2) *3\} * \{(3-Y) + 1 + 5 + 1 + 3 + 2.63)\}]dy$

= 14.66 .... Case 20

For 10 % of the time the third bus will be early, i.e., bus arrives between JK (same as EF)

Wait time will be:

= YF+ FG + GH + HI + cg of area e_e from point I

Total $= \int^3_0 \{e_y/ e_e$ * (EF+ FG + GH + HI + cg of area e_e from point I)$\}dy$

$= \int^3_0 [\{½ (0.2 + 0.6Y + 0.2)(3 - Y\} / \{½ (0.2 + 2) *3\} * \{(3-Y) + 1 + 5 + 1 + 1.91)\}]dy$

= 10.6 .... Case 21

Total for 3/4th proportion = case 19+ 90% of case 20 and 10 % of case 21

= 2.11 + 90% * 14.66 + 10% * 10.6

= 16.36

AWT = 1/3*16.36 = 5.45 ....Case 22

AWT for 10% time = 3/4th of case 22 and 1/4th of case 18

= ¾ * 5.45 + ¼ * 2.41

= 4.69 ....Case 23

AWT for proportion 'b' = 90% of case 4 and 10 % of case 23

= 0.9 * 4.63 + 0.1 * 4.69

= 4.64 .... Case 24

Average waiting time (AWT) for passengers (c) arriving between FG:

Irrespective of the departure time of the first the waiting time for 'c' will always depend on second and third bus. For 90% of the time the second bus will depart on time (between FH), therefore the waiting time for 5/6th time when second bus is between GH the AWT will be same as case 5

= 2.54

For 1/6th of the time, the bus will depart between FG and the waiting time will depend on the second and the third bus departure times.

For 90% of time when third bus is on time the waiting time will be same as case 6

= 4.02

However for 10% of time when third bus is early the waiting time will be:

$= \int_0^1 \Big[\Big\{ (e_1 - e_z)/e_1 * \text{cg of area } (e_1 - e_z) \text{ from point Z}\Big\} + \Big\{ (e_z/e_1) * (\text{ZG + GH + HI + cg of area } e_e \text{ from point I})\Big\}\Big]dz$

$= 0.24 + \int_0^1 Z\,(9 + 5Z)/9 * (8.91 - Z)dz$

= 0.24 + 5.67 = 5.91 .... Case 25

For 1/6th time AWT will be:

= 0.9* case 6 + 0.1 * case 25

= 4.21 .... Case 26

For 90% of time when the second bus is on time, AWT will be:

= 5/6th of case 5 + 1/6th of case 26

= 2.82 .... Case 27

For 10% of time the second bus will arrive early or between EF

The waiting time will depend on the arrival time of the third bus, which for 90% of the time will be on time and therefore the waiting time for passenger arriving at any point X from F will be:

= FG + GH + HJ (same as DF) + cg of area (e_1+ e_2) – X

= 12.03 ....Case 28

10 % of time the third bus will be early and therefore the waiting time for passenger arriving at any point X from F will be:

= FG + GH + HI (same as DE) + cg of area e_e – X

= 1 + 5 + 1 + 1.91 – X

= 8.41 ....Case 29

Therefore AWT for 10% time will be:

= 0.9* case 27 + 0.1 * case 29

= 11.67 ....Case 30

Waiting time for 'c' will therefore be:

= 10 % of case 30 and 90% of case 27

= 0.1 * 11.67 + 0.9 * 2.82

= 3.70 ....Case 31

Average waiting time for a uniform passenger arrival profile:

= (CD *case 17 + DF * case 23 + FG * case 32)/CG

= (5* 6.22 + 4* 4.64 + 3.70)/10

= 5.34 minutes

Using the same logic the average time for 10% late scenario, and 10% late and 10% early scenario for all the frequency services were calculated. Entering all the cases (for example, from case 1 to 31 calculated above) in an excel spreadsheet the waiting time can be calculated for varying degree of lateness and earliness. This technique was used to calculate the values required for figures 6.17 to 6.22 in the main text.

Glossary

This Glossary includes common terms with reference to their interest for this research.

Arrival profile:

Passenger arrival profile – Distribution of passenger arriving at a bus stop over a fixed time period.

Bus arrival profile - Distribution of buses departing from a bus stop over a fixed time period.

Assignment - Assigning of trips (public and private) to their corresponding networks.

Bus lane – Segregated road space, which can be used by buses only (cycles and taxis are generally allowed to use such spaces).

Bus priority – Any activity, which assist bus service by reducing congestion, improving flow or decreasing junction delays along a bus route.

Bus service - The bus line, which runs along a route

Degree of earliness - Proportion of a service that is early at a bus stop over a fixed period of time. Buses are termed early if they depart 1 minute earlier then the scheduled time from a bus stop.

Degree of lateness – Proportion of a service that is late at a bus stop over a fixed period of time. Buses are termed late if they depart 5 minutes later then the scheduled time from a bus stop.

Degree of Saturation - The ratio of demand flow to capacity for a particular stream of traffic in a particular time segment.

Delay - The total stoppage time at a junction/bus stop.

Destination – The final location of a journey.

Dwell time – Total stoppage time at a bus stop, which includes boarding, alighting and an extra (fixed) time to open and close door/s.

Fare stage - A stage of a route where the fare changes

Fare system - The whole set of techniques used for fare collection

Frequency - The number of buses on a service which pass a given timing point within a specified period (hour/day/week)

Generalised time - A measure of the total duration of a journey, combining the individual components into a single measure, usually with different weights attached to each component.

Headway - The scheduled interval between two successive buses on a section of road.

Information

Pre-trip – Any form of information provided to travellers before they start their journey.

At- stop – Any form of information provided to travellers at a bus stop.

En-route – Any form of information provided to travellers the during the course of a journey

Interchange - The transfer of passengers from one line to another at a connection point, when no direct line is available towards their destination.

Journey - The movement of passengers between two specified points, e.g., an OD pair.

Journey time - The total time taken to complete a journey.

Junction delay - Delay suffered by vehicles at a junction.

Level of service – A subjective description of the quality of service of a system.

Link - A discrete element, which connects two nodes in a transport network

Mode – Any of the different transport systems (namely private and public transport) that travellers can use for their journey

Sub-mode – Any of the different transport systems of a mode, for example bus, trains and trams in public transport.

Network (Bus/PT) - The total collection of physical routes, operated by an operator or under control of a Transport authority

Node – A discrete point representing junctions or bus stops in a transport network.

Off Peak - The period outside the morning peak and evening peak periods.

On time – A bus is termed to be on time if it departs within –1 to +5 minutes of the scheduled time from a bus stop.

Origin - Initial location of a journey.

Parking - The standing of vehicle, whether occupied or not, otherwise than temporarily for the purpose of and while actually engaged in loading and unloading

Passenger - Users of the bus service

Passenger Information -All activities providing information to passengers of the services

Passenger distance - Distance travelled by passenger (passengers x distance travelled)

Patronage – Number of public transport users for a given fixed period of time.

Peak periods - The period of traffic day with high traffic movements.

Punctuality – The proportion of bus service, which departs from a bus stop within a time window (– 1minute to +5 minutes in this thesis) of the scheduled time generally for schedule based services (usually for low frequency services) for a fixed period of time.

Regularity – The proportion of bus service, which departs from a bus stop at specified regular intervals generally for headway based services (usually for high frequency services) for a fixed period of time.

Reliability – A subjective measure of the degree travellers can rely on a service; to depart from a bus stop on time, depart from a bus stop at a specified regular interval or reach them to their destination.

Route:

> *Bus route* - The ordered list of links defined by the sequence of nodes defining a path taken by a bus service
>
> *Optimum route* – The choice among the available alternative bus routes, which is perceived to be the best option for the users either to minimise the total travel time or for convenience (for example to reach destination on time).

Saturation flow - Maximum flow which can be passed through a intersection for an approach in a junction.

Schedule/ Timetable - The plan of the journeys, for one or more services, for a whole day, showing departures times.

Selective detection – A technique where buses are individually identified at signal controlled junction.

Slack time – Time users plan to arrive before the scheduled departure time at a bus stop

Total passenger journey time (TPJ time) – Aggregate of the total time (door-to-door) taken to complete a journey for all the public transport (bus) users in the network (passenger-minutes).

Traffic signal - A signal, operated manually or (usually) electrically, by which traffic is alternately commanded to stop and permitted to proceed.

Transfer - The transfer of passengers from one vehicle to another at interchanges.

Transport model – Abstract representation of transport systems by replicating the system and its behaviour using mathematical equations based on theoretical statements about it

Trip - The complete movement of a passengers form an origin to the final destination.

Vehicle capacity - The total passenger carrying accommodation in a vehicle, usually broken down into standing and seated passengers.

Waiting time (at a bus stop) - The amount of time users wait at a bus stop (both outside and inside the bus) where they board a bus before it departs.

> *Average waiting time* – The average amount of time users wait at a bus stop (both outside and inside the bus) where they board a bus before it departs between two consecutive buses for a fixed interval of time.
>
> *Perceived waiting time* – The amount of time users perceive to have to wait (or have waited) at a bus stop (both outside and inside the bus) where they board the bus before it departs.

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