AUTOMATIC VEHICLE LOCATION TECHNOLOGY:
APPLICATIONS FOR BUSES

by

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ABSTRACT

A combination of technological advances in systems which track buses and the continuing fall in prices of computing hardware has led to Automatic Vehicle Location (AVL) systems becoming an attractive, affordable proposition for many bus operators. Local authorities are also showing a great deal of interest in this technology since AVL data can be used to drive systems which provide real-time passenger information at bus stops (which are perceived to be a potential source of increasing patronage and also have a high on-street profile).

However AVL technology is still relatively new to the bus industry and little research has been carried out as to the potential benefits of these systems with the result that many systems have been bought ‘off-the-shelf’ without consideration as to whether the system could be better with re-specification. Therefore guidelines for system specification have been produced as part of this research as a result of a comparison of the advantages and disadvantages of the various AVL technologies.

Although real-time AVL data is being utilised successfully in this country, little attention has been given to the benefits of using non real-time data. This research aims to demonstrate the potential use of non real-time AVL data, such as to identify sections of a bus route which would benefit most from bus priority measures, estimate the passenger arrival rate at stops (when used in conjunction with an on-board patronage survey), improve scheduling and compile punctuality statistics.
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CHAPTER 1: INTRODUCTION

Abstract

Buses provide a cheap, efficient and environmentally friendly mode of transport for the millions of people who use them daily. However bus patronage has been declining steadily over the last thirty years and measures need to be implemented which will reverse this trend and allow buses to form a viable alternative to the car.

This research aims to investigate the role that Automatic Vehicle Location systems (which are emerging technologies with huge and, so far, untapped potential) can play in the bus industry to help achieve the objectives of providing a more attractive bus service to passengers and improve the efficiency of operations.
1 INTRODUCTION

1.1 THE ISSUES

The increasing awareness of the impact on the environment from pollution emitted from various transport modes has led many transport planners to encourage the use of public transport as an alternative to the car. However some schemes (light-rail in particular) have proved to be costly and attention has turned towards the bus to provide a cheap, efficient and environmentally-friendly mode of transport. Buses also fulfil a social role in allowing older members of the community who may be mobility handicapped to travel to their destination (often at a reduced cost) and are also economical on valuable road space, e.g. in central London the double decker bus carries on average 15 times more passengers than a car would carry in the same road space (London Buses, 1994). However the bus industry in the UK is suffering from a number of problems:

- the decline in patronage experienced outside London (Department of Transport, 1996c) has led to a vicious circle of fewer people using buses leading to less revenue for the operator, which in turn leads to a poorer service which causes fewer people to travel by bus and so on.

- traffic congestion is a severe problem for buses in large cities who share their ‘track’ with other road users, notably, private car users.

- bus bunching, i.e. the phenomenon of buses arriving at stops in pairs or in groups of three or more. Bus bunching due to traffic congestion is out of the operator’s control but there are other causes of bus bunching, namely, driver behaviour, which may be eradicated with proper training and disciplinary procedures. ‘Driver behaviour’ includes the different speeds at which drivers are prone to drive at, leaving termini late and bad driving practices such as skipping stops even if there is room left on the bus etc. A combination of traffic congestion and bus bunching means that waiting time at stops can have a high degree of uncertainty associated with it.

- the bus is often perceived as being noisy, dirty and uncomfortable by many people. Although this factor probably does not actively discourage bus use, it does nothing to encourage it either.

- the lack of clear passenger information is also a problem for potential bus users, especially those who are unfamiliar with the local area.
Passenger journeys on local buses in Great Britain increased by just under 1% in 1994/95, halting the decline of the last decade (Department of Transport, 1995a). Although, this upturn in the recent trend is encouraging, buses still have a long way to go before they regain much of the patronage lost in the years after deregulation. The continuing fight against the car means that solutions need to be found to combat the problems buses face in urban areas. Some solutions to the problems buses face include:

- bus priorities such as bus lanes, priority at traffic lights, bus gating etc. Some bus priority measures offer instant benefit, such as contra-flow bus lanes, allowing buses access to roads which do not allow access to cars and allowing buses to make turns which are otherwise banned to normal traffic. However the success of other measures, notably unsegregated with-flow bus lanes, depends on the compliance of other road users not to block access to these facilities by inconsiderate parking etc.

- improved driver training may help combat the problems of bus bunching. Incentives such as performance related pay (e.g. bonuses related to percentage of buses on time) may help motivate staff. Obtaining and retaining good drivers is probably one of the most difficult tasks a bus company can undertake.

- investing in low floor buses or ‘clean’ buses which produce significantly less emissions may help to improve the bus’ current image problem.

- a good maintenance program will allow maximum flexibility over vehicle and staff utilisation. Mechanical failure of buses whilst in service can severely disrupt schedules and cause much consternation amongst passengers.

- static passenger information at stops (e.g. paper timetables and route guides) must be of a high quality and be easy for a first time user of the system to understand. Information should be up-to-date and easy obtainable, e.g. deliveries of timetables to homes and information hotline numbers.

No one measure will combat the aforementioned problems but if implemented together, progress may be made. Many bus companies are striving to reverse the trend in ridership by utilising emerging technologies such as Automatic Vehicle Location (AVL) systems. A combination of technological advances in systems which track buses and the continuing fall in prices of computing hardware has led to AVL systems becoming an attractive, affordable proposition for many bus operators. AVL systems can help improve reliability by providing bus route controllers with more information in the face of non-recurrent traffic congestion (which can arise due to a combination of illegal parking, road works,
accidents and inconsiderate driving and which is, by its nature, impossible to predict) and can also help in identifying buses which are starting to bunch before bunching actually occurs. The reduction of bus bunching will provide a more regular service for passengers and improve the quality of service offered. AVL systems can also be used to provide real-time passenger information at stops, which gives the expected number of minutes until the actual arrival time of the next few buses, thereby reducing the uncertainty of the wait time and improving the image of bus services.

AVL systems have the added benefit of allowing bus operators to reduce costs by reducing the number of roadside inspectors, since the AVL system performs the same function as roadside inspectors at a fraction of the cost and continuously throughout the day.

Local authorities are showing a great deal of interest in real-time passenger information systems which are perceived to be a potential source of increasing patronage and also have a high on-street profile. The image factor of real-time passenger information systems is very important because it projects a technologically advanced concept and also provides tangible proof that the local authority is trying to promote the use of public transport.

AVL technology is still relatively new to the bus industry and little research has been carried out as to the potential benefits of these systems with the result that many systems have been bought ‘off-the-shelf’ without consideration as to whether the system could be better with re-specification. The main problem lies with the fact that the bus market is a new area for many AVL system suppliers and so the problems faced by the bus industry are not considered when designing these systems. Similarly, professionals in the bus industry are not technical experts and so are unaware as to what these systems are capable of offering. This research aims to bridge the gap between these two camps and provide guidelines for system specification with the problems of the bus industry in mind.

Although real-time AVL data is being utilised successfully in this country, little notice has been given to the benefits of non real-time data. This research aims to demonstrate the potential use of non real-time AVL data. As this data provides a continuous record of the bus’ movements throughout the day it provides a valuable data source from which speeds of buses can be obtained. However the reason for a slow bus speed is not provided in the AVL data and so part of this research aims to separate the speed of a bus as it moves between stops (i.e. the moving speed) from the commercial speed (which implicitly
includes the time spent at stops. If the moving speed of the bus is isolated then it can be
used as evidence of congestion along certain roads in a bid for bus priority measures.

Another use of the moving speed of buses is in simulation modelling, which can be used
as a tool to train bus route controllers and hence aid improved bus operational control.

1.2 Objectives

The rational for operators and local authorities to be investing in AVL systems and real-
time passenger information systems has been outlined above. This research aims to
identify:
- the capabilities of AVL systems
- potential areas of exploitation of AVL data which are currently not being utilised
- the pitfalls associated with AVL technology

It is hypothesised that organisations are implementing AVL technology without thinking
about the consequences of their actions or about what they actually want the system to
do and whether it is capable to achieving it.

This research aims to:
- identify the various technologies which can be used to drive AVL systems for
  buses
- develop guidelines which should be considered before specifying an AVL
  system
- identify applications for real-time AVL data
- identify applications for non real-time AVL data
- compare real-time passenger information systems currently being
  implemented in the UK with the aim of identifying best practices
- describe how non real-time AVL data can be used to estimate the speed of
  buses as they move between stops
- describe a model which simulates the movement of a bus along a route and
  uses data derived directly from AVL data as its inputs
- identify the limitations of real-time and non real-time AVL data
1.2 STRUCTURE OF THESIS

The research is presented in the following manner: A literature review can be found in Chapters 2 and 3 which focuses on the different types of bus tracking technologies available and provides a background to the environment a bus has to operate in. Chapter 4 describes the problems associated with using non real-time AVL data and describes how passenger arrival rates can be derived using a combination of non real-time AVL data and on-board bus surveys and shows how this passenger arrival rate can then be used to calculate the speed of buses as they move between stops. A model which is based on non real-time AVL data which simulates buses as they travel along a route and the results of the model will also be presented in this chapter. The different technologies on which AVL systems are based will be compared in Chapter 5 and guidelines for system specification will be provided. Various implementations of real-time passenger information systems will also be compared in this chapter, together with systems used for operational control based on a variety of technologies. Conclusions and recommendations for further work will be presented in Chapter 6.

1.3 SUMMARY

Automatic Vehicle Location can help to reduce the disruption caused by non-recurrent traffic congestion and can be used to reduce bus bunching thus providing a more regular service for passengers and improve the quality of service offered. Local authorities benefit from real-time passenger information systems by improving the image of buses at the same time as providing information which reduces the uncertainty of waiting time. It is hoped that a combination of these two factors will generate an increase in patronage and cause a modal shift from car use which will in turn reduce congestion and environmental pollution. This research aims to assess to what extent the potential of AVL systems and real-time passenger information systems is being realised and to identify the problems associated with this new technology with the aim of producing guidelines for system specification.

Before one considers specification of AVL systems or what type of data may be available for modelling purposes, it is necessary to know what technology is currently available to drive these systems. A description of the various technologies currently used to drive AVL systems is described in Chapter 2.
CHAPTER 2: AVL SYSTEMS AND THEIR APPLICATIONS

Abstract

AVL systems can be based on a variety of technologies, namely, dead reckoning (odometer and compass), beacon and either tag or radio, radio triangulation (using a network of ground-based transmitters) or Global Positioning System satellites. Even though beacon-based systems seem to dominate the AVL UK bus market, they are by no means ideal for every situation. Many factors need to be considered before specifying an AVL system but the type of technology on which the system is based is probably the most important for many applications.

The potential of AVL systems has not yet been fully realised but real-time data from AVL systems is mainly used for two purposes in the bus industry: bus operational control and real-time passenger information. Non real-time AVL data is mainly used to help bus prediction algorithms ‘learn’ a route. Some enlightened operators are using this data to help aid scheduling but this practice is generally the exception rather than the rule.
Automatic Vehicle Location systems are gaining in popularity in the UK (ETSU, 1993). However most users buy complete systems from manufacturers with little regard as to whether a better system can be specified using the available technology. System specification is a global process: all issues must be considered before deciding on the type of technology to use. But before one decides on the most suitable technology for a given application it is necessary to be aware of the advantages and disadvantages of all the options. This chapter aims to highlight the positive and negative features of current AVL technologies and provide examples of how real-time and non real-time data from AVL systems can be used. With this information informed decisions can be made by potential users as to what functions their AVL system should be capable of carrying out and the most appropriate technology (or combination of technologies) which serves these functions.

Vehicle location can be established using one of the following technologies:

- dead reckoning: using odometers (devices which measure distance travelled by counting the number of wheel revolutions) and compasses
- beacon and either tag or radio, e.g. microwave, infra-red, inductive loops
- radio triangulation, e.g. Loran-C, Omega, Datatrak
- satellites, e.g. GPS

Sections 2.1 to 2.4 describes AVL systems based on the technologies given above and Section 2.7 describes some technologies which may be able to drive AVL systems at some time in the future.

### 2.1 Dead Reckoning

The predecessor to dead reckoning was odometer-only position location. Smith et al. (1994) note that with a fixed route transit system, distance travelled is sufficient for vehicle location but it was not uncommon for these devices to be quite inaccurate due to wheel slippages and overtaking. Since odometers only measure straight line distance, any changes in the route would mean that the new route would have to be surveyed so that the relative locations could be ‘mapped’ on to the absolute locations. Also, if vehicles went off route, all location estimates collected afterwards would be incorrect since the system assumes that vehicles stay on the route (Goodchild and Fairhead, 1993; Lam, 1994; Engels and Bonara, 1995).
The distance travelled by an odometer, \(d\), is given by (Engels and Bonara, 1995):

\[
d = n_r \cdot l_w
\]  

where 
- \(n_r\): number of wheel revolutions
- \(l_w\): wheel circumference

The odometer provides a number of electrical impulses which correspond to the distance travelled. The on-board control unit counts these impulses and calculates the distance travelled using a conversion factor, called the odometer factor \(o_f\). Therefore the distance travelled, \(d\), can be represented as (Engels and Bonara, 1995):

\[
d = n_{\text{imp}} \cdot o_f
\]  

where 
- \(n_{\text{imp}}\): number of impulses

Calibration of odometers is carried out by travelling a pre-set distance during which the number of impulses is counted. The \(o_f\) factor can then be saved into the configuration data of the on-board system. Calibration needs to be carried out on a regular basis since variation in the \(o_f\) factor can be caused by worn tyres and passenger loadings (Stone, 1970; Engels and Bonara, 1995). Stone (1970) estimates that the error in \(o_f\) factor due to passenger loading is of the order of 0.5% of distance run.

The minimum instrumentation required for dead reckoning AVL are (Skomal, 1981):

- instruments that measure the change in the direction of movement (e.g. a heading sensor) and distance travelled (e.g. odometer)
- radio transmitter and receiver for each vehicle.

Dead reckoning AVL requires that the position of the vehicle relative to a given reference point is known at the start of the route, i.e. at the initialisation point. As the vehicle moves away from the initialisation point, pairs of distance increments and turn angles are formed and summed vectorially (see Figure 2.1). During the progress of the vehicle along the route, errors in measuring distance and change in angular direction occur in the vehicular instrumentation (Skomal, 1981; Engels and Bonara, 1995). Therefore the actual location of a bus could lie within an error circle whose radius depends on the accuracy of the odometer used (i.e. the smallest incremental value of the odometer) and the frequency of position report (Tyler, 1994). Odometer accuracy has been estimated as being between 1-3% of
distance travelled since re-initialisation (Bartlett, 1986; Chesnoy, 1994; Lam, 1994; Briolat, 1995; Engels and Bonara, 1995).

**Figure 2.1** Dead reckoning positioning

![Diagram of dead reckoning positioning](image)

Courtesy of T. Horbury (based on Skomal, 1981)

The error circle enlarges with the passage of time or distance travelled since the last initialisation which means that dead reckoning systems must have provisions for re-initialisation of the vehicle’s position at regular intervals or at designated locations (Skomal, 1981). Whenever a vehicle passes a re-initialisation point, both the distance and the angle measuring instruments are adjusted to a predetermined setting and a new track is initialised. Throughout this procedure, data descriptive of the distance travelled along a compass bearing and the change in bearing angle are transmitted by radio from the vehicle to the control centre (Skomal, 1981).
Summary

The advantages and disadvantages of dead-reckoning AVL are highlighted below (Engels and Bonara, 1995):

**Advantages**
- Low cost
- Possibly no roadside infrastructure or line-of-sight requirement

**Disadvantages**
- The system is vulnerable to inaccuracies in initialisation at the starting point and failure of the on-vehicle measuring device to give an accurate distance or direction (Finn, 1992)
- the odometer has to be calibrated regularly as the wheel circumference changes due to changes in tyre pressure

The performance of such systems has improved over the last few years, as the cost of electronics has fallen and solid state heading references have become more widely available. The accuracy of these systems is inversely proportional to the time since re-initialisation (Scorer, 1993).

2.2 **Beacon-based systems**

Beacon-based AVL systems utilise several beacons or road loops positioned at known locations along the route. There are many ways of detecting a vehicle, e.g. pressure detection, magnetic detection, inductive loops or ultrasonic, UHF radio, microwave, and optical (infrared) beacons (Taylor *et al.*, 1987; Sommerville, 1991, M Smith, 1993). Early AVL systems, such as London Transport’s BUSCO system, were based on inductive loop and transponder technology but this type of technology is no longer used in the UK because of the disadvantages outlined below (Taylor *et al.*, 1987; Bell and Cowell, 1988; Cowell *et al.*, 1988; Finn, 1992):
- low information transmission rate
- greater maintenance requirements since more wear and tear
- costly to re-position
- the need to dig up the road and close the road to traffic in order to install and
maintain loops

- sensitivity methods are required to distinguish changes in inductance due to vehicles and those due to environmental and equipment instability
- the inductive loop is known to be affected by steel-reinforced pavements

Bell and Cowell (1988) note that microwave and infra-red beacons tend to suffer from a line-of-sight requirement. They add that infra-red beacons suffer a reduction of signal strength if the line-of-sight is obscured by dirt or snow which may affect the accuracy of the identification.

Location information can be transferred to the control centre via either 'intelligent beacons' or 'intelligent buses'.

2.2.1 Intelligent buses

'Intelligent buses' refers to AVL systems where the vehicle location information is held in the on-board bus computer and beacons are used to re-initialise the on-bus location equipment. In cases such as these, beacons or road loops continuously broadcast very low power radio signals which incorporate an identification code unique to that beacon. Vehicles carry the appropriate radio receiving equipment which can detect and decode the transmissions from any beacon when the mobile is within the area of beacon coverage. The vehicle stores the code and resets the odometer count to zero. The decoded beacon identity symbol and the identity of the vehicle are then transmitted to the control centre via radio from the bus. The central computer relates the beacon code designator with a geographical location and notes when the vehicle passed the beacon (Skomal, 1981).

Since the bus forms the intelligent component of this system, beacons can be easily repositioned should the route change. Sommerville (1991) points out that the weak link in this type of system is the vulnerability of the on-board transponder to disablement, either by deliberate intervention from the driver or a loose connection from the power feed. He notes that this problem is overcome by using transponders which are powered by an internal battery.
2.2.2 Intelligent beacons

AVL systems which utilise ‘intelligent beacons’ require that vehicles transmit a unique identification code on a dedicated radio channel or utilise ‘tags’ which are energised by power transmitted by the beacon. Tags are sealed units with no external power supply and are generally not very vulnerable to outside interference and damage (Sommerville, 1991).

Communication between beacons and the control centre can be via dedicated cables, leased telephone line or radio paging and can either be instigated by the control centre or by beacons on receipt of a vehicle’s transmission. If the latter method is used the beacon sends the vehicle identification code and its own identifier to the control centre where the time of receipt is recorded (Skomal, 1981). Usually communication is instigated by the beacon in ‘intelligent beacon’ AVL since it reduces the amount of communication between the control centre and the beacon and is, therefore, more cost-effective.

Intelligent beacons are more unaccommodating to changes in the route if landlines are used as the medium for communication between the beacon and the control centre since moving a beacon will also mean re-routing the land lines to the control centre. The precise configuration used tends to be determined by the practice of the preferred supplier or by the existence of a landline or radio infrastructure which can be exploited for an additional function.

The most popular beacon and tag systems sold in the UK are low frequency systems. Low frequencies transmissions penetrate virtually all non-metallic materials making tags usable when moulded into objects, covered in dirt or submerged in water (Ollivier, 1993). They do not consume much power.

Summary

‘Intelligent beacons’ AVL can only represent vehicle movement as a series of step position changes occurring between beacon locations. The advantage of this type of system is that the cost of on-bus equipment is very cheap and eliminates the need for buses to be equipped with data radios (M Smith, 1993). ‘Intelligent bus’ AVL has the benefit of providing continuous locational information since odometer information can also be sent to the control centre by the bus.
The advantages and disadvantages of beacon-based technology are outlined below:

**Advantages**

- the exact position of the vehicle is known when it passes the beacon
- if a tag is used then the on-bus equipment is inexpensive

**Disadvantages**

- roadside infrastructure is required
- beacons are limited to fixed routes and have to be relocated if the route suddenly changes (as sometimes happens in a deregulated environment which forces bus companies to be swift in their reaction to competition)
- if a beacon fails, all buses on the route are affected
- buses cannot be tracked if they travel off-route, e.g. in cases of road closures or road works which cause buses to divert from their normal route
- if an odometer is used in vehicle positioning then it has to be regularly calibrated
- tags require line-of-sight to the beacon

The accuracy of beacon-based systems is highest at the location of the beacon but errors in the odometer reading increase until the next beacon is reached. Therefore beacons have to be sited such that the maximum error obtained is acceptable, e.g. if odometer accuracy is 2-3%, then beacons placed every 1km would result in a maximum error of 30m and an average error of 10-15m.

### 2.3 RADIO TRIANGULATION

Radio triangulation systems establish vehicle position relative to the navigation network by calculating the distance between the receiver on the vehicle and the radio transmitters (which are the basis of the navigation network). The separation distance may be established by one of two methods (Skomal, 1981):

- time of transit of the signals between the points
- total phase change that the signal experiences between its transmission from various transmitters and reception at the mobile

Skomal (1981) explains that the state of the radio signal at the instant of its emission from
the transmitters does not need to be known, the only measure of relevance is the difference, in either time or phase of reception of pairs of signals arriving at the vehicle from three or more fixed transmitters and to know the fixed relationships that govern the emission times of phases from each transmitter.

2.3.1 Datatrak

Although many radio triangulation systems exist, the only system which is widely used in the UK is the Datatrak system which was developed specifically for road-based vehicle location and has been in operation since 1989 (Scorer, 1993; M. Smith, 1993). The reason for this apparent monopoly of the radio triangulation market is that Datatrak is far more accurate than any of its competitors since it offers an accuracy of the order of 50 metres as opposed to the 200m accuracies currently obtainable with other similar systems (Scorer, 1993; M. Smith, 1993; Securicor, 1994). R and I Buses (now MTL London) use this system although they are one of a select number of bus companies who chose radio triangulation as a means of vehicle location (the system is more popular with emergency and distribution services).

The system incorporates a dedicated, advanced, high speed data reporting network for sending vehicle position information (Scorer, 1993). This information is transmitted in an encrypted form from each vehicle by a locator unit connected to a small, roof mounted antenna. The locator unit receives radio signals transmitted by the navigation network and measures the phase relationship between pairs of signals. These phase differences are used to compute lines of position (lines of equal phase difference) which locate the vehicle relative to the navigation network station. The locator then converts its position to an exact coordinate.

2.3.2 CURSOR

CURSOR is a technique for land-based navigation which makes use of existing transmitter infrastructure (e.g. public broadcast stations or television stations), instead of using dedicated radio transmitters such as those used by Datatrak, to calculate position (Jabez, 1993c). Phase differences from three independent transmitters are measured at the vehicle receiver and at a receiver in the base station (M. Smith, 1993). The system requires that all readings have to be passed back to the base station before position calculation can take place (Scorer,
Unlike other radio navigation systems, the system has to be initialised i.e. the position of the user has to be established before starting (Scorer, 1993; M. Smith, 1993). The benefit of CURSOR over Datatrak is that there would be no monthly subscription charge, as there is no (direct) associated cost for the upkeep of the transmitters. The manufacturers of this system are aiming to bring vehicle equipment costs down from the current £500 to around £100 (Jabez, 1993c).

Cambridge Research and Innovation who are pioneering this system claim it will have a better performance and be cheaper than an equivalent GPS-based system. Trials are currently being carried out in Heathrow Airport but this system has not been tested on an urban bus route and therefore it is not (yet) a feasible option.

**Summary**

The advantages and disadvantages of radio triangulation are outlined below:

**Advantages**
- independent of route and roadside infrastructure
- no line-of-sight requirement between the transmitter and the receiver
- the system is fully automatic and does not require any initialisation prior to daily use

**Disadvantages**
- the frequency spectrum is crowded and so it is difficult to obtain more radio channels. Therefore the operating cost of the system will depend on the subscription cost to the network of an existing provider.
- cost of establishing the infrastructure of the radio network means that there must be many users or potential users (Finn, 1992).
- the Loran-C system is vulnerable to interference from large metal structures such as bridges and strong electrical fields generated by power lines (Manzie, 1995)
2.4 Global Positioning System (GPS)

Although other satellite-based AVL systems exist (M. Smith, 1993), the only one which is used by the bus industry in the UK, at present, is the Global Positioning System (GPS) (also known as NAVSTAR, NAVigation System using Time And Ranging) which consists of 24 satellites orbiting some 20,200km above the surface of the Earth (M. Smith, 1993). Currently, there is no associated charge for GPS data from the satellites and this situation is envisaged to remain the same until, at least, the year 2003 (Stewart, 1993) but this privilege could change after that time and is entirely dependent on the goodwill of the US Department of Defense who are responsible for the system (Wells, 1986; M. Smith, 1993).

Vehicles fitted with GPS receivers are able to determine their three dimensional position and velocity continuously anywhere in the world and in all weather conditions. M. Smith (1993) describes how the system works: each satellite transmits two radio frequencies for positioning purposes. If a satellite transmits a signal at a known time, the bus receives the signal some time later and the distance between the receiving unit and the satellite can be calculated. The locus of the position of a vehicle at a given distance $x$ from a satellite is a small circle. The small circle determined by a second satellite has two intersection points with the first circle (see Figure 2.2). The distance between the two points is large enough to avoid ambiguity. A third satellite is required to calculate any timing errors between the satellite’s internal clock and the receiver clock and to fix a two dimensional coordinate. A three dimensional positional coordinate can be obtained with a fourth satellite fix and a fifth satellite can be used to calculate the exact positions of all the other satellites.

GPS receivers can be either switching or continuous tracking (Wells, 1986). The main difference between the two receivers is the number of channels the receiver has, i.e. the number of satellites which can be tracked simultaneously (Engels and Bonara, 1995). A ‘channel’ is defined as (Wells, 1986):

The radio frequency, digital hardware and software required to track the signal from one GPS satellite at one of the two GPS carrier frequencies

(Wells, 1986)
A continuous tracking (or parallel) receiver has 4 to 12 dedicated channels, each of which tracks a single satellite and maintains continuous code and/or phase lock on the signal. Continuous tracking receivers have greater signal to noise ratios than switching receivers since the satellite signal is continuous available. Also, there is potential redundancy since even if one of the channels fail, it may still be possible to obtain a position fix. The disadvantage of multichannel receivers is that the differences in signal path delay in the channels must be well calibrated (Wells, 1986; Engels and Bonara, 1995).

A switching (or sequential) receiver utilises 2 to 3 dedicated channels, each of which samples more than one satellite signal. Code and/or carrier tracking for the individual signals is performed by software in the receiver’s microprocessor. Positioning is achieved by tracking a number of satellite signals by sampling the signals in sequence. Hybrid receivers combine continuous and switching channels in the same receiver (Wells, 1986; Engels and Bonara, 1995).
Engels and Bonara (1995) note that the higher the number of channels, the higher the probability that the receivers will not lose synchronisation and will still be able to provide a position fix. Also, the time to re-acquire synchronisation after losing it will be shorter. They estimate that a 5 or 6 parallel channel receiver is usually good enough for most applications and that most commercial receivers provide very similar performance.

Channels can either be multiplexing or sequencing. Wells (1986) explains that the difference between the two types of channels is that a multiplexing channel is one for which the sequencing time to sample all satellites assigned to the channel is equal to 20 milliseconds, the period of one bit in the satellite message. The sampling can be arranged so that no message bit boundary is spanned by any tracking interval, which provides simultaneous reading of all messages from the satellites tracked by the channel. If a channel switches between signals at a rate which is asynchronous with the message bit rate, the channel is referred to as a sequencing channel.

GPS receivers were fairly expensive when originally launched on to the market but have become far more competitively priced (costing between £100 and £600) and technologically advanced in recent years (Wells, 1986; Orlowski, 1993). The accuracy of GPS is dependent on the amount of deliberate distortion, known as Selective Availability (SA), which is introduced into the signal available to civilian users. The US Department of Defense has retained the right to continue to degrade the GPS positional accuracy (Scorer, 1993; Smith et al., 1994).

With SA switched off (as during the Gulf War), GPS positional accuracy is about 30m (Stewart, 1993). With SA switched on, GPS is estimated to be accurate to within 100 metres (Goodchild and Fairhead, 1993; Stewart, 1993; Chesnoy, 1994; Briolat, 1995; Engels and Bonara, 1995). This accuracy can be increased with the use of dead reckoning or differential GPS (DGPS).

Differential GPS utilises a reference station which is an accurate GPS receiver, located at a known surveyed position which broadcasts errors in the GPS signals received from the satellite to the vehicle receiver so that they can be used as corrections to the GPS signal (M. Smith, 1993). Engels and Bonara (1995) note that differential corrections can be supplied by one provider and used by all the GPS users in the areas, thereby sharing the cost of the increased accuracy. Systems which employ differential GPS are reported to have an accuracy
of 5-10 metres (Lam, 1994; Briolat, 1995; Crawshaw and Shaw, 1995; Engels and Bonara, 1995; Gallagher, 1995). Chesnoy (1994) reports that this accuracy can be obtained 95% of the time and that if differential corrections are sent at greater than 20 second intervals, the accuracy of up to 10m could be undermined. The relative accuracy of GPS is about 1 metre, provided that the receivers compute their positions using the same satellites at more or less the same time. This means that the error which affects the estimation of the distance between two buses is less than 1 metre and therefore even stand-alone GPS is very effective in interval control applications (Engels and Bonara, 1995).

When considering the accuracy of GPS systems, it should be noted that manufacturers and users have reported different levels of accuracy. For example, Williams Industries Ltd (1994) who sell GPS-based AVL systems quote that 99% of the time uncorrected GPS is accurate to within 100m. However Engels and Bonara (1995) report that tests performed by a Flemish transportation company showed that the accuracy of GPS was within 179m for only 90% of the time (the maximum error recorded was 235m). Similarly while Williams Industries claim that 75% of GPS measurements are accurate to within 50m, Engels and Bonara (1995) note that 50m accuracy was only observed for 37% of the time in the Flemish tests. So there appears to be a discrepancy of a factor of two between the accuracies reported by the manufacturers and the users. Therefore the accuracies quoted by the manufacturers are best regarded as the accuracy which can be obtained in the most favourable circumstances whereas the accuracies reported by the Flemish test are considered more representative of reality.

Summary

The advantages and disadvantages of GPS are given below (Wells, 1986; Finn, 1992; M. Smith, 1993; Blackledge, 1994; Engels and Bonara, 1995; Tyler, 1995):

Advantages

- independent of route and roadside infrastructure
- does not rely on privately owned transmitters and their associated costs
- relatively low cost
- does not require initialisation at start of trip

Disadvantages

- in built up areas, tall buildings, bridges and tunnels obscure signals
• multipathing, i.e. the process by which signals are ‘bounced’ off buildings and other objects in such a way that the receiver calculates the location on the basis of these reflections rather than the true position of the vehicle, may occur in urban areas (Middlebrook, 1995)

• the whole system is dependent on the goodwill of the US Department of Defense

In rural areas, GPS availability is nearly 100% but in urban areas, satellites are visible for only 40-70% of the time (Chesnoy, 1994; Briolat, 1995; Engels and Bonara, 1995). Therefore dead reckoning which involves calculating the vehicle’s position by matching information transmitted by motion and odometer sensors to the last GPS signal is needed to ensure continuous positional information in urban areas (GEC Marconi, 1993).

2.5 SUMMARY OF AVL TECHNOLOGIES

The advantages and disadvantages of various AVL technologies are given in Table 2.1.

Dead reckoning systems must be used in conjunction with some other system for a reasonable level of accuracy to be maintained, e.g. if the AVL data is to be used for real-time passenger information purposes or any analysis of the performance of the route (Engels and Bonara, 1995). A stand-alone dead reckoning system may be suitable for real-time operational control (where an approximate estimation of where the buses are at any given time is more important) but this would very much depend on the layout of the route in question and the performance of the system itself.

Beacon-based systems are by far the most popular form of AVL system employed in the UK at present. Only a few beacons are needed per route for service control purposes but more are need if information from the AVL system is to be used for real-time passenger information. Beacon-based systems are also popular in Europe (M. Smith, 1993) with bus priority schemes at traffic signals integrated into some systems, e.g. Turin (Hounsell, 1996). One of the attractions of these systems is that existing radio communication between buses and the control centre can be used to transmit data at little extra cost. For real-time passenger information purposes, an odometer is usually used to estimate the position of the bus between beacons and is reset when arriving at the next beacon.
Radio triangulation offers a flexible AVL system which performs well in urban areas (Scorer, 1993). Its main drawback is its relative lack of positional accuracy. This could be increased via odometers or some other supplementary system, but the cost of such a hybrid system may be prohibitively large for many bus companies. The cost of the radio triangulation system alone is comparable with that of a beacon-based system with regard to on-vehicle equipment but the yearly running cost may be much higher due to subscription cost to the radio navigation network, which is between £10 and £113 per vehicle per month, depending on the level of usage (Jabez, 1993b).

Table 2.1 Advantages and disadvantages of AVL technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead reckoning</td>
<td>Low cost</td>
<td>Vulnerable to inaccurate instrumentation and initialisation</td>
</tr>
<tr>
<td></td>
<td>Possibly no roadside infrastructure or line-of-sight requirement</td>
<td>Odometer has as to be calibrated regularly</td>
</tr>
<tr>
<td>Beacon-based</td>
<td>Exact position of bus known at beacon</td>
<td>Roadside infrastructure is required</td>
</tr>
<tr>
<td></td>
<td>If tag is used, low cost on-bus equipment</td>
<td>Lack of flexibility in route choice</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus cannot be tracked off route</td>
</tr>
<tr>
<td></td>
<td></td>
<td>If beacon fails all buses are affected</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Odometer has to be calibrated regularly</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Line-of-sight requirement for tags</td>
</tr>
<tr>
<td>Radio triangulation</td>
<td>No roadside infrastructure</td>
<td>Subscription charge to network may be high</td>
</tr>
<tr>
<td></td>
<td>Flexible route choice</td>
<td>Vulnerable to interference</td>
</tr>
<tr>
<td></td>
<td>No line-of-sight requirement</td>
<td>System may be owned by third party</td>
</tr>
<tr>
<td></td>
<td>No initialisation required</td>
<td></td>
</tr>
<tr>
<td>GPS</td>
<td>No roadside infrastructure</td>
<td>Line-of-sight requirement</td>
</tr>
<tr>
<td></td>
<td>Flexible route choice</td>
<td>Inaccuracies introduced near high buildings</td>
</tr>
<tr>
<td></td>
<td>Relatively low cost</td>
<td>System owned by third party</td>
</tr>
<tr>
<td></td>
<td>No subscription cost</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No initialisation required</td>
<td></td>
</tr>
</tbody>
</table>

The available literature suggests that GPS data should only act in a confirming role rather than as the single source of location data in towns and closed areas (Goodchild and Fairhead, 1993; Scorer, 1993; Engels and Bonara, 1995). However users in cities in the UK have reported reasonable performance from stand-alone GPS systems in these areas. All but two of the large smart-bus systems in North America and the real-time passenger information
system in Paris, are based on GPS systems (Manzie, 1995).

2.6 Compatibility between systems

AVL systems are highly adaptable and can be configured to each user’s own requirements. Therefore it may be advantageous to combine two or more technologies to exploit the strong points of each. However with any combination of technologies, the complexity of the system (as well as the cost) increases (Lam, 1994; Engels and Bonara, 1995). Compatible systems include the two GEC Marconi products Tele-Tag and Star-Track and Peek Traffic’s Bus Tracker and GEC Marconi’s Tele-Tag system. However it should be noted that Bus Tracker was previously manufactured by GEC Marconi and so this apparent compatibility between systems may not be achievable between other systems.

In Germany a number of standards have been agreed by the Association of German Public Transport Companies which are used to specify equipment forming part of a vehicle location control system (ECMT, 1989). Elkins (1993a) reports that the aim of such specifications was to produce a modular system with simple interfaces so that different suppliers can provide peripherals such as ticket machines, displays and audible announcement units. The standards also cover the operation of radio systems and roadside beacons. Manzie (1995) adds that the US transit industry has also standardised on interfaces for peripherals to AVL systems thereby giving greater freedom in specifying equipment from different manufacturers. One component of real-time passenger information systems which can currently be sourced from different suppliers at low risk is the information display used at stops because the interface for these displays is so well defined (Orlowski, 1993).

Balogh (1995) announced that London Transport Buses (LTB) have been testing the feasibility of integrating various AVL technologies into their COUNTDOWN passenger information system. He goes on to say that LTB may even have to curtail the commercial freedom that operators have in choosing a system by generating an approvals list based on ‘best of type’ for a given technology and, over time, the ability to link satisfactorily to LTB’s COUNTDOWN system may become mandatory, which may result in a single universal system in London. ECMT (1989) questions whether the constraints of standardisation creates an obstacle to future innovation. However Engels and Bonara (1995) argue that standardisation of AVL equipment would reduce the cost of components and open up the AVL market.
The ideal solution is to form some sort of consortium which includes manufacturers, current and potential users of these systems and then, by common agreement, decide on standards and protocols which are common to all systems but which allow each manufacturer enough flexibility to market their system on its individual merits.

2.7 PROPOSED AVL TECHNOLOGIES

Sections 2.1 to 2.4 have described the AVL technologies currently available on the market today. This section discusses technologies which may be used as the basis of AVL systems in the future.

2.7.1 Image Processing

A number of projects have been carried out to establish techniques for decoding the registration number of vehicles from digitised video pictures taken from the roadside (Yuen, 1988; Turner, 1995). However Yuen (1988) observes that whilst this method may be used to establish the location of the vehicle, development of this technology is still at a relatively early stage so it will be expensive to use this type of technology as the basis of an AVL system.

2.7.2 Daisy-chaining information from stops

Middlebrook (1995) proposes that AVL systems can be simplified if their only aim is to provide real-time passenger information. He bases this simplified system on the beacon and tag principle in which the bus transmits its identity to the bus stop on arrival at the stop, but instead of utilising a central control to distribute predicted arrival times at stops, Middlebrook suggests a distributed method of control in which the stop receives the bus’ identity and transmits this information via radio to all stops downstream, cascading from stop to stop. The sign changes to ‘bus approaching’ when the stop first receives the bus identity and clears after the bus leaves the stop, i.e. the radio range of the beacon. The displays at the stop calculate the bus arrival time and amend their display accordingly. The same information can be sent to a central computer which could update the route profile and download the new profile to the stops as required.

Middlebrook (1995) undertook on-bus surveys to validate his model and found that it was
possible to obtain highly accurate arrival time forecasts but warns that the system is only
suitable for routes in which the daily journey times of buses do not vary significantly.

2.7.3 Fare stage data AVL

The next-stop passenger information systems in Bournemouth and Cleveland approximate
location information from fare stage data which is sent to the next stop display on-board the
bus. In this way, next stop information is provided on-board the bus without utilising an
AVL system or any communication infrastructure. In addition to this, since the ticket
machine has a programmable memory, the information presented on the display can be
customised on a day-to-day basis, to display messages such as "Roadworks along this road
are causing buses to experience delays", so relevant local information can be displayed to
passengers when the bus reaches the appropriate fare stage along the route.

If the fare stage and service number information was sent to a data radio instead of to a
display unit this data could be used as the basis of an AVL system, albeit a crude one, at
very low cost as the only additional infrastructure required would be that of the data radio
and a computer connected to a radio base station/decoder at the bus operator's garage. West
Midlands Travel have been using this sort of AVL system since 1989 to receive service
number and fare stage information. The system is event-driven with information sent to the
control centre only when fare stages are manually updated. The control room display is text
based and so does not incorporate a route map, but the controllers are experienced enough
to ascertain positional information from the service number and fare stage data. Information
shown in the control room includes: driver signed on/off status, bus fleet number, garage
code (since 12 garages use the same control centre), board number, service number, trip
number and fare stage (Boffey, 1996).

Fare stages have to be manually updated by the bus driver as stops are passed and is
therefore subject to human error, especially since (for next stop information) every stop must
be defined as a fare stage. Errors are more likely to occur when the driver does not pick up
any passengers and when the bus passes a bus stop without stopping.

Harper et al. (1996) interviewed bus route controllers about the ability of journey fare stage
data alone to provide sufficient information to satisfactorily locate buses. The majority of
respondents felt that fare stage data alone was inadequate for this purpose and needed to be
supplemented with other data such as odometer readings, as fare stage data was too susceptible to human error to be relied upon.

2.8 COMMUNICATIONS

The major questions that need to be addressed when contemplating commissioning an AVL system are:

- what type of technology will the system be based on?
- how is information regarding the position of a bus sent to the control centre?

If the AVL system is to drive a real-time passenger information systems then one further question needs to be addressed:

- how is information sent to the bus stop displays?

The first question has been considered in Sections 2.1 to 2.5. This section will focus on answering the other two questions.

2.8.1 Communication between the bus and control centre

There are several technologies currently being used by public transport operators to transfer location information from a bus to the control centre (Scorer, 1993):

- **Private mobile radio**: These are dedicated frequencies for voice communication primarily for use by large users. Voice and data can be sent over the same channel or the voice channel could be dedicated to data only. The actual data throughput achieved tends to be much lower than dedicated data networks.

- **Band III**: This is the generic name for the frequency band vacated by the old 405 line TV transmission. A number of operators provide a fixed cost trunked network for voice and data transmission. The major provider is National Band III Radio Ltd. The user does not require a radio frequency licence but only has to buy the vehicle radios and a control centre and pay a regular monthly subscription to the network provider.

- **Mobile public data networks**: the most popular mobile data network in use by bus operators is RAM Mobile Data who use the Mobitex network technology on the UHF band and promote the open system architecture that allows third parties to easily link to their system. In addition to investing in a mobile transceiver,
subscribers must pay a subscription fee (Orlowski, 1993).

- **Cellular phone services**: GSM (Global System for Mobile Communication) is becoming increasingly popular and is a European digital cellular telephone network capable of high security.

Voice and data can be transferred to the control centre on the same radio channel by either ‘back parching’ (which transmits data at the end of voice transmissions) or simultaneous transmission of both voice and data by using communication channel sub-bands to pass data (Terrafix Ltd, 1993). However channel saturation often occurs when there is a heavy reliance on voice communications between controllers and drivers in order to maintain performance which uses channel capacity inefficiently (Lam, 1994; Smith et al., 1994). Also, licensing agreements may be broken if voice and data are transmitted on the same channel as some suppliers of radio channels require that either no data or a limited amount of data may be passed over the channel, as it is shared among many users and if one user transmits large quantities of data then the service received by the other users will be downgraded.

There are three ways in which the control centre may receive vehicle updates. Regular updates can be achieved by either *sequential polling* or *time-slot polling*. Event-driven updates (e.g. when a bus reaches a beacon) can be obtained by *exception reporting*.

### 2.8.1.1 Sequential polling

In most centralised systems where a fleet of vehicles is to be controlled, many vehicles have to be monitored at once which means that communication channels cannot receive locations from one vehicle continuously. Generally this problem is dealt with by the control centre by transmitting an ‘individual enquiry message’ which is received by all vehicles. Only the vehicle to which the message refers to responds (Smith et al., 1994). This is known as sequential polling and takes location data from each vehicle in turn over one or several communication channels.

The rate at which vehicle positions are updated in the control centre is dependent on the capacity of communication system employed and the number of vehicles in the fleet. Usually only one channel is set aside for vehicle reporting. Emergency prioritised polling allows quicker updating of a particular vehicle (M. Smith, 1993; Smith et al., 1994). Some systems, such as Terrafix and Peek Traffic etc, allow the operator to instigate a poll to one or a group
Engels and Bonara (1995) note that the capacity of an owned communication infrastructure will dictate how much communication there is between vehicle and control centre as sending more data will increase polling times and the refresh time of the position information at the control centre. Therefore bus operators should ensure that the capacity they have available is able to accommodate all the buses they have in their fleet with additional provision for any extra buses they may acquire later. If there is insufficient capacity then buses will be 'missed' when polled, resulting in gaps in the data obtained. This will have severe repercussions on accuracy if the information is used to provide real-time passenger information at stops. Small gaps in the data are not that significant if the system is used only for control purposes.

### 2.8.1.2 Time-slot polling

Time-slot polling gives each bus a unique periodic time-slot during which it can transmit its current status. The precise clock synchronisation of all mobiles which is required to maintain the integrity of this communication method means that this method can only be used with GPS systems, since GPS is based on a principle which requires extremely accurate timing. The concentration of bus transmissions that are possible on a single radio frequency (RF) channel is far greater with time-slot polling than is achievable with sequential polling which utilises the traditional request and acknowledge handshake mechanism (Williams Industries Ltd, 1994).

### 2.8.1.3 Exception Reporting

Exception reporting (or event-driven mechanism) is the term used to describe an AVL system where the bus initiates communication with the control centre when a certain condition has been reached, e.g. the bus has reached a certain point along the route, is not running to schedule or the headway between buses is below a pre-specified minimum value (Lam, 1994; Engels and Bonara, 1995).
2.8.2 Communication between the control centre and bus stop display

2.8.2.1 Centralised or distributed control

If the AVL system is to be used for real-time passenger information purposes then the system can be controlled in two ways depending on the requirements of the operator, the size of the system and the complexity of the route network. The first method, centralised control, utilises a centrally based control computer which receives details of bus positions and calculates the expected time of arrival of the bus at each stop. This information is then transmitted to individual bus stop displays by leased telecom lines or radio paging. The other method, distributed control, uses distributed controllers located at bus stops. A computer on-board the bus has knowledge of its destination, schedule, running time and exact position which allows it to know how long it will take to arrive at each stop along the route. This data can be transmitted directly to a bus stop controller using radio or infra red communications (Elkins, 1993a).

Middlebrook (1995) notes that communication costs for the first type of system can be very high and so the second method has the potential benefit of greatly reducing the operating cost as there is a minimum amount of communication between the control centre and the displays.

Williams Industries Ltd (1994) note that if a distributed system is used, communication costs do not increase with number of displays and so there can be unlimited display expansion with the only restriction to adding more displays being that the radio modems must be within ‘earshot’ of one of the base station transmitters. Even if radio frequency surveys are undertaken in the area to be serviced, the exact nature of the radio communications will only be understood once the equipment is installed and after intensive field trials.

2.8.2.2 Landlines or radio paging

Control centres can communicate with displays at stops by multi-drop communication lines, leased telephone lines or radio paging. Multi-drop communication lines are essentially landlines in which a message is transmitted to all displays with a code attached and if the code matches that of the display then the display accepts the message and changes the sign accordingly. In this way, the system can be expanded by simply connecting other stops to
Landlines are very expensive to run and require the road to be dug up for maintenance purposes. Balogh (1993) explains that landlines were used in the COUNTDOWN system because they were a fixed cost and that electricity was cheap. He adds that landlines also allow telephones to be incorporated into shelters, thereby improving the waiting conditions at stops. Landlines restrict the flexibility of the AVL system as they are fixed infrastructure.

Brown (1993) argues that radio paging increases the flexibility of real-time passenger information systems since the signs can be easily removed should the routes change or the stops be temporarily removed. However it should be noted that although the paging unit is easily transferable, the power supply for the sign (which is usually mains electricity) is probably not so easy to re-locate.

2.9 Error Reduction Techniques

A prime requirement for an AVL system is good positional accuracy. Map matching techniques use computer algorithms to match the vehicle’s actual path with that of the feasible path to reduce any errors in the location information. For example, if a location system shows a vehicle’s position is beyond any feasible path on the map (e.g. the locator puts a vehicle in the middle of a park) the algorithm will compute the closest feasible position to the path and will relocate the vehicle to that position. This technique is meant to complement (not replace) any other error reducing techniques (Lam, 1994; Engels and Bonara, 1995). Map matching is currently being utilised in the GPS based real-time passenger information system in Paris (Chesnoy, 1994).

For most AVL systems, the marginal benefit of improving accuracy reduces as the level of accuracy increases (Tyler, 1994). Engels and Bonara (1995) note that the accuracy of a positioning system must be high when the bus leaves a stop to avoid announcing the arrival of a bus which has already left. They recommend that to avoid stringent accuracy requirements which would be costly, the problem can be overcome by adding event related signals to the positioning information, such as door opening and closing.

Lam (1994) notes that in order to assess if the accuracy of a system is acceptable, one
should look at the implications of errors on system performance. For example, a positional accuracy of around 70m for a bus travelling at 10mph results in 15 seconds of error which would be unnoticeable to most passengers and route controllers. However this error may result in the bus missing priority at a traffic signal (Tyler, 1994).

Since buses usually move along fixed routes, the probability of finding the bus at a location which is away from its allocated route is extremely low and so the error bounds of the bus system should lie exclusively in one dimension along the route (Tyler, 1994). Therefore error reduction techniques such as these will only be required for 2 dimensional navigation systems such as GPS, radio navigation and dead reckoning, since one dimensional systems are already (by their nature) fixed to the route. Since the error reduction techniques outlined above are dependent on modifications to the road network, the road database associated with the AVL system must be kept up-to-date for them to be effective (Engels and Bonara, 1995).

2.10 **Real-time applications of AVL systems**

AVL systems can be used to improve the service given to passengers by using information on the current position of buses to maintain even headways or increase reliability by improved operational control, provide an estimate as to the arrival time of the next bus at the stop, reduce journey time by giving priority at traffic lights and ensure connections at interchange points. Each of these applications of AVL data will be dealt with in turn in the following section and potential uses of this data will also be identified. Non real-time uses of AVL data will be discussed in Section 2.11.

2.10.1 **Bus operational control**

AVL systems for bus operational control purposes has achieved a much wider penetration amongst operators than for real-time passenger information purposes because the costs of investing and the internal productivity gains can be directly linked and translated to bottom line performance, since route controllers are able to quickly identify disruptions to service and possibly remedy the situation before it is exacerbated (Khorovitch *et al.*, 1991; ETSU, 1993; M. Smith, 1993).
2.10.1.1 History

Before the advent of AVL, roadside inspectors sited at specific locations along the route used telephones and hand-held radios to control the service. This method was found to be very labour intensive and could yield poor results if the inspectors were not coordinated. Also, since inspectors were only aware of buses which passed them, an overview of the route’s performance could not be attained. Consequently, in-cab radios began to be used by operators so that instructions could be issued directly to drivers and traffic conditions could be relayed to controllers (Wileman, 1995).

Jackson and Stone (1975) developed a simulation model to investigate the effectiveness of three types of operational control (i.e. roadside control, voice control and AVL control) when applied to a London bus route. The results showed that operational control improved the average passenger waiting time on the simulated route by an average of about 11% for roadside control, 14% for voice radio control and 16% for AVL control, the maximum benefits being attained when the level of disruption was greatest. They concluded that a law of diminishing returns governs the benefits which can be realised by increasing the sophistication of control methods. Although the benefits of AVL control seem to be only marginally better than voice control as regards the average waiting time at stops for passengers, the information AVL provides the route controller is significantly better than its previous route control counterparts.

The cost of implementing an AVL system is often offset against the savings which can be made by reducing the number of roadside inspectors. However Wileman (1995) notes that the advantages of having roadside inspectors were that they could:

- ascertain the cause of a problem
- see how many passengers were on the bus
- influence drivers’ timekeeping by their presence
- had face-to-face contact with the drivers, thereby personalising communication
- were high profile and could be seen to be controlling the route by the general public

She concludes that an AVL system used in conjunction with a mobile supervisor is the most cost-effective method of service control, since AVL is only a tool for operational control and cannot be used in isolation. This is a view which has been echoed by many bus operators who have implemented AVL systems and have retained inspectors at city centre locations.
because they argue that inspectors can judge traffic conditions more accurately than central controllers and carry out other functions apart from checking the time of buses as they pass (such as answering passenger queries). Retaining mobile supervisors also reduces the impact of the loss of face-to-face contact that drivers had with on-street inspectors, which is seen to be a regrettable consequence of the introduction of AVL by some drivers (Whitley, 1984; Atkins, 1994).

AVL does have its advantages in that it (Wileman, 1995):

- provides an overall picture of where all the buses are
- gives time to plan ahead and make informed decisions
- provides immediate contact with the drivers through the in-cab radio system (if one is fitted)
- is cost-effective

It is for exactly such reasons that London Transport have been striving, from as early as 1958, to develop an automatic vehicle location system capable of satisfying all their information needs. The first AVL system tried in the UK was called BEST (Bus Electronic Scanning Indicator). This system used coded beacon plates on the sides of buses to reflect a light beam generated by a roadside detector in a pattern unique to each passing bus. The detector passed the bus information and its own code via landline to the service control room where a light panel matrix was provided for each route, with each row corresponding to a particular bus on that route. Therefore when a bus passed a detector an appropriate lamp was lit. Roadside detectors were sited at about 15 minutes running intervals (Stone, 1970; Freeman, 1972; Cohen, 1975; Whitley, 1984; Wileman, 1995).

Sommerville (1991) identifies some disadvantages of this type of technology:

- performance is degraded by snow, rain, ice, fog and dirt
- it is highly sensitive to scanner/label misalignment
- focusing problems
- depth of field limitations

The drawbacks of a simple display and maintenance problems eventually led to the discontinuation of BESI in 1978 (Whitley, 1984).

From 1972 to 1980, an experimental system involving location reporting and control utilising two-way speech radio was implemented on Route 76 in London. The drivers reported to the
controller when they passed five specific locations en-route and also when they arrived and left termini. However only 30 to 40 buses could be controlled on one speech channel (Whitley, 1984) so London Transport would have needed in excess of 100 channels to control its entire fleet, compared to the 15 channels it was then allocated. Therefore it became necessary to find a more efficient use of the scarce air-time than human voice communication (Wileman, 1995). The answer was found in CARLA (Computer And Radio Location Aid) which was the first radio-based AVL system in the UK.

CARLA was developed by Marconi and was commissioned in March 1973. It was an odometer-based system whose method of operation was very similar to current practices, i.e. sequential polling of buses on a radio link (Freeman, 1972; Cohen, 1975; Whitley, 1984; Wileman, 1995). However CARLA was not without its problems and Cohen (1975) observes that:

"For the controller to make effective use of the system it must be working reliably"

Cohen (1975)

Whitley (1984) echoes this view by saying that reliable information on all buses is required as it only takes a small proportion of non-fitted buses on the route to quickly make nonsense of controllers’ actions and bring the system into disrepute, e.g. trying to plug non-existent gaps. He notes that the main lessons learnt from London Transport’s experiments with AVL are:

- the importance of establishing and maintaining confidence in the system amongst the staff using it
- that confidence in the system is easily broken with what, in other circumstances, might be classed as minor lapses in equipment reliability

2.10.1.2 Current real-time control practices

Cassidy (1995) found that the extent to which AVL systems are used for real-time operational control purposes is very much dependent on the environment in which the controller has to work and their general aptitude for using the system. If the system is consulted for bus operational control purposes regularly, then the performance of the route can be greatly enhanced providing, of course, that the information presented to the controller is an accurate representation of activities taking place on the route and the system is not
malfunctioning (Harper et al., 1996). Engels and Bonara (1995) note that the accuracy of the information presented to the route controller on the screen at the control centre depends on the:

- accuracy of locationing equipment (which is the prime consideration)
- availability of positioning information (this is important for GPS applications)
- on-board processing time
- time to transmit information between the vehicle and the control centre
- processing time at the control centre
- refresh time of information on the controller’s screen

The potential increase in operating performance was realised in Moscow, where the introduction of an AVL system resulted in a 50% increase in punctuality and a more regular service which resulted in a 12% reduction in average passenger waiting time at stops (Khorovitch et al., 1991).

Wileman (1995) observes that none of the studies into the early London Transport systems showed any convincing or conclusive evidence that radio or AVL led to improvements in regularity (Atkins, 1994). Therefore although AVL has led to favourable passenger perceptions of reliability through real-time passenger information systems, it does not appear to have achieved its operational benefits (in the UK). Wileman (1995) adds that although reliability has not improved on all routes in London with AVL, the improvement in reliability on low frequency routes with AVL has been more significant than those without the benefit of AVL. This is also illustrated by the results from the SuperRoute 66 in Ipswich, which has a service frequency of 15 minutes in the peak and 20 minutes in the off-peak and which experienced significant improvements in reliability (Suffolk County Council, 1995).

It is difficult to attribute reliability improvements solely to AVL since there are many other factors which affect reliability (e.g. changing traffic conditions, staff and bus shortages) which are not given in the statistics produced and which are rarely constant (Wileman, 1995). Tyler (1995) attributes the lack of improved reliability in many systems to constraints, such as traffic congestion, which he sees as a strong influence on reliability.

AVL systems in bus garages are mainly used to (Cassidy, 1995):

- inform a driver of the predicted arrival time of the next bus (in cases of vehicle breakdown) so that this information can be relayed to transferring passengers
• highlight bunching
• assess if buses are early/late with regard to schedule

In order to carry out the tasks mentioned above, a route controller requires (Freeman, 1972; Wileman, 1995):
• up-to-date and accurate positional information of all buses
• rapid and reliable communication with drivers

Harper et al. (1996) observes that if the AVL system is deemed unreliable then voice communication will increases as controllers check up on the position of buses.

Wileman (1995) notes that the predicted journey times of buses must be accurate if the information is to be used by controllers to make control decisions. She observes that for the full benefits of AVL to be realised, the controllers’ job should be re-specified so that they dedicate all their time to controlling the route and are not distracted by having to attend to other minor tasks. Existing methods of service control may have to be adapted to utilise the functions offered by the AVL system (Gillingwater, 1995; Wileman, 1995).

Headway control

The traditional methods of operational control are schedule-based, with route controllers in radio contact with individual drivers in order to assess how much ahead or behind schedule they are. The problem associated with schedule-based control is that unless buses arrive at stops exactly on time, passengers at stops have a perception that the service is not running to schedule as the time between buses is not uniform. This problem, of course, still exists even if the buses did arrive at the stops according to a schedule, if the schedule itself did not provide an even headway between buses.

Real-time information about the position of all buses along a route enables controllers to move towards headway-based control strategies which, for high frequency services, fosters the perception of increased reliability for passengers at stops as the headway between buses approaches a constant average time. Wileman (1995) found that in interviews with controllers of a high frequency route, this transition from schedule-based control to headway-based control did not appear to be taking place, with traditional methods (e.g. checking the time of arrival of buses at timing points) still prevailing. This lack of change in working practices
may be a result of the absence of structured training for controllers using AVL systems (Wileman, 1995; Harper et al., 1996).

2.10.2 Real-time passenger information

Real-time passenger information has been around for many years in various formats. Initially information was provided over the telephone, then via Visual Display Units (VDUs) at major interchanges and finally by display signs at stops and signs in other public places which show the expected number of minutes until the arrival of the next bus or next few buses at the stop. Information presented to passengers at stops usually includes, route number, destination and expected wait time. Real-time passenger information systems are discussed in more detail in the Chapter 5.

2.10.3 Real-time bus priority at signalised junctions

Inductive loops embedded in the road are currently used to locate the position of a bus so that it can be given priority at a signalised junction. Since AVL systems continuously track buses, one would assume that it would be a simple process to extend the AVL system to interface with a bus priority system. However Marsden (1995) reports that trials carried out by the University of Southampton have not yet provided conclusive evidence about the suitability of active bus priority measures using dead reckoning AVL systems. He notes that there are benefits which come from having a system which is able to decide if a bus is late before awarding it priority at traffic lights, but a high frequency of polling is required which may increase the running costs significantly if the operator has to pay for air-time. In addition to this, the AVL system may not be able to predict the time of arrival at the stop line sufficiently accurately enough since the time spent at stops is not usually known by these systems. He concludes that even though these problems are not insurmountable they require further work.

Deregulation also causes some problems for this type of bus priority system. Carden and Glover (1995) observe that if a truly comprehensive service is to be provided using bus priority, all operators within a city should be on the system. With a deregulated market it may be difficult to secure financial contributions from many operators, even if the system is commercially secure. Since bus companies are now in open competition with each other, real-time passenger information and bus priority schemes which utilise buses from more than
one company ensure that workstations at each operator’s garage only show buses running along the route from that particular company and not its competitors (Brown, 1993). Transport planning organisations who do not operate buses usually act as a base station for these schemes and therefore are able to view all buses on the route regardless of the operator.

If only some buses are on the priority system then they may be awarded priority to the possible determent of other buses who are not on the system. A similar argument can be made for the provision of real-time passenger information in a deregulated environment, where buses which are not on the system will not be shown on the displays at stops, thereby indicating a more infrequent service than exists in reality.

High accuracy and continuous availability are prerequisites for bus priority at traffic lights via AVL (Tyler, 1994). Priority can either be given via a short range communication link between the bus and the controlled light (decentralised control) or via the UTCC (centralised control) (Khorovitch et al., 1991; Engels and Bonara, 1995). Since it is estimated that 15-25% of a bus’ trip time is spent at traffic lights, bus priority at signalised junctions can make significant reductions in in-vehicle travel time (Khorovitch et al., 1991).

2.10.4 In-cab driver displays

Goldsack (1986) hypothesises that if drivers are able to monitor their own progress via on-board displays they can play a vital role in easing the problem of bus bunching and will not be so concerned about the ‘big-brother is watching’ driver doubts about AVL.

On-board driver displays can either show the headway from the bus in front or the departure from schedule (ITS America, 1994). Adherence to schedule could either be calculated on the bus if the on-board control unit stored scheduled information or processed at the control centre (Engels and Bonara, 1995). Stone (1970) recommends that headway information should be given to drivers in peak periods (when regularity is the prime consideration) and departure from schedule information should be given during the off-peak (when punctuality is generally more important).

An argument against using such a device as a method of route control is that it takes the ‘control’ away from the management and places it with the workforce. This may be
beneficial or disastrous depending on the motivation and personalities of the drivers involved. Also, by placing the onus on the driver to maintain even headways, each driver will be acting independently of every other driver on the route and their collective actions may counteract the benefit of their individual actions. It may also cause the driver to be distracted from his main duty of driving, leading to more accidents.

Although Stone (1970) emphasised the importance of controllers concentrating all their efforts on the actual task of controlling a route, Cassidy (1995) and Wileman (1995) found that in some garages this is not current practice. Therefore the argument for in-cab displays is that it may be more effective to allow each driver to identify when they are getting too close to the bus in front and to slow down accordingly, given the fact that controllers are not always able to monitor route performance. In this way, the onset of bunching will be minimised to situations where it is inevitable, such as accidents blocking the road. This strategy has the advantage of providing a variety in the driver’s duties which may make their job more interesting and enjoyable, leading to an increase in morale.

The future of in-cab displays as a method of route control is entirely dependent on the attitude of individual bus companies and their staff and also on whether the investment in the displays can be financially justified.

2.10.5 Coordination of services

AVL systems can be used to ensure connection of bus services at interchanges, if an ‘intelligent’ bus stop which is aware of the schedule of connecting buses is used. This can then pass messages to the driver’s display unit when the first of the two connecting buses arrives at the stop, informing the driver how long they must wait for the other connecting service to arrive. The system can ignore waiting times beyond a pre-specified maximum which can be adjusted so that the coordination of services may be altered to suit the bus company and can be dependent on the interchange and the time of the day (e.g. rush hour, late transport) (Elkins, 1993a, 1993b). Hani-Prolectron currently offer this facility in the AVL systems they produce.

Assuring connections at interchanges is highly desirable since it increases the attractiveness of public transport by reducing waiting times at stops and provides a more user-friendly bus network. However to achieve this level of automation in connectivity requires:
• all vehicles of connecting services to be fitted with in-cab displays
• all drivers to use their displays at interchanges and to obey the instructions given to them

Both these requirements are non-trivial, with the former increasing the cost of the AVL system. Therefore it is not envisaged that this sort of advancement in improving connections at interchanges will used in the UK in the near future.

2.10.6 Update fare stages

AVL data can be used to automatically update fare stages thus eliminating driver input. However this requires accurate position location since the system needs to know whether the bus has passed a stop even if it did not stop and would increase the complexity of the whole system unless integration with the ticket machine was already being implemented (Engels and Bonara, 1995). The stringent positioning accuracy required could be circumvented by placing beacons at each fare stage which would then automatically update information on the ticket machine (GEC Marconi, 1991a, 1991b). Williams Industries Ltd (1994) report that they are in consultation with Wayfarer Ticket Machines to provide automatic fare stage update without driver intervention via their AVL system.

2.11 Non real-time applications of AVL systems

Finn (1992) points out that an AVL system literally provides a continuous record of all the operator's service activities for every day. This data contributes significantly to the generation of performance measures of journey times and speeds, thus enabling cost-savings to be made by a more efficient allocation of resources through improvements in scheduling (Khorovitch et al., 1991). Once the average speed of a bus on a section of the route is known, the cost attributable to that part of the service can be calculated. It is in the operator's interest to increase the average bus speed since slow moving buses cost proportionately more per mile than free moving buses. Also a reduction in the amount of congestion experienced by the bus will lead to less bus bunching which causes some buses to be under utilised and increases the number of buses needed to provide the same frequency of service. Bigger gaps between buses leads to user dissatisfaction and, hence, a reduction in patronage (GEC Marconi, 1991b).
Previously, bus speed measurements was made by observers with synchronised watches placed at a limited number of fixed points along the route. In this way, each person could record up to 40 buses per hour (regardless of the direction of travel) noting route number, bus number and time to the nearest second (Freeman, 1972). Turner (1995) reports that manually collected travel speed data was within 2 mph of that obtained by AVL. It has been found that bus speeds give a good indication of the general traffic flow since the Paris system showed that, even with dedicated lanes, buses have the same speed pattern as cars (Engels and Bonara, 1995). The information on average speeds can also be used by the bus operator as supporting evidence in campaigning for bus priority measures (see Section 4.3.2.2).

Since a record of the position of buses is kept throughout the day at regular intervals, this data can be for statistical purposes: e.g. reliability and punctuality statistics (see Section 4.3.2.3). London Transport Buses have identified the potential of this source of information and will soon be using this data for contract monitoring purposes when their new Fleet Wide AVL system comes into effect (Balogh, 1996b).

Although non real-time AVL data can be used for a variety of purposes, the reality is that this data is mainly forgotten about and is only used by bus operators to check passenger complaints of late arrival or early departure at certain points along the route.

As mentioned previously the potential of non real-time AVL data is enormous. One possible use of this data is to use it as the basis of a training package for bus route controllers. Currently bus route controllers are mainly trained 'on-the-job' and learn the skills associated with controlling a route through experience of 'trial and error'. Apart from the time involved in training a controller, this process is unsatisfactory because it stifles innovation in control methods as controllers are reticent about trying new methods in case they exacerbate problems instead of solving them. Therefore a training package which allows controllers to try out different strategies in the safety of a 'virtual world' will quicken the training process and may provide new innovative solutions for bus operational problems. A simulation model was developed as part of this research with this aim in mind and is described in Section 4.1.
AVL systems can be based on one or a combination of four technologies:

- dead reckoning
- beacon-based
- radio triangulation, e.g. Datatrak
- GPS

Technologies can be combined if desired, but this will increase the complexity and cost of the system. Vehicle position updates can be obtained by either sequential polling, time-slot polling or exception reporting. Exception reporting is by far the most economical as far as communication costs are concerned but does not enable continuous vehicle tracking to be achieved as the position between reports is not known.

The introduction of AVL systems has had the most beneficial effects on the reliability of low frequency routes. This may be due to the fact that low frequency routes are easier to control since there are fewer buses to monitor. Changes in operational practices do not seem to have taken place with many operators still using schedule-based control strategies instead of moving to headway-based control which would improve passengers' perception of reliability (for high frequency services). However the lack of implementing headway-based control may be more to do with the difficulties such a change in practice would bring about, rather than inflexibility on the part of the route controller.

Real-time AVL data is mainly used for operational control and real-time passenger information purposes with a minority of applications implementing bus priority at traffic lights. In-cab driver displays are not currently used in the UK.

Non real-time AVL data has the potential to aid in optimising resources and schedules. However very few operators use non real-time AVL data in this manner. One possible use of this data would be to use it as the basis of a training package for bus route controllers. In order to develop a realistic tool for training purposes it is important to understand the sort of environment in which buses have to operate and the options available to the controller to remedy the situation when the service deteriorates. These issues will be discussed in more detail in Chapter 3.
CHAPTER 3: THE BUS ENVIRONMENT

Abstract

This chapter outlines the environment in which the bus has to operate, i.e. the political, legal, operational and financial aspects of bus operations. The chapter mainly focuses on previous work undertaken by researchers who have tried to determine the factors which affect bus operations and alternatives which could be used to reduce the unfavourable impacts of these factors. Approaches taken vary between researchers, however: analytical and simulation modelling appear to be prevalent in most of the research undertaken.
3 THE BUS ENVIRONMENT

As buses share their ‘track’ with other users, the bus ‘environment’ can be regarded as very localised, i.e. bus operational control in London is significantly more difficult than bus operational control in rural areas. Therefore in this chapter the bus ‘environment’ considered is that a large urban area. Particular reference is made to London on occasion since the non real-time AVL data used in the development of the simulation model described in Section 4.1 originated from a route in London. London is anomalous in bus operational terms since it experiences traffic congestion for long periods of the day and is not subject to a deregulated operating regime. The differences between the operating regime in London and the rest of the country is explained in more detail in Section 3.1. Section 3.2 describes the legal constraints imposed on a bus operator (regardless of location). Other aspects of the bus environment, namely: bus operational control, behaviour of buses and patronage estimation are discussed in Sections 3.3 to 3.5 respectively.

3.1 POLITICAL

3.1.1 Deregulation

In order to remove the perceived inefficiency of bus operations in the country and to encourage a free market to prevail, the government decided to deregulate buses in Great Britain (with the exception of London) by using the Transport Act 1985. Deregulation means that bus operators run services on a commercial basis and are required to have a operators licence (see Section 3.2) and to register their services with the local Traffic Commissioner six weeks before the service becomes operational. Similar notice is required to withdraw or introduce changes to the service. The Department of Transport (1993c) insist that all quality controls on operator licensing and vehicle safety have been maintained.

Under the Act, local authorities have powers to decide what socially necessary (but unprofitable) services they need to provide under subsidy. In place of the previous system of blanket network subsidy paid by local authorities to operators, competitive tendering for each service was introduced. These measures ensured that there was competition on the road for commercial services as well as competition for subsidised services under...

Although deregulation has had positive benefits on operating costs, subsidy paid by local authorities and innovation, other aspects of service have deteriorated, namely (Balcombe *et al.*, 1988; Isaac, 1989; Evans *et al.*, 1991; Pickup *et al.*, 1991; Fairhurst 1992; Majumdar, 1992):

- information available to the passenger
- less frequent services
- loss of integration through facilities, interchanges and ticket availability
- unreliable services
- fare increases (as a result of the abolition of low fares policies)

Passengers of all ages and social groups were found to be of the opinion that bus services had deteriorated post deregulation and had correspondingly reduced their use of buses, therefore leading to the decline in patronage experienced across the country (Walmsley and Simpson, 1989; Pickup *et al.*, 1991; ETSU, 1993; Department of Transport, 1995b).

The registration of local services is currently the basis for the provision of information. Local authorities retain the discretionary power to produce comprehensive cross-operator information. However the frequency with which timetables change make it more difficult to provide full and up-to-date information for the travelling public (Hamilton, 1988; Isaac, 1989; Cahm, 1990; Evans *et al.*, 1991; Cartledge, 1992a; Fairhurst, 1992; Majumdar, 1992; Parry, 1992; Department of Transport, 1991b, 1993a; ETSU, 1993). Frequent changes to the route are less prevalent today than in the first few years of deregulation, mainly because the number of different operators in the bus industry is contracting as a result of the three largest companies (FirstBus, Cowie and Stagecoach) taking over smaller companies and now dominating over 50% of the UK market share (Local Transport Today, 6 June and 15 August, 1996). This change from on-the-road competition to ‘board room’ competition took place in the third year of deregulation and is due to the fact that market entry is most profitable by company mergers and takeovers rather than by competition on the road and through tenders (Pickup *et al.*, 1991; Fairhurst, 1992). In addition to this, falling profit margins in difficult economic circumstances put further pressure on the industry to concentrate. In fact, as Bradshaw and McGreevy (1994) observed, for the last decade monetary costs and financial competitiveness have been the driving force in the provision of urban bus services in Britain. However Pickup *et al.*
(1991) note that although local monopolies have been formed in some areas, small operators still regain a significant, if limited, role.

Cahm (1990) points out that passengers cannot feel confident about using a transport system, if they have difficulty finding out about it. She goes on to say that although bus operators recognise the value of coordinated information for passengers, they argue that such collaboration is very difficult to carry out where there is any significant level of change and/or competition. Trent Buses’ managing director, Brian King, illustrates the need for cooperation between operators in order to build customer confidence in a competitive bus market arguing that:

"Whilst operators still continue to fight for market share, it is in everyone’s interest to ensure that the overall, long term size of that market is not restricted by our short term fear of promoting the opposition"

Bus and Coach Council (1993)

Partial information supplied by individual operators can be positively misleading, encouraging the view that the service is not as frequent as it is in reality or suddenly stops running in the evenings and at the weekend when, in fact, it is run on a contract basis at these times by a different operator (Hamilton, 1988; Cahm, 1990; Evans et al., 1991). It is in the operator’s interest to provide comprehensive bus timetabled information as Cahm (1990) estimates that this can increase patronage by up to 15% and can also have a stabilising effect as operators strive to make service changes around the date of the next issue of the new timetable. However comprehensive timetables are usually only possible when bus companies are not in head-to-head competition with each other (Cahm, 1990; Cartledge, 1992a).

Fairhurst (1992) observes that the problems arising from deregulation in Great Britain are not country specific. On the contrary, if a comparison is made with Chile where fares rose by 100%, bus fleet size rose by 50% and load factors dropped by 60%, after the first ten years of deregulation, one could argue that deregulation in Great Britain has been a resounding success!
3.1.2 Privatisation

In December 1992, the government announced its intention to allow the privatisation of London Buses’ subsidiaries to go ahead prior to full-scale deregulation (Department of Transport, 1991a, 1991b, 1993b; London Transport, 1993b). Privatisation requires that all London Transport bus routes be gradually transferred from ‘gross cost’ tendering to ‘net cost’ tendering. Gross cost tendering means that bus operators return all fare revenue collected, together with ticket machine information to London Transport in return for a one-off payment for running the route. Net cost tendering (or a minimum subsidy contract) requires that the operator bids for the minimum subsidy required to cover the costs of operating that particular route and retains all the revenue from it (London Transport, 1993b; Bradshaw, 1994; Lam, 1994; White, 1994; Local Transport Today, 10 October 1996).

Bradshaw (1994) notes that since net cost tendering means that operators keep all the revenue collected they should, in theory, have a stronger incentive to both collect the revenue which is due and to seek to increase that revenue by giving a better service. He goes on to say that the drawback of such a system is that on common sections of the route served by more than one operator, a bus driver might be encouraged to ‘hang on’ bus stops with the highest revenue potential to collect those passengers who might otherwise catch the bus behind.

Unlike deregulation, privatisation has meant that there is still an official body (London Transport Buses) which coordinates bus routes, sets fare levels and ticketing policies, provides passenger information etc., so that the change in bus services from pre-privatisation to post-privatisation was probably not noticeable most to passengers. The only real change which has occurred in the operation of bus routes in London since privatisation is that operators are now more ‘image aware’ and promote their company name/logo more fiercely than in days gone by. Most operators have kept the familiar livery of the red bus (although there was no compulsion for them to do so) as they are aware of its high status in the eyes of the passengers.
3.2 Legal Requirements

Before an operator can run a bus service, they must first obtain an operator's licence which ensures that their vehicles are of a reasonable standard and that their company is fit to trade. This means that the company must (Department of Transport, 1993b):

- be of good repute
- appropriate financial standing, i.e. have sufficient funds to run the business
- have adequate facilities or arrangements for maintaining vehicles
- obey the law as regards speed limits, insurance etc.

It is the legal responsibility of operators and drivers of vehicles to ensure that the vehicles they use are roadworthy (Health & Safety Commission, 1993). Each operator has to undergo 'spot checks' of vehicles by the Department of Transport. Usually these checks are made during the day when the most un-roadworthy vehicles are in the garage. If too many vehicles are found to be faulty or a few vehicles are found to have major faults then the operator’s licence can be suspended until the necessary repairs are made (or may even be revoked).

In addition to this, operators have to ensure that drivers do not exceed their drivers’ hours which is a set limit on the number of hours a driver can driver without a break. For bus service operations, this means that a driver can drive for no longer than five and a half hours without (at least) a break of half an hour and cannot drive for more than ten hours in any given day. In addition to this, there must be at least a 10 hour rest between shifts and a 24 hour break from commercial driving every two weeks (Health & Safety Commission, 1993). In general, drivers shifts are eight hours long, but split shifts of 12 hours in which the driver works for the first four hours, has a four hour unpaid break and works for the next four hours are also common practice in bus companies around the country. The drivers’ hours limit applies in all circumstances and so duty rosters (i.e. schedules) have to incorporate slack time in order to allow for traffic congestion or other incidents will may cause a driver to be driving for longer than anticipated.

Although the legal drivers' hours seem fairly long, a combination of individual bus company policy and negotiations with drivers’ unions mean that a different set of conditions for drivers prevail, which are more restrictive in operational terms, such as longer meal breaks and breaks after every trip.
3.3 BUS OPERATIONAL CONTROL

Buses operate in a difficult operational environment because the bus system is highly dependent on factors which are out of the operator's control due to the very nature of operations. In order to provide a reasonable service to passengers, the bus operator must strive to improve the reliability of service thus making bus arrivals more predictable. Reeks (1974) defines the word 'reliable' as:

"Of proven consistency in producing satisfactory results - that which can be counted on to do as expected"

Reeks (1974)

and maintains that reliability covers all aspects of the service: safety, punctuality, regularity, cleanliness, passenger comfort, staff/customer relationship, documentation, security etc. In what follows, reliability will be taken to mean punctuality in the case of a long headway service and will be interchangeable for regularity (i.e. the evenness of the gap between two consecutive buses) in the case of a short interval service. This section will mainly focus on the actions which can be taken by a bus company to try and improve reliability.

Movement of buses on a fixed route public transport service can be controlled either by stop scheduling or headway control or a combination of both (ITS America, 1994). Stop scheduling sets fixed departure and/or arrival time for each bus at several points along the route and is suited to operations with few monitoring facilities (Vandebona and Richardson, 1986). Headway control attempts to establish a fixed average time interval between adjacent buses along each route (i.e. the headway between two buses) and is most suitable for routes operating with a short, uniform headway, when passenger arrivals are random (Abkowitz, Eiger and Engelstein, 1986; Abkowitz and Tozzi, 1986). The fixed time spacing is maintained by monitoring transit times at set locations.

Either movement control method will be perturbed by random events that are unpreventable in metropolitan traffic (e.g. congested traffic flow, accidents, unsynchronised traffic signals and variable passenger demand) which leads to vehicle bunching (Skomal, 1981). Welding (1957) notes that in practice, under normal traffic conditions, all that is possible is to correct the service after it has been upset. For this purpose the warning of the onset of irregularity must be obtained quickly and remedial action taken immediately. In order to achieve this, bus route controllers have devised
various control strategies which are based on a combination of experience, layout of the route in question and staff and vehicle availability. Some common control strategies are given below (Bly and Jackson, 1974; Bly and Jackson, 1975; Jackson, 1976; Andersson et al., 1979; Goldblatt and Yedlin, 1981; Spiller, 1981; Victor and Santhakumar, 1986; Bell and Cowell, 1988):

- **turn a bus which has left the termini**: this involves cutting short a journey in one direction so that the driver may be able to fill a gap in service in the other direction or, if the driver is running late, make up time which he or she has lost so that they are put back on to schedule. This strategy means that some passengers on-board the bus will be inconvenienced and may have to wait until the next bus (and possibly pay again if the bus they transfer to is from a different bus company), which is not a good public relations exercise for the bus company involved. Also, turning buses short may make coordinating driver meal breaks and change of shifts difficult (Huddart, 1973). Bly and Jackson (1974) note that the long term effects of turning buses must be considered if this strategy is to be effective.

- **reduce trip length before bus starts trip**: this effectively means that a bus is turned before any passengers have boarded. Even though passengers waiting to board the bus after the turning point will experience a longer waiting time than scheduled, this strategy has the benefit of being less obvious to the travelling public that a change has taken place unless the passengers are very familiar with the schedule of the route, thus instilling greater confidence in the service.

- **delay or 'hurry' a departure from a terminus**: schedules incorporate some slack time at the terminal called lay over or recovery time so that drivers can complete their log card, change the blinds on the bus, are able to start their next trip on time (even if they arrive late) or have a rest (Barnett, 1974). This control strategy will reduce or extend the effective lay over time and is usually only implemented when a gap in service or bunch occurs close to the terminus.

- **inject a bus**: this involves placing a bus from a bus pool into service in the middle of the route to prevent a gap in service. After the bus has completed the trip, it will return to the pool. This strategy is not often used in practice as it is very resource inefficient and also disrupts driver meal breaks and relief times.
remove a bus from service: this involves a bus travelling in a bunch to join a bus pool and wait for the next appropriate opportunity to rejoin service. As with the ‘inject a bus’ strategy, it is not often used as it is resource inefficient.

run light: this strategy is similar to ‘turn a bus’ in that passengers are asked to alight the bus before its scheduled destination but instead of returning in the other direction, the driver will drive to the scheduled destination with a ‘bus not in service’ board and will be able to make up lost time by not picking up or letting down passengers. The advantage of this strategy over ‘turn a bus’ is that the trip in the opposite direction is complete and so the mileage lost is reduced and the passenger wait time at stops close to the destination in the opposite direction is not increased. However the disadvantage of this practice is that it is infuriating for passengers at stops between the turning point and the scheduled destination who witness a bus travelling to their destination empty.

slow down: this merely requires that a bus driver who is about to enter a bunch of buses or who is ahead of schedule drives as slowly as possible until schedule is regained or the gap between the bus and the bus is front is sufficiently large.

speed up: a driver who is behind scheduled may be requested to speed up but this is not often practicable because a driver who is behind schedule will, probably, already be driving as fast as possible.

skip stops: if a driver is behind scheduled, he may be instructed to skip some stops (i.e. only stop if passengers on-board the bus wish to alight) until he has regained scheduled. This is intensely annoying for the passengers waiting at the stops especially if the bus is empty but, in practice, this instruction is only given when a bus is already in a bunch so the time until the next bus arrives at the stop is small. Huddart (1973) recommends that if two buses are within sight of each other, the lead bus can deliberately skip a stop. However this practice makes the assumption that the bus behind has spare capacity, which may not necessarily be the case. ‘Run light’ is a ‘skip stop’ strategy but with no passengers on-board the bus. Bly and Jackson (1974) found that skipping stops and running light are ineffective control strategies as headways are not noticeably decreased but passenger waiting times at ‘skipped’ stops are greatly increased.

wait at stops: if a bus is ahead of schedule, the driver may be instructed to
wait at stops for a few seconds so that he may lose some time and regain schedule. This may be annoying for passengers on-board the bus who find themselves unnecessarily delayed, especially if another bus which would have taken them to their destination passes their bus whilst it is waiting at a stop. However Bly and Jackson (1974) note that waiting at stops effectively slows down the progress of a bus whilst not impeding other traffic by reducing the bus road speed.

- **extend a trip**: some bus services provide a higher frequency over part of the route and a lower frequency over the rest. In cases such as these, buses may be instructed to extend their scheduled trip to cover the whole route to fill a gap, e.g. which may have been left by a bus running early or turned short. Jackson (1976) notes that invariably if a trip is extended then a future trip by the same driver needs to be curtailed so that meal breaks and change of shifts are taken at the appointed times.

- **wait at timing point**: if buses reach a timing point (i.e. a bus stop for which the scheduled departure time is specified) early they should wait there until the appointed departure time. In most bus companies, this is the default method of control and does not require voice instruction by the route controller to be implemented. In most cases, drivers make their own judgements as to whether they should wait or not, which may be dependent on traffic conditions, the position of other buses visible on the route and individual driver attitude and motivation. However Chapman *et al.* (1976a) note that whilst reliability would improve if strict observance of timing points was kept, it should be remembered that this could possibly mean an irritating delay for passengers on-board the bus which might outweigh the benefit of the reduced waiting times at bus stops.

- **substitute bus**: if a bus breaks down en-route, a replacement bus can be sent to replace it (possibly with a replacement driver if the new shift is about to start) or the bus can be taken out of service. In most cases the latter is implemented unless the bus breaks down close to the garage premises.

It should be noted that although these measures may correct the schedule or even out headways, they also degrade the service for some passengers (Koffman, 1978).

The problem of making control decisions which fit in with the change over of duties and
drivers' meal breaks is probably one of the most difficult to resolve, since intervention in this respect has a cumulative effect throughout the whole day and the controller may find that one operational control decision has consequentially led to a dozen more.

In addition to this, controllers in London feel that they are forced to make control decisions which are inappropriate to maintaining an even headway for fear of not meeting the mileage targets set by London Transport (Wileman, 1995). The percentage of scheduled mileage actually run for each route is London is monitored by London Transport and is used as a quality of service index for the bus route tendering process. If the bus operator fails to run a minimum percentage of scheduled mileage, they may not get their contract for that route renewed at the next tender. This stipulation puts pressure on route controllers not to turn buses before they complete their scheduled trip, unless it is a result of traffic congestion in which case the lost mileage is exempt from the calculation of this statistic.

3.4 BUS BEHAVIOUR

Reliability is not the only issue facing bus operators. If scheduled transit journey times are grossly disproportionate to car travel times, the survival of a transit system will have to depend entirely on the captive ridership (Seneviratne and Loo, 1986). De Ivey and Anson (1995) found that nearly 30% of passengers surveyed were not 'captive' to the bus system and may therefore be lost to another mode if bus travel is not satisfying their needs. Relying solely on captive ridership is obviously inadequate for the long-term economic viability of the bus service and therefore it is important that planners have a detailed knowledge of the factors affecting natural journey time, i.e. the journey time excluding the built-in slack (Seneviratne and Loo, 1986) and reliability (since reliability and frequency are considered the two most important attributes of a bus system in surveys undertaken around the country) (Butcher, 1972; De Ivey and Anson, 1995).

An obvious sign of bus service unreliability is that of the bunching of buses. Bus bunching is the term used to describe two or more buses travelling along the route in close proximity, with an effectively zero headway. The most widely used explanation of how buses come to travel in bunches originates from Newell and Potts (1964), who describe this phenomenon as follows: consider a bus which gets slightly delayed at a stop and begins to get behind schedule. At the next stop, more than the usual number of
passengers will have arrived and these will take longer to load. The bus then gets further behind schedule and the original delay gradually amplifies along the route. The bus behind this particular one will find relatively fewer passengers at each stop and so it will (unless purposely delayed) get further and further ahead of schedule, until it reaches the bus in front. The subsequent bus will then get behind schedule and so on, alternate buses getting ahead and behind leads to a tendency for off schedule running and the pairing of buses.

The amount of time buses spend travelling between stops is important to both the operator and the passengers, but it is the variation in bus travel times about that mean (sometimes caused by drivers who drive consistently faster or slower than others in the same conditions) which introduces irregularity into bus operations and can lead to bunching (Chapman et al., 1976a). Variation caused by different driving speeds is more noticeable in uncongested conditions where speed is not restrained by prevailing traffic conditions (Bly and Jackson, 1974; Tai, 1985). In order to gain an insight into other causes of variability of bus reliability and link transit times, researchers have focused on two methodologies: analytical (or deterministic) modelling and simulation modelling.

3.4.1 Analytical models

Newell and Potts (1964) developed a deterministic model which predicted that the ratio of the arrival of passengers at each stop to the rate at which these passengers can be loaded determines how much time is gained or lost at a stop. They note that the passenger arrival rate is usually much smaller than the passenger loading rate so that each stop should gradually return to schedule. This condition will not occur if the passenger arrival rate is greater than half the loading rate in which case all buses will tend to form pairs. The ratio of arrival rate to loading rate can be minimised by rapid loading (Newell and Potts, 1964).

In order to retain simplicity, Newell and Pott's model made many unrealistic assumptions, namely:

- buses moved at constant speed between stops
- bus speed is independent of stop
- the rate of arrival of passengers is assumed to be the same at all stops
- the stops are equidistant
- the loading rate is the same for all buses, i.e. the boarding time per passenger is constant
- buses have infinite capacity
- buses cannot pass each other

Newell and Potts (1964) acknowledge that in reality the passenger arrival rate and travel times between stops vary both with time and stop and that there are several compensating factors which offset the tendency to bunch, e.g.:
- if the headways are small bus drivers can see the bus ahead and can resist the tendency to pair by purposely staying a constant distance behind the bus in front
- in peak periods a bus running too far behind the bus in front may fill and then be able to gain some lost time
- waiting at the next check point would stabilize the schedule
- if bus passing were allowed the tendency to pair would be confused

Tyler (1995) adds that the dependency between bus trajectories and passenger arrival rates is broken if passengers have a choice of buses which will take them to their destination.

Sayers et al. (1994) analysed AVL data from the real-time passenger information system in London (COUNTDOWN) in order to test Newell and Potts hypothesis, i.e. slower buses would tend to be followed by faster buses because of the tendency of slower buses to lose time as it picks up more passengers thereby leaving fewer passengers for the next bus which hence travels faster along the link. However a study of correlations failed to find any evidence to support this hypothesis. Sayers et al. suggest that the lack of agreement with Newell and Potts (1964) hypothesis is a result of traffic effects which tend to outweigh driver, vehicle or passenger effects and note that link travel times are only predictable to a certain degree in terms of previous link travel times on the same or adjacent links.

The common problem associated with all analytical models is the number of unrealistic assumptions which need to be made in order to proceed with model development. Powell and Sheffi (1983) developed two probabilistic models of bus route performance. Both the models make the following assumptions:
- buses may not pass each other
the load on a bus is independent of the time it leaves the stop
if the alighting time exceeds the boarding time, the bus leaves when the
alighting time ends, therefore not allowing new passengers to arrive just as
the alighting process is about to end. The effect of this error is relatively
small since in most cases the arrival rate at the stop will be quite small if the
alighting time tends to dominate, with the notable exception of a busy
shopping street where both passenger arrival rate and proportion of
passengers alighting are high.

The difference between the two models developed by Powell and Sheffi (1983) is that one
model assumes that buses have infinite capacity and the other model correctly assumes
buses have finite capacity. Powell and Sheffi (1983) aimed to describe the tendency of
buses to form pairs by finding the distribution of time at which each bus reaches each
stop whilst incorporating the trajectories of previous buses using their model. The authors
acknowledge that their second assumption, the load on a bus is independent of the time
it leaves the stop, is not very realistic since it ignores the fact that a bus that is behind
schedule probably has a larger load of passenger and suggest that their model may apply
to routes with low demand and long headways. Therefore Powell and Sheffi’s aim of
describing bus bunching using a probabilistic model seems to be one of a purely
mathematical nature and can have little relevance to real life bus operations since bus
bunching is most likely to occur on high demand, short headway routes: a scenario which
their model does not represent accurately.

Newell’s (1971) model to describe the optimum dispatching policies of buses from a point
showed that if the capacity of the bus is large enough to serve all waiting passengers and
the number of buses was large, then the optimal flow rate of vehicles and the number of
passengers served per vehicle both vary with time at approximately the square root of the
arrival rate of passengers. Newell notes that his model has limited applicability because
of at least two assumptions made, namely:
• vehicles can be dispatched at any time
• vehicles have infinite capacity

Although the second assumption is not too unrealistic for low demand routes, the first
requirement of arbitrarily set departure times from termini or other points along the route
is extremely difficult to carry out in practice, since the bus schedule not only serves to
provide a guide to drivers of their ideal position along the route at a given time but it also
schedules drivers' meal breaks and changes of shift at a convenient location and time.

In most models (analytical and simulation), passenger arrivals at stops is assumed to be a Poisson process which follows a Poisson distribution (Barnett, 1974; Heap and Thomas, 1976; Goldblatt and Yedlin, 1981; Sadullah, 1989; Adamski, 1992). Similarly, the binomial distribution is often used to describe the alighting characteristics of passengers (Chapman et al., 1976a; Andersson and Scalia-Tomba, 1981; Guenthner and Sinha, 1983; Glaister, 1985; Tai, 1985; Adamski, 1992). Both these distributions assume no travelling in groups, which is clearly not the case for some passengers (Tai, 1985).

Whilst analytical models are a useful aid in understanding how a bus system operates, they are not applicable for making predictions about the future state of the system since, as Tyler (1994) points out, bus systems are essentially chaotic in nature and so it is impossible to predict subsequent system states precisely as the number of possible states increases with time. The unpredictability in bus operations is due to the fact that buses usually operate in mixed traffic and are, therefore, subject to variation in travel time due to congestion and traffic signals etc. (Sterman and Schofer, 1976; Chapman and Michel, 1978; Polus, 1979; Shanteau, 1981; Tyler, 1994) and since there is such a high level of human interaction at stops, the basic differences between people (e.g. agility, confidence in using the system and mobility) also introduces variation in the time spent at stops.

In order to try and represent the variation in travel time, many simulation models have been developed. The findings from some of these simulation models are summarised below.

3.4.2 Simulation models

Vandebona and Richardson (1985) note that analytical techniques that allow operators to evaluate changes to operational strategies before committing themselves to implementation in the field are in great demand due to the increasingly difficult problems in providing adequate levels of service at reasonable cost. In an attempt to meet this demand, many researchers have developed simulation models to represent bus operations. These models all have supply characteristics, demand characteristics and operational commands which are responsible for the management of the simulation process.
Much of the input data required in simulation modelling, which includes both supply characteristics and demand characteristics such as bus journey times, passenger arrival rates, average boarding times etc., can be derived from on-board bus surveys (Oliver, 1972; Cundill and Watts, 1973). Lesley (1975) observes that roadside surveys showed that the fear that observers on buses tended to modify driver behaviour was unfounded and outside bodies such as universities or county councils had an advantage over the employer in this respect, as it was not a ‘them and us’ situation.

3.4.2.1 Supply characteristics

Supply characteristics include (Oliver, 1972; Bly and Jackson, 1974; Jackson and Stone, 1975; Jackson, 1976; Jenkins, 1976; Kraft and Deutschman, 1977; Andersson et al., 1979; Andersson and Scalia-Tomba, 1981; Goldblatt and Yedlin, 1981; Vandebona and Richardson, 1985; Adebisi, 1986; Pogun and Satir, 1986; Cowell, 1988; Gupta et al., 1988; Santoso, 1988, 1989; Sadullah, 1989):

- description of the route, e.g. distance between stops or link lengths, number of stops
- transit vehicle type, e.g. capacity, number of doors, driver/conductor or driver only
- method of fare payment
- maximum cruise speed of bus
- penalty for stopping, e.g. acceleration and deceleration rates
- travel time along links or between stops which is usually time dependent and may incorporate factors such as the amount of traffic congestion
- type of stop, i.e. a bus must always stop at a compulsory stop but only stops at a request stop if there are passengers wishing to board or alight there
- schedule information, including when drivers change shift and are supposed to wait at timing points
- effect of parallel routes
- ability of buses to pass each other (although, Bly and Jackson (1974) found that this had little effect on the regularity of service since once a bunch is formed it rarely breaks up until it reaches the terminus where the bunch may be broken due to the regulation by the schedule. They note that the prohibition of passing in a simulation model only serves to maintain the order of buses in a bunch. In addition to this, Welding (1965) observes that, in
practice, there is very little overtaking between buses on the same route). Therefore if this factor is omitted it will probably not make much difference to the results of the simulation.

- bus driver characteristics
- traffic signal control states
- disruptions in supply, e.g. staff or bus shortage, major traffic hold-ups, accidents, bus breakdowns (including repair times and probability of breakdown)

Some factors such as stop spacing, acceleration and deceleration rates, number of junctions etc. are governed by operational and technical capabilities and are, therefore, constant (Seneviratne and Loo, 1986).

Oliver (1972) maintains that if the travel time along a link is a random value taken from the observed distribution of running times over that link, then characteristics such as acceleration, deceleration, maximum speed, driver characteristics, traffic density and flow do not have to be represented explicitly in a simulation model. Although, Oliver (1972) is correct in his surmise that the observed distribution of running times along a link implicitly incorporates variation in such factors, correlations which occur between consecutive links due to driver characteristics and prevailing traffic conditions are not represented. Also, running times between consecutive buses are not independent because when two buses bunch, the running time of the second is dependent on the running time of the first.

Seneviratne and Loo (1986) note that wide variations in the layout of roads, travel habits, location of stops and external factors such as traffic volume etc. from one urban area to another and from one link to another in the same area, makes it difficult to derive a universally applicable travel time relationship. They argue that the use of a generalised predictive model of travel time for an entire route, as opposed to individual segments, could produce erroneous results.

In order to predict future system performance under hypothetical control decisions (so as to select the best) or provide real-time passenger information at stops, accurate forecasts of journey times are required. Bell and Cowell (1988) predicted journey times using three methodologies, namely: recursive estimated mean journey time, exponentially smoothed journey time and latest estimated journey time and compared the results of the predictions
with data from an AVL system. They found that the introduction of a discount factor reduces predictive accuracy, the last observed journey time appears to give the best prediction and that journey times do not appear to conform to a moving average process. However they note that the route considered was not a typical urban bus route: with stops spaced far apart, relatively little congestion and low passenger demand.

Welding (1957) found that considerable variation exists in the journey time of buses at different times of the day and different days of the week. However it is the day to day variation of journey time that is important for the regular user who arrives at the stop at the same time every day (Chapman, 1976). There is some dispute as to whether ridership varies on different days of the week and parts of the month since McCord and Cheng (1986) found that ridership (estimated from ticket receipts) was variable across days of the week but Danas (1980) found from bus stop surveys that the passenger arrival rate does not vary significantly between days. One is more inclined to favour Danas (1980) version of events as it is based on disaggregate data and McCord and Cheng (1986) themselves admit that obtaining patronage from ticket sales could give biased results since passengers tend to buy passes when their disposable income is high, e.g. at the beginning of the week or month.

3.4.2.2 Demand characteristics

Demand characteristics usually vary along the route and throughout the day and include (Oliver, 1972; Bly and Jackson, 1974; Jackson and Stone, 1975; Jackson, 1976; Kraft and Deutschman, 1977; Andersson et al., 1979; Andersson and Scalia-Tomba, 1981; Goldblatt and Yedlin, 1981; Vandebona and Richardson, 1985; Pogun and Satir, 1986; Cowell, 1988; Sadullah, 1989):

- demand at stop (e.g. passenger arrival rate) which is dependent on the land use patterns which influences the stop spacing (Seneviratne and Loo, 1986)
- stop time. i.e. the total amount of time the bus spends at a stop
- attractiveness of the stop, e.g. alighting proportions

The demand at stop and stop time are both important as they affect the ultimate reliability of service.
Demand at stops

For a short headway (i.e. time between two successive buses passing the same point) service, regularity is more important to the passenger since it has been shown that, for headways of less than approximately 12 minutes, passengers can be assumed to arrive at random according to a Poisson process (Seddon and Day, 1974; Turnquist, 1978; Danas, 1980; Bowman and Turnquist, 1981). In general for short headway services, no timetable is published but a guide to frequency is posted at each stop (Zegarra, 1991). Danas (1980) found that during his survey of passenger arrivals at two London bus stops at which buses arrived with a short headway, the assumption of random arrivals for only holds for some of the observation periods (which varied between 20 minutes and 2 hours). However he adds that if the observation time intervals considered were made small enough, passengers do indeed arrive at random according to a Poisson process. The average passenger waiting (AWT) time at individual stops under the conditions of random passenger arrivals and a perfectly regular bus service is given by (Bly and Jackson, 1974; Seddon and Day, 1974; Day, 1976):

\[ AWT = \frac{h}{2} \]  

where: \( h \): headway of service

If the service becomes irregular, the time intervals between buses are not all of the same length and more passengers will arrive in the long intervals than in the short intervals. Consequently, there will be more people with a waiting time of longer than half the mean headway than people whose waiting time is less than half the mean headway and hence the average passenger waiting time increases and can be derived as follows (Welding, 1965; Seddon and Day, 1974; Lesley, 1975; Day, 1976; Ceder and Marguier, 1985). Assume that (Bly and Jackson, 1974; Chapman et al., 1976a):

- passengers arrive at the stop at random, i.e. there is no association between the times of arrival of passengers and the scheduled or expected departure time of buses
- passengers board the first (desired) bus that arrives
- the arrival rate and headway distributions do not vary with time

and let the bus headway in time interval \( i \) be \( h_i \). If there are \( n \) intervals then the length
of the observation time is:

\[ \sum_{i=1}^{n} h_i \]  \hspace{1cm} [3.2]

Assuming passengers arrive at random during the interval, the probability that a passenger will arrive during the length of time \( h_i \) is given by:

\[ \frac{h_i}{\sum_{i=1}^{n} h_i} \]  \hspace{1cm} [3.3]

Given that a passenger arrives during a period of length \( h_i \) and assuming that they are able to board the next bus to arrive, the expected length of wait is:

\[ \frac{h_i}{2} \]  \hspace{1cm} [3.4]

The expected value of a variable \( X \), \( E(X) \), is defined as:

\[ E(X) = \sum_{i=1}^{n} x_i P(X=x_i) \]  \hspace{1cm} [3.5]

where \( P(X=x_i) \): probability that \( X \) equals \( x_i \)

Therefore the average expected wait time (AWT) during the interval is the sum, over the \( n \) headways, of the probability that a passenger arrives during a period of length \( h_i \) multiplied by the expected value of their wait, i.e.

\[ AWT = \sum_{i=1}^{n} \left( \frac{h_i}{\sum_{i=1}^{n} h_i} \cdot \frac{h_i}{2} \right) \]  \hspace{1cm} [3.6]

\[ AWT = \frac{\sum_{i=1}^{n} h_i^2}{2 \sum_{i=1}^{n} h_i} \]  \hspace{1cm} [3.7]

If this is rewritten in terms of the expected value of the headway, then:
The variance of the headway, var(h), can be written as:

\[ \text{Var}(h) = \frac{\sum_{i=1}^{n} (h_i - \bar{h})^2}{n} = E[(h - \bar{h})^2] \]  

[3.10]

where \( \bar{h} \): average headway between buses at a stop

Using properties of expectations:

\[ E[(h - \bar{h})^2] = E(h^2 - 2h\bar{h} + \bar{h}^2) = E(h^2) - 2E(h)\bar{h} + \bar{h}^2 \]  

[3.11]

since

\[ E(h) = \bar{h} \]  

[3.12]

\[ \text{var}(h) = E(h^2) - 2\bar{h}^2 + \bar{h}^2 = E(h^2) - [E(h)]^2 \]  

[3.13]

\[ AWT = \frac{E(h^2)}{2E(h)} = \frac{\text{var}(h) + [E(h)]^2}{2E(h)} \]  

[3.14]

since

\[ E(h) = \bar{h} \]  

[3.15]

this can be rewritten as:

\[ AWT = \frac{\text{var}(h) + \bar{h}^2}{2\bar{h}} \]  

[3.16]

\[ AWT = \frac{\bar{h}}{2} \left(1 + \frac{\text{var}(h)}{\bar{h}^2}\right) \]  

[3.17]

This expression is the most common form of describing the average waiting time at stops (Holroyd and Scraggs, 1966; Seddon and Day, 1974; Chapman et al., 1976a; Jackson et
at, 1977 Bowman and Turnquist, 1981; Ceder and Marguier, 1985; Tai, 1985) and shows that the average passenger waiting time can be decreased if the irregularity of service, \( \text{var}(h) \), can be decreased (Bly and Jackson, 1974). The difference between the average waiting time due to an irregular service (Equation 3.17) and the waiting time which would result from a perfect service (Equation 3.4) is called the excess waiting time (Tai, 1985).

For headways greater than 12 minutes, reliability (or schedule adherence as it is sometimes called) is more of an issue, since passengers are assumed to time their arrival at a stop to be in time to catch a particular bus (Seddon and Day, 1974; Turnquist, 1978; Danas, 1980; Bowman and Turnquist, 1981). Jolliffe and Hutchinson (1975) note that a substantial fraction of passenger arrivals is casually dependent on the bus' arrival at the stop as people run to catch the bus when they see it approaching the stop.

More recent research by Bowman and Turnquist (1981) has indicated that passenger wait time is much more sensitive to schedule adherence improvements than previously supposed and that sensitivity to service frequency is not as great as previously assumed. Their findings imply that resources may be better applied to improving schedule adherence than to simply increase service frequency. However it is difficult to find a general result for the pattern of passenger arrivals since passenger behaviour varies from place to place, according to the knowledge and experience of the regularity of service (Chapman et al., 1976a). Whatever the arrival pattern of passengers, there exists a maximum acceptable wait time at stops after which time passengers will seek an alternative mode of transport or defer their trip (Koffman, 1978).

In many simulation models (Chapman et al., 1976a; Jackson, 1976; Danas, 1980; Victor and Santhakumar, 1986), the passenger arrival rate was calculated by means of observers situated at stops who recorded the number of passengers arriving in specified time intervals. Although this method has the benefit of being accurate, it is very labour intensive and requires observers spending many hours at bus stops in all weather conditions in order to obtain a reasonable amount of arrival rate data. A new, more cost-effective method of estimating the passenger arrival rate at stops utilising AVL data is given in Section 4.1.3.
Stop time

The stop time, or dwell time as it is sometimes called, is defined as being from wheel stop to acceleration away from the stop with closed doors (Andersson and Scalia-Tomba, 1981; Tyler, 1992). Chapman et al. (1976a) found that 72% of the variation in stop time could be accounted for by the number of passengers boarding and that a further 8% could be explained by differences between drivers. This leaves 20% of the variation unaccounted for but likely to be caused by a number of factors including differences in mobility, readiness to tender the fare, fare payment method used, need of reassurance or directions from the driver, etc. There is sometimes a delay between when the driver is ready to leave the stop and acceleration away from the stop due to difficulty in entering the traffic stream or congestion at bus stops (which is when buses are unable to leave a stop due to obstruction by other buses) (Gibson et al., 1989). The total time spent at stops (i.e. the stop time) can be calculated as follows:

For a one door bus where boarding and alighting occurs sequentially

\[ S = C + T_a + T_b \]  \hspace{1cm} [3.18]

For a two door bus where boarding and alighting occurs simultaneously

\[ S = C + \text{Max} \ (T_b, \ T_a) \]  \hspace{1cm} [3.19]

where

- \( S \): stop time or dwell time
- \( C \): dead time
- \( T_b \): time taken for the boarding process
- \( T_a \): time taken for the alighting process

The dead time, \( C \), is the part of the stop time not attributable to either the boarding or alighting process and usually encompasses the time taken to open and close door, for the driver to check traffic before moving off etc. (Chapman et al., 1976a; Chapman and Michel, 1978). The time taken for these processes reflects the characteristics of the bus and the skill of the driver and varies with bus types, from an average of less than 1 second to more than 7 seconds per stop (Cundill and Watts, 1973).
3.4.2.3 Results from simulation models

The outputs from simulation models are often used to establish factors which affect reliability of service and usually include (Bly and Jackson, 1974; Jackson, 1976; Jackson et al., 1977; Vandebona and Richardson, 1985; Sadullah, 1989; Vijayakumar and Jacobs, 1990):

- average passenger waiting time at each stop
- in-vehicle travel time
- bus occupancy at each stop
- average dwell time at stops
- average commercial speed, i.e. the speed along a section of a route including all stops but excluding any time in which a bus is not operating at either end of the section, e.g. meal breaks, lay over times (Tyler, 1992)
- departure from schedule at timing points
- generalised cost to passengers
- bus headways at each stop for each bus
- coefficient of variation, i.e. the ratio of standard deviation to mean, of headway at stops which is 0 when the service is regular
- operating cost

Chapman (1976) notes that the coefficient of variation of headways is not an ideal indicator of quality of service because it utilises an equal treatment of early arrivals and late arrivals at stops. Although this may be reasonable for a short headway service, it is not applicable for a service for which passengers time their arrival at a stop to meet a particular bus. Lesley (1975) recommends that stops whose coefficient of variation of headways increases by more than twice the average value should be selected as timing points for the route.

Bell and Cowell (1988) developed a simulation model in order to isolate the effects of passenger flow. Their model essentially added random noise to the elements of the Newell and Potts (1964) deterministic model. They assumed that passenger arrival at stops is a Poisson process (i.e. there is no tendency to arrive in groups) and that between-stop running times and bus boarding times were normally distributed variates. The results of the simulation indicated that service regularity decreases with increasing passenger arrival rate for a given service frequency and supported Newell and Potts finding that the system
tends to lose stability as the passenger arrival rate at any stop approaches half the boarding rate. This last result was also obtained by Bae and Kachroo (1995).

The most comprehensive simulation model of urban bus operations was developed by Bly and Jackson (1974) who used their model to test the effects of various control strategies. Bly and Jackson’s model did suffer, at times, from a certain lack of reality in some of the control decisions offered to controllers. They defend this stance by saying that practical problems could be considered in light of the findings of their work.

Factors which affect reliability

The impact of variations from the different sources on the reliability of buses has been quantified by Chapman et al., (1976a, 1976b) as follows:

- **Large impact:** travel time between stops (which is affected by traffic conditions, traffic control signals and driver behaviour), probability of bus stopping, boarding time of passengers, number of passengers boarding
- **Medium impact:** number of alighting passengers and their alighting times
- **Small impact:** dead time at stop, penalty for stopping

Many researchers (Welding, 1957; Chapman et al., 1976a; Jackson et al., 1977; Abkowitz and Engelstein, 1983, 1984) have found that punctual departure from termini and traffic management measures (such as bus lanes, parking controls and priority at traffic lights) provide the greatest improvements in bus reliability. However Abkowitz and Engelstein (1983) and Welding (1965) maintain that although road characteristics influence delay, they do not influence variation in delay and suggest that investment strategies which emphasise improved control rather than street improvements may produce a more reliable service.

To improve the probability of punctual departure from termini, the running time allowance or lay over time at the termini can be extended but this may also increase operating costs, reduce the frequency of service and increase in-vehicle running time. Extending the running time allowance may prove to be frustrating for passengers on-board who perceive that their journey time has unnecessarily increased and extending the lay over time may be impractical due to a lack of sufficient standing room at the termini (Welding, 1957; Lesley, 1975; Abkowitz and Engelstein, 1984; Tai, 1985). In addition to this, Bly and
Jackson (1974) found that in the surveys they carried out, drivers often left early from the termini so increasing the lay over time would not have any practical effect. If the schedule is to be adhered to, it is important that it is realistic (Butcher, 1972; Lesley, 1975; Jackson et al., 1977).

Abkowitz and Engelstein (1983) found that shortening the route leads to service improvements at the expense of additional delay to passengers who must transfer. Sterman and Schofer (1976) also identified this problem and recommended that if a significant number of passengers are making long trips then the introduction of an express service should be considered.

Fare collection policies and door configurations have been identified by many researchers as being important in reducing dwell time at stops (Jowett, 1972; Cundill and Watts, 1973; Kraft and Bergen, 1974; Werz, 1975; Jackson et al., 1977; Goldblatt and Yedlin, 1981; Levinson, 1983; Gibson et al., 1989; York, 1993). Many regression models have been developed to describe the time spent at stops due to the boarding and alighting process from bus survey data (Kraft and Boardman, 1969; Boardman and Kraft, 1970; Zografos and Levinson, 1986; Pretty and Russell, 1988). Jackson et al. (1977) estimated that a decrease in the mean boarding time from 5.5 seconds to 2.5 second, which is equivalent to changing the method of fare collection from cash fares to passes (Lobo, 1995), causes a reduction of 8% in the mean passenger waiting time and 10% in the mean on-bus travel time during the evening peak period. It is estimated that passengers take an average of 20% (Kraft and Deutschman, 1977) to 30% (Werz, 1975) longer to board buses which are already heavily loaded and that a 10-15% reduction can be made in the boarding time in the peak hours compared to the off-peak (Werz, 1975).

**Headway-based control**

Abkowitz and Tozzi (1986) examined the benefits of headway-based control and found that holding a bus until the headway between it and the previous bus was equal to a pre-specified minimum produced little or no saving in passenger wait times if the boarding profile was such that the majority of passengers boarded at the start of the route and alighted anywhere from the middle to the end of the route. This is because the control is only effective if the number of passengers boarding after the control point is large enough to outweigh the disadvantage to those passengers who will be detained on the bus whilst
it waits for the headway to increase (Abkowitz and Engelstein, 1984; Abkowitz, Eiger and Engelstein, 1986; Vandebona and Richardson, 1986). Bly and Jackson (1974) also note that although this control methodology improves the regularity of service significantly, it can only increase short headways and not reduce long ones and that departure from schedule increases although regularity improves and hence can only be used when passenger arrivals are random and not timed in order to catch a particular bus.

3.4.2.4 Potential areas for further research

Jenkins (1976) made a comparison of several techniques for simulating bus routes and noted the important features which are absent from almost all models. A more up-to-date list (based on Jenkins’ original) is given below:

- time of day variations in the pattern of passenger movements
- a flexible treatment of the passenger boarding and alighting times including variations between passengers and variations with time of day
- correlations of bus travel times between the same bus on different parts of the route caused by driver characteristics
- realistic passenger arrival patterns for long headways, where passengers time their arrivals for specific buses

Abkowitz and Engelstein (1983, 1984) point out that many researchers have used analytical and simulation models to study the factors affecting running time due to the lack of empirical data caused by the high costs associated with direct observation. They note that a major limitation of simulation models is the assumptions made in model development. However even in the development of empirical models, unrealistic assumptions have to be made (in Abkowitz and Engelstein’s (1984) case, the independence of routes within the network). Therefore greater use of empirical data in simulation modelling is seen as an area of future research.

Cowell (1988) describes a simulation model which was used to investigate the efficiency of different arrival time estimation algorithms under various conditions. He assumed normally distributed bus journey times between stops, a Poisson process of passenger arrivals and a regular service pattern, i.e. a bus every $n$ minutes. Cowell’s model is somewhat different from other simulation models in that it incorporates the ability to simulate automatic vehicle detection by allowing the user to enter the position of beacons
along the route so that different beacon spacings can be tried to test the performance of the prediction algorithms. This model provides a useful starting point for the incorporation of features of AVL systems in simulation modelling but a more realistic treatment of bus scheduling is required in order to improve its credibility.

Stone (1970) highlights the need for a combination of empirical methods of control (i.e. day to day experience of route controllers) which is a slow process and simulation models which are much quicker but which are not terribly realistic. Therefore simulation models should be expanded to allow evaluation of AVL control information in various operational environments, in order to increase the opportunities for controller training (Cassidy, 1995).

3.5 PATRONAGE ESTIMATION

An increasing number of routes in London are now being tendered on a net cost basis (see Section 3.1.2). Net cost tendering requires that bus operators bid for routes with the aim of minimising subsidy in order to increase the chances of a successful bid. Patronage estimation is a crucial component of this process as the operator needs to be able to estimate both revenue and costs accurately in order to make a bid which yields a reasonable profit whilst minimising subsidy. This section describes existing methods of estimating patronage at stops.

3.5.1 Bus stop surveys

The most labour intensive method of estimating patronage is by using bus stop surveys. For a reasonable quantity of stop-specific data to be obtained, surveys must be taken over large periods of times at all bus stops along the route. The cost of carrying out this exercise can be reduced if only the most popular stops are included in the survey and an estimate is made as to the patronage at less popular stops. However this can result in a hybrid of high quality and low quality data. Even though transport operators do not necessarily require a great level of accuracy in estimating patronage the use to which the data can be put is limited, as modelling of bus routes tends to require high quality stop-specific data (since the time a bus spends at a stop forms a crucial component of the overall performance of the route).
3.5.2 On-board surveys

London Transport have historically estimated patronage by using Origin-Destination (OD) surveys. In these surveys the number of passengers boarding and alighting are recorded as part of an on-bus survey which also requests that passengers supply information about themselves (e.g. adult, child, pensioner) and their journey (e.g. origin and destination, journey purpose). This information is then used to extract the mean number of boarders per bus for each of several different subsets of the survey data, for example, Monday-Friday only, work trips only (Wood, 1988).

3.5.3 Electronic ticket machines

More recently, the number of people who board the bus between groups of stops (called stages) can be obtained directly by downloading information from electronic ticket machines on-board buses. Ticket machines can be configured so that every stop is a stage but this would require greater driver participation and could lead to greater errors in estimates if drivers forgot to update stages as they pass stops (especially if they are not required to stop for boarding and alighting purposes). Stage data is also subject to error if the driver fails to update the stage but if stages are set to be busy stops there is a greater likelihood of the bus stopping and the driver updating the stage. The ticket machine can be configured to prompt the driver for an updated fare stage via the display on the machine (if the fare stage has not been updated within a given period of time). However this is not fool-proof process as the driver may not look at the ticket machine display if there are no boarding passengers. In practice, a stage-based (as opposed to stop-based) approach is the preferred option as it minimises driver input.

During the course of dispensing tickets the driver must enter the passenger’s destination into the ticket machine so that the fare can be calculated from the fare table stored in the machine (unless, of course, the passenger states the fare to be paid as opposed to the destination required). Since the origin is known (if stages are defined on an individual stop basis) origin-destination matrices can be obtained from the ticket machine data, but only for fare-paying passengers who state their destination (as passengers with passes who form approximately 70% of the bus market (London Transport, 1994; Lobo, 1995) are not required to state their destination on boarding a bus).
This method of patronage estimation has the advantage of being cost-efficient but has the disadvantage of providing an estimate of patronage on an aggregate basis if stages encompass more than one stop. Whilst aggregation is acceptable for patronage information, it is generally not acceptable for detailed modelling of bus operations which requires stop-specific patronage estimation.

3.5.4 Smart technology

Smartcards are currently on trial in many fields where cashless payment is desirable. A trial which used smartcard ticketing for passes and a traditional electronic ticket machine for cash fares was carried out on buses in Harrow (London) between the beginning of 1994 and the end of 1995. Smart ticket machines allow information to be downloaded automatically via modems on-board buses and beacons at selected sites, such as in the garage. Collection of patronage information can then be automated with buses being polled at night whilst in the garage, thus making the process effortless. However this technology has its disadvantages:

- modems and beacons will increase the cost and complexity of the ticketing system
- smartcards are currently used by passengers who would otherwise have used some type of a pass (e.g. concessionary, season) and so the number of passengers who pay by cash, which accounts for approximately 30% of the total patronage in London (London Transport, 1994; Lobo, 1995), must be estimated using conventional ticket machines which means that data from two sources needs to be combined. This problem can of course be overcome by insisting that all passengers (including occasional users) are obliged to use stored value smartcards or passes. However this would create a barrier to entry to bus travel since it would be much more inconvenient to purchase a ticket. Therefore economic evaluation and political backing is required before this type of scheme is implemented.

As with electronic ticket machines, smart ticketing is also operated on a stage basis with stages being manually updated by drivers. However 'smart' technology has the added benefit of allowing market segmentation to be carried out as the type of pass used is automatically recorded and thus has the potential to provide an enormous database of patronage information.
3.5.5 Other techniques to estimate patronage

Bus passenger loading can also be estimated by using (Yuen, 1988; Khorovitch et al., 1991):

- equipment which reacts to the overall weight of the vehicle using scale detectors which can be based on:
  - pressurised air changes in air spring bags on buses which have air suspension
  - tensiometric sensors for vehicles with other types of suspension systems
- infra-red sensors fitted to all doors of the bus
- pressure sensitive or inductive mats: these are installed at each door. Two mats can be used for a one door bus as the sequence in which the mats are activated indicates the direction of passenger movements. This technology has been implemented by several public transport operators in America (Yuen, 1988).

3.6 Summary

Reliability has been highlighted as an important attribute of bus services in many passenger surveys. However many control strategies which have been devised to improve reliability of services, have their effectiveness greatly reduced by the presence of passengers on the bus or at a stop. For example, if a bus skips a stop where there are passengers waiting, the time the bus might have regained on its schedule may be overshadowed by the fact that the passengers left waiting at the stop will be unhappy with the service the bus company is providing and may decide that they would rather not use the bus again. Also, if bus drivers drive slowly when traffic conditions are slack then they might get public complaints of deliberate dawdling. The same applies for drivers who wait at bus stops so that they may regain schedule. Passengers who have waited with uncertainty for their bus do not want to be faced with an increase in their journey time and further uncertainty caused, not by traffic conditions, but by the driver of the bus they patiently waited for. Therefore it is much better to shorten or lengthen lay overs at termini than to hold buses at stops, since the former control strategy is ‘invisible’ to passengers whereas the latter increases in-vehicle travel time for passengers and travel time uncertainty. Similarly, drivers should be notified of a curtailment of their trip before they
leave the termini, so that passengers do not suddenly find themselves inconvenienced by having to alight from the bus half way through their journey because the trip was curtailed. Other constraints also make some control strategies inoperable in practice. For example, an increase in lay over time at termini may be ruled out by inadequate standing accommodation at the termini.

Analytical and simulation models have been used to identify the factors which affect the reliability of services but have made many unrealistic assumptions in doing so, due to a lack of empirical data. Stone (1970) highlighted the need for a combination of empirical methods of control and simulation models and Cassidy (1995) pointed out that better controller training could be achieved by the detailed evaluation of AVL control information in various operational environments. However attempts to incorporate the features of AVL systems into simulation modelling have been few and far between and it is the apparent lack of relevant work in the area which has promoted this current research.

The emergence of AVL technology has enabled large quantities of empirical data to be available, as AVL systems provide detailed information concerning the travel time of buses along links and their relative position (which would, otherwise, be very costly to collect). Since AVL data represents actual events which have occurred, the number of unrealistic assumptions which have to be made in using this data in modelling is reduced. It is hypothesised that a simulation model based on empirical data will yield more realistic results. This hypothesis was tested in the simulation model developed and described in Chapter 4.
CHAPTER 4: ANALYSIS AND MODELLING OF BUS ROUTE OPERATIONS

Abstract

Non real-time AVL data is not currently being used to its full potential. This chapter highlights the problems which may be incurred when using non real-time AVL data and describes how non real-time AVL data can be used to calculate the passenger arrival rate at stops (when used in conjunction with an on-board bus survey) and consequently how the average speed of buses between stops can be established. The average speed of buses between stops is important in order to highlight areas along the route where buses are being delayed (so that the introduction of bus priority measures can be prioritised).

It is argued that non real-time AVL data provides detailed running time information about individual buses which would provide a better representation of bus operations if used as the basis of a simulation model, as the model would be based on empirical data. This hypothesis is tested and the results are presented.
The advantages of AVL systems are often regarded as being:

- improved schedule adherence and regularity of headways of buses
- greater efficiency in disruption management
- provide better service information for the operator which can be used to improve the schedule and compile reliability and punctuality statistics
- reduced operating costs through reductions in fleet size, unnecessary mileage and roadside inspectors

Improved schedule adherence and greater efficiency in disruption management can only be realised if the information presented to the route controller is an accurate representation of the actual situation on the road and the controllers make use of the information given to them. The former requirement is dependent on the system and the operating environment but the latter requirement is dependent on the personality of individual controllers, their skill (i.e. knowledge and experience) and, to a certain extent, the environment in which they have to work. Therefore the operator can enhance the prospects of good service control by improving the environment in which the controller has to work (e.g. isolating the control room and allowing the controller to concentrate all their efforts on controlling the route) and providing suitable training for controllers.

Training is most effective when it represents reality closely, i.e. provides pseudo experience. A means of providing realistic training would be to replay the activities of buses for a day in ‘fast motion’ and to ask the controller to make control decisions based on the information presented. AVL systems are currently able to replay a day’s worth of bus operations but the problem with using this feature for controller training is that the controller has no input into the system and so is effectively watching a record of past events. In order to make the training process more interactive (i.e. where a decision made by a controller has an effect on future bus movements) a simulation model is required. Stone (1970) and Cassidy (1995) identified the need for simulation models of bus route operations to be based on empirical data. Such a model has been developed in this research and utilises non real-time AVL data. The model also requires other data, notably patronage information, which could not be extracted from the AVL data. Therefore a patronage survey of the case study route (the Route 18 in London) was carried out. The following sections describe how data from both the patronage survey of the route and the...
AVL system can be used to estimate the input data required for the simulation model (i.e. passenger arrival rate at stops and the speed of buses as they move between stops) and compares the benefits which can be accrued from each data set.

4.1 SIMULATION MODEL METHODOLOGY

4.1.1 Model description

AVL data provides the time a bus took to complete a link but it does not explain why this time may be unusually long, e.g. if it is due to an unusually high passenger arrival rate or traffic congestion. Therefore in the model, the time spent at stops along a link (with an assumed passenger loading (i.e. the passenger loading for the given stop, day, time of day and headway between buses) which is calculated from the passenger arrival rates obtained from the patronage survey and AVL data) is subtracted from the actual link travel time and the remaining time is assigned to be the travel time of the bus moving between stops along the link. By doing this, any disruption experienced by the bus in practice will also be experienced by the buses in the simulation.

The moving speed of the bus is then calculated by dividing the link length by the travel time of the bus along the link after the time at stops has been removed. This definition of moving speed implicitly includes the time the bus spends queuing at traffic lights, unlike the definition of moving speed used by Chapman et al. (1976a) which reflects the actual speed of the bus when it is moving.

After the bus spends the required amount of time at the stop to complete the boarding and alighting processes it starts to move away. The speed at which the bus moves at is determined by either:

- the average moving speed of buses along the link in that time period of half an hour (Model A) or
- the actual moving speed of that particular bus (i.e. trip: a journey by a bus from scheduled origin to destination) along that particular link as obtained from the AVL data (Model B)

The simulation model was written in PASCAL. The simulation was carried out for days which AVL data was available (i.e. between September and October 1994) using
passenger arrival rates obtained from the Route 18 survey (and associated AVL data) carried out during April and May 1995. More specific details of the model are given in Section 4.1.3.

4.1.2 Assumptions

Tai (1985) notes that every assumption made in a simulation simplifies the complicated reality and reduces the closeness of the representation of the real situation. However in order to proceed with the research some assumptions have to be made. The assumptions made in the development of the simulation model are as follows:

- passengers arrive at bus stops independently of each other and in a random fashion according to a Poisson process. This assumes that (Law and Kelton, 1991):
  - passengers arrive one at a time, i.e. not in groups
  - the number of arrivals in the time interval \((t, t+s]\) is independent of the number who arrived in the earlier time interval \([0, t]\) and also of the times at which these arrivals occur. This condition would be violated if a large number of arrivals in \([0,t]\) caused some customers arriving in \((t, t+s]\) to go away immediately because they find the system too congested.
  - the distribution of the number of passengers arriving in the interval is independent of the time of day. It would appear that this condition is unrealistic since the arrivals of passengers is known to be dependent on the time of day. However if the time period of interest is relatively short then the arrival rate can be assumed to be reasonably constant over this interval and the Poisson process is a good model for the passenger arrival rate during the interval (Danas, 1980).

- passengers are assumed to board the first bus to arrive which has spare capacity

- buses are only assumed to stop at a bus stop if there are passengers wishing to either alight from the bus or board the bus. Observations from the patronage survey of the case study route showed that this was representative of driver behaviour in such circumstances.

- there is independence between alighting passengers, i.e. no travelling in groups
• the alighting proportion is independent of the passenger's origin stop
• buses arrive at the scheduled origin stop on time. Normally, this would be a
dangerous assumption to make as many authors (Bly and Jackson, 1974;
Abkowitz and Engelstein 1983, 1984) have found that departure from the
terminal significantly affects the performance of the route (as large initial
deviations result in more pronounced instability downstream). However it is
believed that this assumption is a reasonable one since observations from the
patronage survey of the case study route indicated that buses leave the terminal
within approximately ±1.5 minutes of the scheduled departure time.
• duty change overs occur immediately at the change over point, i.e. the bus
does not wait until a relief driver arrives (as would happen in practice) since
the simulation does not know when this is likely to occur.
• buses do not break down along the way.
• an assumed headway of 5 minutes is used as an initial condition in the
model.

4.1.3 Outline of model

The trips which are present in the AVL data file for the day to be simulated are recorded,
so that the simulation can be run for either all the scheduled trips or just the trips which
appear in the AVL file. The simulation runs from 0300 to 0259 for each day simulated
(scheduled day buses start running at around 0500). However since reliable data was only
obtained for the midday off-peak (i.e. 1000-1600) only the results from this time period
are of interest. The time before 1000 is simulated to ‘warm-up’ the model. At the start of
the simulation there are no buses in service. Since there is no bus before the first bus a
headway cannot be calculated so an assumed headway of 5 minutes is used as an initial
condition.

The schedule is known in the program so buses arrive at their scheduled origin at the
appointed time and proceed until they arrive at their scheduled destination where they
unload all their passengers and leave the simulation. The computer program only takes
action when the bus is due to change from one state to another. Since the behaviour of
one bus affects the behaviour of other buses, all bus events are taken in strict
chronological order and the program iterations are carried out using a fixed increment
time advance of one second. When the simulation clock reaches the time for the end of
the simulation the program is terminated.

In the following analysis, $N_b$ will be used to denote the number of passengers waiting for a bus (at stop $i$) and $N_{bi}$ will be used to denote the number of passengers actually able to board a given bus. If the bus has sufficient capacity to accommodate all the waiting passengers then $N_b$ will be equal to $N_{bi}$, otherwise $N_{bi}$ will be less than $N_b$ and in the case of full buses (which have no passengers alighting) $N_{bi}$ will be equal to zero.

Before the passenger arrival rate can be calculated, the estimated time of arrival of buses at stops had to be extrapolated from the AVL data so that the headway between buses at stops could be calculated. This was done in the following manner:

$$T_i = T_{le} - \frac{(D_i - D_0) \times t_i}{D_i}$$  \[4.1\]

where:
- $T_i$: arrival time of bus at the stop
- $T_{le}$: arrival time of bus at the end of the link on which the stop is on
- $D_i$: length of the link on which the stop is on
- $D_0$: distance of the stop from the start of the link
- $t_i$: time bus takes to travel along the whole link

Since it is not known when the last bus left the stop, the headway between buses is calculated as the difference between the arrival times of buses at the stop and not as the difference between the departure times of buses at the stop, which would have yielded more accurate results. The passenger arrival rate was calculated as follows:

$$p_i = \frac{N_{bi}}{T_{i, k} - T_{i, k-1}}$$  \[4.2\]

where:
- $p_i$: passenger arrival rate
- $N_{bi}$: number of boarding passengers
- $k$: bus arrival at that stop, where $k$ is the present bus and $k-1$ is the last bus to arrive at that stop

The speed at which the bus moves between stops on a given link (i.e. the moving speed) is given by:
\[
\nu_m = \frac{D_l}{t_m}
\]

where:

\[
t_m = t_l - \sum_{All \ stops \ on \ link} S_i
\]

where: \[S_i; \quad \text{stop time or dwell time}\]

At the start of the simulation all the trip states are set to 'Not started'. When the simulation clock reaches the start time of a trip, the position of the bus is set to the position of the origin stop of the trip, the occupancy is set to zero, the time the bus arrives at the stop (\[T_j\]) is set to the simulation clock time, the trip state is switched to 'Arrived at stop' and, if the stop is at the end of a link, the time at which the bus completed the link is set to the simulation clock time and the record of the last link which the bus completed is updated.

When the bus arrives at a stop, the occupancy of the bus is altered to take account of the passengers boarding and alighting, the amount of time the bus spends at a stop (i.e. the stop time or dwell time) is calculated and the time at which the bus leaves the stop is subsequently set. The bus state remains as 'Stopped' (therefore not requiring any further action) until the appointed time to leave the stop is reached. In order to assess whether the bus needs to stop at a bus stop, the number of passengers who wish to board and alight must first be calculated.

The number of passengers alighting from a bus, \[N_{ai}\], is calculated by rounding down to the nearest passenger the product of the total number on board the bus and the average proportion of the bus load which alights at that stop, which is appropriate to the time of day.

\[
N_{ai} = O_{i-1} \times f_{i, t, d}
\]

where: \[f_{i, t, d}; \quad \text{proportion of bus alighting at that stop, which is dependent on where the bus terminates at (or originates from) and the time of day}\]

\[O_{i-1}; \quad \text{occupancy of the bus on leaving the previous stop}\]
When a bus arrives at a stop, the number of passengers wishing to board is calculated by multiplying the time elapsed since the last bus departed from the stop by the passenger arrival rate appropriate to that stop at that time of the day and adding this number to the number of passengers who are already at the stop because they could not board the previous bus. This estimate of the number of passengers waiting to board does not take into account that some people have a cut-off point where they will not wait any longer for a bus and may seek an alternative mode or cancel their trip. For the first trip in either direction an initial headway of 5 minutes is assumed, so that some passengers are generated at stops.

\[ N_b = [(T_{i,k} - T\text{Leave}_{i,k-1}) \times p_{i,t}] + F_i + L_i \]  \[ 4.6 \]

where:
- \( N_b \): number of passengers waiting at stop
- \( T_{i,k} \): time at which the present bus, \( k \), arrives at the stop
- \( T\text{Leave}_{i,k-1} \): time at which the previous bus, \( k-1 \), left the stop
- \( F_i \): fraction of a passenger left at the stop
- \( L_i \): number of passengers left at the stop from previous bus(es)
- \( p_{i,t} \): passenger arrival rate at that stop for the relevant time interval

The number of passengers waiting to board, \( N_b \), is rounded down to the nearest integer and \( F_i \) is assigned the remainder. The buses are assumed to have a capacity of 80 passengers which was found to be the practical capacity of the buses during the patronage survey of the case study route (as opposed to the advertised capacity of 71 seated and 20 standees). The available capacity of the bus when it arrives at a stop is calculated as being the available capacity it had when it left the last stop plus the number of people alighting at the current stop. Passengers who are not able to board the first bus plus \( F_i \) are left at the stop to wait for the next bus.

Passengers are assumed to board the first bus to arrive which has spare capacity so if there is already another bus at the stop when a second bus arrives, the model will represent the alighting process of the second bus and will only represent the boarding process of this second bus if the first bus has no space on it to accommodate all the waiting passengers.

For \( N_b = 0 \) and \( N_{ai} = 0 \)

\[ S_i = 0 \] \[ 4.7 \]
For $N_b > 0$ or $N_{ai} > 0$

\[ S_i = \max \left( C_b + T_{bi}, C_a + T_{ai} \right) \]  \[4.8\]

where:
- $N_{ai}$: number of alighting passengers
- $N_{bi}$: number of passengers boarding the bus
- $S_i$: stop time or dwell time
- $C_b$: dead time for boarding process only
- $C_a$: dead time for alighting process only
- $T_{bi}$: time taken for the boarding process
- $T_{ai}$: time taken for the alighting process

where

\[ T_{ai} = A + BN_{ai} \]  \[4.9\]

where: $A$, $B$: constants

\[ T_{bi} = C + DN_{bi} \]  \[4.10\]

where: $C$, $D$: constants

The calculation of the stop time used in the simulation model does not take into account the delay caused by congestion on the bus due to large numbers of passengers alighting from the bus or a high bus occupancy, which on a two door bus as used on the Route 18 can prevent passengers from moving along the bus, thereby delaying the boarding process. The effect of the latter omission is discussed in Section 4.3.1.2.

The spare capacity of the bus, $R_i$, is calculated as follows:

\[ R_i = R_{max} - (O_{i-1} - N_{ai}) \]  \[4.11\]

where: $R_{max}$: maximum capacity of the bus

If the number of passengers waiting to board ($N_b$) is greater than the spare capacity of the bus ($R_i$) then
If the number of passengers waiting to board \((N_b)\) is less than or equal to the spare capacity of the bus \((R_i)\) then

\[
N_{bi} = N_b
\]  
[4.15]

\[
O_i = O_{i-1} - N_{ai} + N_{bi}
\]  
[4.16]

\[
L_i = 0
\]  
[4.17]

As no individual passenger records are kept, the principle of first to arrive at the stop is the first to board the bus cannot be exercised.

If

\[
(S_i \times p_{i,i}) + F_i > 1
\]  
[4.18]

then additional passengers would be generated during the stop time. The time it takes these passengers to board is the average marginal boarding time found from the Route 18 patronage survey. Passengers who have been generated during the stop time are only added to the bus occupancy (and the time taken for them to board to the boarding time) if there is space on the bus, otherwise the number of passengers generated is added to the total of passengers who are left behind at the stop (with no alteration to the boarding time). This process is repeated for the boarding time of the generated passengers until the number of passengers generated in the extra boarding time is less than one. Fractions of passengers are left at the stop to await the next bus. If a bus becomes full, the boarding time will end when the last passenger who is able to board the bus has been processed.

The time at which the bus leaves the stop, \(T_{Leave_{i,k}}\), is set to:

\[
T_{Leave_{i,k}} = T_{i,k} + S_i
\]  
[4.19]

The state of the bus is set to ‘At stop’ if the stop time \((S_i)\) is greater than zero otherwise the state of the bus is set to ‘Moving’. If the bus state is ‘At stop’, it remains in this state until the simulation clock time reaches \(T_{Leave_{i,k}}\). Then the state of the bus either changes to ‘Finished’ if the stop is the destination of the trip or ‘Moving’ if the trip has not ended. Once the bus state is ‘Finished’ the bus plays no part in the rest of the simulation.
If the state of the bus is ‘Moving’ then the new bus position at time \( T \) for trip \( j \) is calculated as:

\[
\text{Position}^*_{T,j} = \text{Position}^*_{T-1,j} + (\text{Moving Speed} \times \text{Time Increment})
\]  \[4.20\]

‘Moving Speed’ is either the average moving speed of buses on the link during the respective time interval \( (v_{i,j}) \) or the moving speed of that particular trip on that particular link as derived from the AVL data \( (v^j_{i,j}) \). If the difference between the new position of the bus and the position of the end of a link is less than the increase in bus position during the time increment but greater or equal to zero, then the record of the last link which that bus completed is updated and the trip number, link number, simulation clock time (i.e. the time at which the bus completed the link) and the link completion time (as calculated by the difference between the time at which the present and last link were completed) is written to the output file for later comparison with the AVL data file. The bus stays in the moving state until it arrives at a stop.

If the difference between the new position of the bus and the position of the next stop at which the bus was due to arrive at is less than the position increase in the time increment but greater or equal to zero, then the bus is deemed to have arrived at the stop and \( T_{i,k} \) is set to the simulation clock time and the next stop at which the bus is due to arrive at is increased by one.

The computer code was verified on a procedure by procedure basis to check that it was performing tasks as required.

4.1.4 Limitations

Since data on individual passenger waiting times and travel patterns are not available for this study, these factors are not explicitly accounted for in the model. Another feature not included in the model is driver behaviour when faced with deviations from schedule, e.g. trying to drive faster when late. However Chapman et al. (1976a) observed that drivers who are ahead or behind schedule do not, as far as can be seen, drive in such a way as to return closer to schedule.
4.2 Data

AVL data from the Route 18 in London which ran from Sudbury to Baker Street and Kings Cross was acquired from London Transport for model development and validation purposes. It should be noted that, as part of a recent route restructuring, all Route 18 buses now terminate at Euston.

A total of 38 AVL data files were used for analysis purposes. Of these 38 files, 28 represented a record of bus movements for days in September-October 1994 and the rest represented days in April-May 1995.

The Route 18 is operated by CentreWest under contract to London Transport Buses and was the trial route for London Transport’s COUNTDOWN real-time passenger information system. At the time of data acquisition, Route 18 buses ran from Sudbury to Baker Street at an approximate headway of 6 minutes in the peak and 12 minutes in the off-peak. Every other bus (until 1900) ran an extended trip which terminated at Kings Cross. Therefore the headway of buses to Kings Cross was every 12 minutes. All buses terminated at Baker Street in the evening off-peak and at weekends.

Table 4.1 provides a list of the input data required for the simulation model and the source of the data.

Table 4.1  Input data required for simulation model

<table>
<thead>
<tr>
<th>Input data</th>
<th>Source</th>
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<td>Schedule information</td>
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<td>Passenger arrival rate at stops</td>
<td>AVL data and Route 18 survey</td>
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The following sections describe the data collection and preparation processes.
4.2.1 Survey methodology

In order to establish the variation in passenger demand along the route at different times of the day and to monitor the effect of these variations on the running times of buses, for use in the development of the simulation model, a survey of the Route 18 was carried out. During the survey, one observer on-board the bus recorded the identification number of the bus, the time at which the bus reached each stop, the number of passengers boarding and alighting at each stop, the method of fare payment for boarding passengers and the total time taken for the boarding and alighting processes. The form used to record measurements in the survey is given in Appendix A.

The Route 18 uses one-man-operated, two door buses. Passengers board at the front of the bus and pay the driver (who dispenses change if necessary), at the same time, passengers alight from a door in the middle of the bus.

Cundill and Watts (1973) found that collecting data for a given bus type at only one or two selected stops could produce misleading results (e.g. stops may be used chiefly by a particular passenger type, or the traffic conditions may not be typical). Consequently, they made observations at a number of stops and the observers normally travelled on the bus so as to cover the whole route. In addition, they noted that by travelling on the bus, observers were better positioned to observe other details, such as the number of persons wanting change.

In light of the observations made by Cundill and Watts (1973) it was decided that patronage information should be gathered by utilising an observer (the author) travelling on-board the bus. Surveying took place between the 24 April 1995 and 15 May 1995 (inclusive) but no surveys were carried out between the 5 May 1995 and the 8 May 1995 as this was a bank holiday weekend and so special traffic conditions and patronage conditions existed which would have been anomalous to the normal conditions which would be expected along the route.

The surveying day started between 7am and 10.30am and finished between 5.30pm and 9.30pm. On average, about 10 to 12 hours of the day was spent surveying. A range of starting times were used to estimate conditions for most of the working day. However since the observer always left from central London and ended the day there, this meant that early times towards London and late times towards Sudbury were not well covered.
Around 4 round trips were made on each weekday from Kings Cross to Sudbury. However at the weekends around 6 round trips could be made each day from Baker Street to Sudbury.

The observer sat either directly behind the driver (where both doors could be easily seen but where observation of alighting passengers was obstructed when the bus became full or many people were boarding) or on the seat opposite (facing the driver). Here the view of some of the alighting passengers was obstructed by those passengers alighting next to them. This problem was particularly acute when children and small people were alighting.

Since there was only one observer, there were no cross-observer variations in the recording of time. The same digital clock was used throughout the surveying period, therefore any error in the recorded GMT time would be systematic. The time when the bus reached a stop was rounded down to the nearest minute. Dead time, alighting and boarding time observations were rounded down to the nearest second.

When the survey data was transcribed, checks were made to ensure accurate input of data, such as printing a warning message if the time at which the bus reaches a stop does not increase as the bus progresses along the route or if the number of passengers paying by the various fare payment methods does not equal the total number of boarding passengers.

4.2.1.1 Number of boarding and alighting passengers

The greatest error in counting boarding and alighting passengers was encountered when there was large numbers of passengers boarding and alighting simultaneously. It was sometimes difficult to see passenger alighting in these conditions as boarding passengers would sometimes obstruct the observer’s view of alighting passengers. Also, when the bus was nearly full, the view of alighting passengers was sometimes obstructed by passengers standing near the door.

The number of passengers boarding only refers to the number of passengers who offered some form of payment or pass. Therefore the bus may have been full but the total number of people on the bus that were accounted for would probably not match the figure required for a full bus due to children occupying seats but not paying. The number of passengers boarding and alighting did not make any distinction between adults and
children.

If nobody boarded the bus then the number of alighting pensioners was sometimes recorded with the time taken for them to alight, in order to assess whether the average time taken for a pensioner to alight was significantly different from that of other passengers.

Discrepancies between the total number of people who boarded the bus and the total number of people who alighted from the bus arise because some alighting passengers who looked over five years old may not have paid (since children under five travel on buses with no associated charge) or through inaccurate counting at busy stops.

4.2.1.2 Boarding time

Boarding time measurements were started after the front door of the bus was opened fully and ended when the last passenger turned away from the driver to move towards the back of the bus. The greatest error in estimating the boarding time was in determining when the boarding process had finished as sometimes this was not clearly defined.

Some observations of boarding time were rejected because the bus moved off before the passenger had found their pass or paid their fare. Therefore the average boarding time obtained is probably a slight underestimate of the true value.

4.2.1.3 Alighting time

The alighting time measurements started when the middle doors opened fully and ended when the last passenger was clear of the bus. This was done because the driver could not move the bus until the last passenger was clear of the bus and is significant when calculating the alighting time of mobility handicapped passengers, such as senior citizens.

4.2.1.4 Concessionary passes

Passengers were recorded as using a concessionary pass (and will be referred to as senior citizens or OAPs for the remainder of this thesis) if they looked over the national retirement age for their sex (i.e. 65 for men and 60 for women) or were visibly
handicapped and used a pass. Since the observer could not see the actual pass used by this category of people some passengers may have been mistakenly assigned to this group or omitted from it. The results for this category of people should therefore be treated with care.

4.2.1.5 Dead time

The dead time was measured as the time from when the bus stopped to when the first passenger was able to board (or alight, if there were no boarding passengers) plus the time from when the last passenger boarded or alighted to when the bus started to accelerate off. This includes the time taken to close the doors and check traffic before moving off. Sometimes the dead time was quite large if traffic was heavy and the driver had to wait for a relatively long time before moving off.

A greater error is associated with the measurement of dead time since it has to be arbitrarily decided as to when the bus starts to accelerate and this can be quite difficult to ascertain when traffic is moving slowly and the bus merely needs to move forward (as opposed to pulling away from the stop into a gap in traffic).

Usually the dead time was measured when either there was nobody alighting or nobody boarding. Hence, boarding dead time and alighting dead time were established independently. If there was nobody boarding or alighting but the bus still stopped, the dead time recorded was the time the bus spent between wheel stop and acceleration off from the stop.

4.2.2 Preparation of data for model

4.2.2.1 Route characteristics

The route details supplied by London Transport Buses have been coded into a format which is easily readable by the computer program. Stops and beacons along the route are identified by a consecutive numbering system, names and their distance from the start of the route. Twenty dummy links have been incorporated to allow for scheduled and unscheduled turnings of buses.
4.2.2 AVL data

The AVL data which was written to file in the COUNTDOWN system at the time of data acquisition consisted of:

- Route number
- Link number
- Time when the bus was first polled after it had completed the link
- Predicted travel time of the bus along the link
- Time the last three buses took to travel along the link
- Default travel time for system initialisation purposes
- Radio identification number

The time at which the bus was polled is assumed to be an estimate of the time the bus completed the link with a maximum associated error of 30 seconds, as this is the length of the polling cycle. This approximation of the link completion time may be inaccurate as the bus may not have had its positional information accepted at the first poll after it had completed the link and also some data may have been lost during polling but since it is not known if, and when, this may have happened no action can be taken to counteract this problem.

The original real-time AVL data file was converted into a more manageable format, for future analysis, which consisted of:

- a new link number. The London Transport link numbers were not consecutively numbered along the route: the new number allowed smaller arrays to be constructed and is consecutively numbered
- time of polling converted into seconds since midnight
- the time the bus took to complete the link
- a new radio number. The garage uses different numbers to identify buses than the AVL system but the relationship between these two numbering systems was known, so a new consecutive numbering system has been employed
- duty number and trip number. These are obtained by comparing the AVL data to the duty data (see Section 4.2.2.3). The duty data file is read and the duties which have used the bus which relates to the radio ID number are identified. The start and end times of the trips which these duties carry out is known from the schedule file so if the time of polling lies between the start and end time of the trip, the data entry is associated with that duty and that
trip, otherwise (if no match can be made) the entry is still recorded but is assigned null values for the trip and duty number. The end time of the trip is estimated as the start time (minus 3 minutes) of the next trip that duty carries out, to allow for late running. Similarly, the start time is estimated as 3 minutes earlier than the schedule, to allow for drivers leaving the terminus/garage early. Three minutes was chosen as the safety margin for early departure and late arrivals because the scheduled lay-over time at termini was usually 5 minutes and so three minutes was approximately half the scheduled lay-over time.

The original AVL data file consisted of processed data and contained some suspect values for the speeds of buses. Suspect data from the original file, e.g. data which indicates that buses travel at speeds of greater than 96.5 km/h (i.e. 60 mph), have been discarded and do not appear in this new converted file since large erroneous values will result in the average speed being overestimated, if the number of observations is small. The file also contained many other variants of suspect data, details of which can be found in Section 4.3.2.1, which had to be discarded.

4.2.2.3 Duty data

At CentreWest, drivers can choose any working bus so the relationship between driver and bus radio changes every day. Therefore the relationship between the buses given in the AVL data and the duty number of the driver of the bus was unknown. Since the AVL data was not accompanied by corresponding duty roster information, this information had to be obtained by visits to the Westbourne Park garage, where the log cards for the Route 18 are held. The log cards are a record of the buses each duty used and are manually filled in by the drivers on a daily basis. Even though the log cards are a mandatory requirement of the bus operator and may be viewed by the traffic commissioner, they were sometimes not filled in completely, i.e. the start or end times of the driver’s possession of the bus or the bus number was not provided. Therefore the times at which the driver took possession of the bus and handed over the bus to another driver had to be estimated from the log card of the driver who took charge of (or was relieved of) the bus at a relief point or from the schedule if there was a change of bus between shifts (and no comparison was available).
Sometimes drivers did not specify which of the two buses recorded in the log card were used in which half of the duty. In cases such as these, if a bus was handed over to another duty and there was good agreement in the time at which the bus was handed over, the bus was assigned to that half of the duty.

Once data from the log cards (i.e. duty, bus number, start and finish time of use of bus) for the days required had been manually copied, the data was transferred into a format that the computer program could read. It was then found that there were many instances where there was overlap in the driver of a bus (i.e. two drivers claimed to have possession of the same bus) which had to be remedied to ensure correct assignment of the trip in the AVL data. This usually happened when the two drivers were changing duty. Therefore the time which was closest to the duty change over time was allocated as the changeover time. Similarly, if the duty which relieved another duty claimed to have the same bus then the end time of the first driver was extended to the changeover time (if it was omitted from the log card).

Another problem which was encountered was deciphering the number of the bus used, as sometimes the handwriting of the drivers was fairly illegible. Therefore a small proportion of the duties may have been incorrectly assigned to a bus. Efforts were made to manually assign a bus to the duty data by visual inspection of the AVL data. However a small number of entries of the AVL data could not be assigned to a trip.

### 4.2.2.4 Schedule data

The Route 18 schedules (different schedules operate on Monday-Thursday, Friday, Saturday and Sunday) have been coded into a trip-based form readable by the computer program. The scheduled arrival time at 6 to 8 points along the route is known for each of the different schedules. However the AVL data provides an estimate of the time the bus completed the link. Therefore for ease of comparison with the schedule, the arrival time at the timing points was interpolated from the AVL data.
4.2.3 Derived input data

4.2.3.1 Extrapolation of AVL data

Gaps may exist in the AVL data because of communication problems, such as congestion on the communication channel or beacon failure, (typically, one in five links were missing from the record of a trip in the AVL data). The time at which buses reach the end of links which are missing from the AVL data can be estimated by extrapolation of the original AVL data so that a complete record of each known trip may be obtained. Trips which are missing because drivers failed to input the relevant information into the system cannot be accounted for.

The method used to extrapolate the AVL data is as follows:
The data was sorted according to the trip number, and the missing trip information was identified. For ease of explanation, known links (i.e. link numbers which are present in the original AVL trip data) will be denoted as $l_{x+1}$ and $l_x$ where

\[ l_{x+1} - l_x \geq 1 \]  \[4.21\]

If

\[ l_{x+1} - l_x = 2 \]  \[4.22\]

then the time at which the bus reaches the end of the link which is not present in the AVL data is estimated by:

\[ T_{le, missing} = T_{le, x+1} - t_i, x+1 \]  \[4.23\]

where:

- $T_{le}$: arrival time of bus at the end of the link
- $t_i$: time bus takes to travel along the whole link

If

\[ l_{x+1} - l_x > 2 \]  \[4.24\]

then the time at which the bus reaches the end of the missing links is estimated by linear interpolation between the estimated arrival time at the end of link $l_{x+1}$ as given by Equation 4.23 and $l_x$. The link completion time of these missing links is calculated by subtracting the time at which the bus completed the previous link from the time at which
the bus completed the current link.

It was found that this method gave a small percentage (i.e. less than 1%) of negative values for the link completion time of the extrapolated data, due to the link completion times which were greater than the difference between the time at which the bus completed successive links. This problem is due to the fact that the ‘original’ AVL data was itself extrapolated before being outputted to file. As the exact nature of the extrapolation is not known, it was not possible to ‘reverse engineer’ the data in order to obtain the actual time at which the bus passed beacons etc. Therefore for links which give a negative link completion time, linear interpolation was used for all unknown links rather than all unknown links minus one.

In order to estimate the link completion time for the extrapolated data, the time at which the bus started the link is subtracted from the time at which the bus ended the link. To see if this approximation is reasonable, the link completion time \( t_i \) given in the AVL data was compared with the estimated time for link completion, \( t_i^{\text{estimate}} \), where

\[
    t_i^{\text{estimate}} = T_{le, i} - T_{le, i-1}
\]

The estimated time for link completion, \( t_i^{\text{estimate}} \), was calculated for all the consecutive links (i.e. \( l_{x+1} \) - \( l_x = 1 \)) in 38 AVL data files provided by London Transport Buses. Approximately 3000 data points were averaged for each link (for links between Baker Street and Kings Cross this number was nearer 1000). The average difference between the link completion time given by the original AVL data and that which was calculated from the difference in times at which buses completed successive links (from the same data) was found to be 0.1 seconds. However the absolute difference is a better comparative indicator as positive and negative differences cancel each other out. The absolute difference in the two estimates of the link completion times was found to be 49.4 seconds with a standard deviation of 55.1 seconds.

The greatest differences in the average link completion time, as estimated from the two methods, are for links which have the largest average completion time. However the order of the difference is less than 30 seconds.

It is unclear as to which estimate of the link completion time is more accurate as the time given by the AVL system was itself extrapolated and the time at which the bus was noted
as completing links suffers from the problems associated with polling (see Section 4.3.2.1). In the absence of any further information, it was assumed that the time to complete the link given by the AVL system was the most accurate estimate but the difference in times at which buses completed links was a reasonable approximation for the extrapolated data, for which no other link completion time data was available.

In conclusion, it seems reasonable to estimate the link completion time from the difference between the time at which the bus completed successive links.

4.2.3.2 Estimation of passenger arrival rate

The passenger arrival rate at each stop is derived by dividing the observed number of passengers boarding the bus (obtained from the Route 18 survey data) by the headway between the bus on which the survey was being carried out and the one in front (obtained from the AVL data for each of the survey days).

The Route 18 patronage survey spanned 18 days and information from 167 trips were recorded by one observer travelling along the route. However due to a combination of system development of the AVL system at the time of the survey and the fact that 4 of the 10 days of AVL data sent by London Transport Buses for this period covered the bank holiday weekend (during which no surveying was done), data for only 6 days was actually useable. During these 6 days, surveys were carried out on 49 trips. However the AVL data files only provided information for 45 of these trips. The average percentage of trips not accounted for in the AVL data is approximately 8% of those that were scheduled in the day, so the number of trips missing from the data during the surveyed time is not disproportionately large (see Table 4.9, Section 4.3.2.1).

Since the survey data does not provide a continuous record of arrival rates at all stops for every day of the week, an average was taken over all the days that AVL data was provided. The pooling together of this data is assumed to be insignificant since Danas (1980) found that there was no significant difference in the passenger arrival rate between different weekdays and that data collected on the same weekday (but during different weeks) do not differ significantly either, so data collected during different weekdays can be regarded as samples of the same population for each bus stop.
In the absence of further evidence, it is assumed that passengers arrive at bus stops independently of each other and in a random fashion according to a Poisson process. Six time intervals (0300-0700, 0700-0900, 0900-1600, 1600-1900, 1900-2100, 2100-0300) have been chosen to reflect the change in passenger arrival rate throughout the day. The average passenger arrival rate at each stop was assumed to be constant during these intervals. The end of the morning peak was chosen to be 0900 to allow for the fact that senior citizens cannot use their concessionary pass before 0900 and so the arrival rate of passengers before 0900 will be significantly different from that after 0900 as senior citizens make up 17% of the total patronage on weekdays after 0900. Senior citizens may use their concessionary pass at any time during the weekend.

Only passenger arrival rates which were derived from buses which had a headway of greater than 30 seconds from the bus in front were used to calculate the average passenger arrival rate. This was a necessary condition because when buses bunched, very large passenger arrival rates were observed which were generally unrealistic. A minimum headway of 30 seconds was chosen because polling is carried out on a 30 second cycle and so the AVL data is limited to an accuracy of 30 seconds. The survey of the Route 18 suggested that arrival rates which exceeded 3 passengers/minute were also generally unrealistic and so arrival rates which exceeded this maximum were also omitted from the calculation of the mean. Passengers who ran for the bus were implicitly included in the passenger arrival rate obtained as the total number of boarding passengers was used in the estimation of the passenger arrival rate.

Most of the observations in the Route 18 survey were taken between 0900-1600, therefore the average passenger arrival rates of the other intervals are based on a small number of observations (typically less than 5) and in addition to this no observations were taken between 2100 and 0700. To avoid using averages which are based on a small number of observations, the London Transport Bus Origin and Destination (BOD) survey results (Wood, 1988), which were based on a large number of observations, were used to estimate the multiplication factor required to obtain the relative amount of patronage observed in the other intervals compared with the midday off-peak, i.e. 0900-1600.

An example, of how this multiplication factor was obtained is given below. The London Transport BOD survey showed that for stop 1, the total number of passengers who boarded the Route 18 bus in a year during the following time intervals on weekdays is given by:
Hence, the average number of passengers per hour is given by:

<table>
<thead>
<tr>
<th>0500-1000</th>
<th>1000-1600</th>
<th>1600-1900</th>
<th>1900-2400</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.81 x 0.27 x 330,000 = 72171</td>
<td>0.81 x 0.33 x 330,000 = 88209</td>
<td>0.81 x 0.29 x 330,000 = 77517</td>
<td>0.81 x 0.11 x 330,000 = 29403</td>
</tr>
</tbody>
</table>

Therefore the passenger arrival rate used for the interval 1600-1900 for stop 1 is given by:

\[
\frac{99.4}{56.5} \quad p_1
\]

where: \( p_1 \): the average passenger arrival rate calculated from the Route 18 survey and associated AVL data, for the interval 0900-1600 at stop 1.

In general, the passenger arrival rate obtained from using the extrapolated AVL data tends to be higher than that obtained from the original AVL data because headways derived from the original data are overestimated due to gaps in the data. This underlines the importance of extrapolating the AVL data before it is used to calculate the passenger arrival rate.

Figure 4.1 shows the differences obtained from calculating the headway from extrapolated and un-extrapolated data.

The headways for links 17 and 40 were unusually large due to the fact that drivers change duties at the Prince of Wales stop which is on these links, westbound and eastbound respectively. Extrapolation was not possible at the termini, which resulted in an underestimation of the passenger arrival rate at the stops on the first link of the trip. However since the numbers boarding at these stops is not large, this approximation is assumed to be insignificant.
4.2.3.3 Moving speed

Only moving speeds which were generated using the un-extrapolated AVL data were used in the simulation model and the averaging process. When calculating the average moving speed in a time interval (for Model A), only speeds which were less than 96.5 km/h (i.e. 60 mph) were used in the averaging process so that an unusually high values would not dominate the average since the average was taken over a limited number of values.

If trip information was missing from the data or the moving speed of the bus for a particular trip was greater than 96.5 km/h then the moving speed of the bus along the link was assumed to be the same as the average moving speed along the link during that time period of half an hour. If there was no average speed available for a given time period then the moving speed along the link is assumed to be the same as that in the half an hour previous to the relevant time period, or if that too is not available, then the average speed in the half an hour after the relevant time period is used. If no moving speed can be obtained by any of these methods then the moving speed is assumed to be 24.1 km/h, i.e. 15 mph, (if there was no information regarding the trip), or 96.5 km/h (if the moving speed of the bus exceeded the maximum permitted moving speed). The results from the
two moving speed scenarios, Model A and Model B, are given in Section 4.4.3.

4.2.3.4 Proportion of passengers alighting

The average proportion of passengers alighting at stops was derived from all the data from observed trips during the Route 18 survey. In order to estimate the proportion of passengers alighting, it was necessary that the total number of boarding passengers was equal to the total number of alighting passengers. It was found that 15% of the trips recorded in the survey could not be used for estimating the proportion of passengers alighting at stops because the total number boarding was significantly different from the total number alighting due to disturbances in the trip information (such as bus breakdowns, transfers from other buses etc.) or the bus was turned short of its destination. Small discrepancies (i.e. less than 5 passengers) in the difference between the total number boarding and the total number alighting were assumed to have taken place at busy stops due to inaccurate counting and therefore the appropriate correction was made at the stop which experienced the largest number of boarding or alighting passengers for that trip. The majority of these corrections were of the order of one passenger and so the effect is assumed to be insignificant.

The average alighting proportions for weekday and weekend data was calculated for the six time intervals (0300-0700, 0700-0900, 0900-1600, 1600-1900, 1900-2100, 2100-0300). Alighting proportions were only calculated for bus occupancies greater than zero. In order to avoid the underestimation of the average alighting proportion due to some surveyed trips being carried out on buses which were travelling closely behind other buses and hence carrying few passengers, an alighting proportion of zero was only included in the averaging process if the bus occupancy exceeded 9 passengers.

If the number of observations used in the calculation of the average proportion alighting was less than 5 for any stop or time interval then the average alighting proportion for that stop and time interval is set to that of the midday off-peak (i.e. 0900-1600) when many observations were made. Different alighting proportions are used depending on the destination of the bus, i.e. Baker Street or Kings Cross. When the destination of the bus is reached, all passengers alight from the bus so the alighting proportion is 1.

Assumptions made about the alighting process are:
there is independence between alighting passengers, i.e. no travelling in groups
the alighting proportion is independent of the passenger's origin stop

The number of people boarding at the last 6 or so stops towards the end of the Route 18 is very small, typically averaging less than one person per stop. For these stops the alighting time is more likely to determine the time spent at the stop. Alighting is also likely to be the dominant process at stops which have a large alighting proportion.

Figure 4.2 shows the average proportion of passengers alighting for stops along the Route 18 during the weekday midday off-peak (i.e. 0900-1600) for buses travelling between Sudbury and Kings Cross.

Figure 4.2 Average proportion of bus occupancy alighting at each stop for buses travelling between Sudbury and Kings Cross (Weekday: 0900-1600)
4.3 RESULTS

AVL data was available for the same trips on which patronage surveys were being carried out on the Route 18, therefore a comparison could be made between the AVL and patronage survey data to ascertain how accurately the AVL data represented conditions being experienced on the route during the survey. Before, this comparison was carried out each data set, i.e. the Route 18 survey data and the AVL data were analysed independently of each other in order to ascertain the relative benefits of using the conventional (i.e. survey) data and new (i.e. non real-time AVL) data.

4.3.1 Survey results

The Route 18 patronage survey provides detailed information on the average amount of time taken to board and alight the bus (according to passenger type) and the relative attractiveness of stops for boarding and alighting passengers which are required for the simulation model developed. The results obtained from this survey are discussed below.

4.3.1.1 Method of Fare Payment

In order to develop a boarding time model based on the method of fare payment, the number of passengers paying with the exact fare, requiring change from the driver, showing a pass or a concessionary permit were recorded at each stop. The percentage of passengers who paid by the various fare payment methods for the 13009 passengers counted during the Route 18 survey is compared with the statistics given by London Transport in Table 4.2.

<table>
<thead>
<tr>
<th>Source</th>
<th>Pass</th>
<th>Cash</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OAP</td>
<td>Other Pass</td>
<td>Exact Fare</td>
<td>Change Required</td>
</tr>
<tr>
<td>Survey</td>
<td>15.3%</td>
<td>54.0%</td>
<td>9.9%</td>
<td>20.8%</td>
</tr>
<tr>
<td>1994 LT Statistics ¹</td>
<td>22.6%</td>
<td>49.2%</td>
<td>28.2%</td>
<td></td>
</tr>
</tbody>
</table>

69% of passengers used a pass with over two-thirds of those paying by cash requiring change. 22% of those using a pass were holders of a concessionary permit. Table 4.2 shows that there appears to be an apparent under-representation of concessionary pass users in the Route 18 patronage survey. However since the London Transport statistics are aggregated over a number of routes in London, it is difficult to establish whether the difference in the relative number of OAPs recorded is attributable to characteristics of the Route 18 or a biased survey sample.

Figures 4.3 and 4.4 compare the distribution of bus journeys by hour and ticket type obtained by the survey and as given by the 1992/3 Greater London Bus Passenger Survey (GLBPS). By comparing Figures 4.3 and 4.4, it can be seen that the difference between the percentage of OAPs recorded by the Greater London Bus Passenger Survey and by the Route 18 survey is greatest during the middle of the day. However this is the time when most observations were taken so it is assumed that the under-representation of OAPs is a Route 18 characteristic.

Figure 4.3 Distribution of bus journeys by hour and ticket type for an average weekday (Route 18 survey results)
4.3.1.2 Boarding and alighting time

In order to calibrate the boarding and alighting time models (i.e. Equations 4.9 and 4.10 given in Section 4.1.3) the Route 18 survey data was randomly split into two files using a random number generator, i.e. if the random number generator produced a number between 0 and 0.5 the line of data would be written to the first file, if the random number was between 0.5 and 1 it would be written to the second file. Half of the Route 18 survey data (i.e. one of the two files) was used to calibrate the models and the other half was used in the validation of the models. The results of the regressions equations developed from half of the collected data are given in Tables 4.3 and 4.4.

<table>
<thead>
<tr>
<th>Calibration coeff from Eqn 4.9 &amp; 4.10</th>
<th>Regression Equation</th>
<th>$R^2$</th>
<th>Obs</th>
<th>F-stat</th>
<th>$F_{0.001, v1, v2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>C=3.59 D=3.92</td>
<td>$T_b = 3.59 + 3.92 N_b$</td>
<td>0.68</td>
<td>1669</td>
<td>3473</td>
<td>10.87</td>
</tr>
<tr>
<td>A=1.67 B=1.13</td>
<td>$T_a = 1.67 + 1.13 N_a$</td>
<td>0.70</td>
<td>1275</td>
<td>3007</td>
<td>10.88</td>
</tr>
</tbody>
</table>
Table 4.4  Validation of regression models for boarding and alighting times

<table>
<thead>
<tr>
<th>Calibration coeff from Eqn 4.9 &amp; 4.10</th>
<th>Regression Equation</th>
<th>Obs</th>
<th>± 1 sec</th>
<th>± 2 secs</th>
<th>± 5 secs</th>
<th>± 10 secs</th>
</tr>
</thead>
<tbody>
<tr>
<td>C=3.59 D=3.92</td>
<td>$T_b = 3.59 + 3.92 N_b$</td>
<td>1683</td>
<td>10.5%</td>
<td>19.3%</td>
<td>55.3%</td>
<td>80.9%</td>
</tr>
<tr>
<td>A=1.67 B=1.13</td>
<td>$T_a = 1.67 + 1.13 N_a$</td>
<td>1239</td>
<td>44.6%</td>
<td>74.7%</td>
<td>95.5%</td>
<td>99.1%</td>
</tr>
</tbody>
</table>

Nomenclature:

$R^2$  Coefficient of determination for the regression equation

$F_{0.001, v1, v2}$  F statistic at the 0.1% significance level, where $v1$ and $v2$ are the degrees of freedom of the regression and the residuals respectively

$T_b$  Boarding time (seconds)

$T_a$  Alighting time (seconds)

$N_b$  Number of passengers boarding

$N_a$  Number of passengers alighting

All the correlation coefficients for the equations given in Tables 4.3 and 4.4 are significantly different from zero at the 0.1% significance level. The independent variables as a group affect the dependent variables at the 0.1% significance level and the coefficients for each independent variable are significantly different from zero at the 0.05% significance level. This is true for both the regression equations given in Table 4.3 so one may conclude that the equations given above provide a good fit to the data collected.

From the boarding time equation given in Table 4.3 we can see that the first passenger takes 3.6 seconds longer to board than subsequent passengers. Similarly, the first alighting passenger takes on average 1.7 seconds longer to alight than subsequent alighting passengers.

In order to develop the boarding time model it was assumed that the time taken for boarding was not dependent on:

- stop
- time of day
- number of people alighting
The last two assumptions may produce inaccuracies in the results, if the boarding time for a given number of passengers is greater than is expected due to movement along the bus being impeded by having to wait for passengers to finish alighting or congestion in the bus due to standing passengers (as the bus occupancy approaches capacity). Therefore the validity of the last two assumptions were tested using regression equations with dependent variables of the average difference between the actual and expected time taken for the boarding process and independent variables of the number of passengers alighting and bus occupancies respectively. The expected boarding time was derived from:

\[ T_b = 3.59 + 3.92 N_b \]  

[4.27]

In order to combat the effect of the abundance of low values of occupancy, the average deviation from the expected time required for boarding as given by the Equation 4.27 was calculated for bus occupancies between 0 and 62. Also, to counteract the effect of the abundance of no passengers alighting, average deviation from expectation were taken for values of alighting passengers between 0 and 13. A minimum of 5 observation were used in all averaging processes. It was found that the boarding time model was not affected by either the bus occupancy or the number of passengers alighting.

Similarly, it was assumed that the time taken for the alighting process was not dependent on the stop, time of day or bus occupancy. However it was hypothesised that the alighting time for passengers would be greater than expected for bus occupancies approaching capacity due to the greater difficulty of passengers getting to the door. The expected alighting time was derived from:

\[ T_a = 1.67 + 1.13 N_a \]  

[4.28]

Using a similar method as described for the boarding time model, it was found that the alighting time model was not dependent on the bus occupancy. Figure 4.5 shows the average bus occupancy for buses running to and from Kings Cross during the midday off-peak, 1000-1600.

Figure 4.5 shows that the average bus occupancy during the time interval when most observations were undertaken in the survey (i.e. 1000-1600) was under 35 passengers. The buses used on the Route 18 have a capacity for 71 seated passengers and so congestion
Figure 4.5 Average bus occupancy for buses running from Sudbury to Kings Cross (Weekday: 1000-1600)

in the bus due to passengers standing very rarely occurred (unless passengers did not take seats because they were carrying heavy shopping etc). Even though the whole survey data set was used in the testing of the hypotheses, there was still a relatively small number of high bus occupancies observed and it is this absence of relevant data which may be the cause of the lack of significance of bus occupancy on the boarding time and alighting time models. Similarly, the relatively few observations of large numbers of alighting passengers recorded in the survey may have yielded the lack of significance of the number of passengers alighting on the boarding time model.

Regression equations were also developed for the boarding time and alighting time which were dependent on the type of passenger (see Tables 4.5 and 4.6).
Table 4.5 Calibration of regression models for boarding and alighting times which are dependent on the type of passenger

<table>
<thead>
<tr>
<th>Regression Equation</th>
<th>$R^2$</th>
<th>Obs</th>
<th>F-stat</th>
<th>$F_{0.001, \nu_1, \nu_2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_b = 2.97 + 3.23 \text{ OAP} + 2.84 \text{ Pass} + 4.64 \text{ Exact Fare} + 7.65 \text{ Change Required}$</td>
<td>0.77</td>
<td>1623</td>
<td>1321</td>
<td>4.64</td>
</tr>
<tr>
<td>$T_a = 2.80 + 1.51 \text{ OAP} + 0.69 \text{ Other}$</td>
<td>0.74</td>
<td>54</td>
<td>74</td>
<td>7.93</td>
</tr>
</tbody>
</table>

Table 4.6 Validation of regression models for boarding and alighting times which are dependent on the type of passenger

<table>
<thead>
<tr>
<th>Regression Equation</th>
<th>Obs</th>
<th>± 1 sec</th>
<th>± 2 secs</th>
<th>± 5 secs</th>
<th>± 10 secs</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_b = 2.97 + 3.23 \text{ OAP} + 2.84 \text{ Pass} + 4.64 \text{ Exact Fare} + 7.65 \text{ Change Required}$</td>
<td>1661</td>
<td>12.0%</td>
<td>25.5%</td>
<td>61.8%</td>
<td>84.2%</td>
</tr>
<tr>
<td>$T_a = 2.80 + 1.51 \text{ OAP} + 0.69 \text{ Other}$</td>
<td>54</td>
<td>29.6%</td>
<td>70.3%</td>
<td>94.4%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Nomenclature:
- $R^2$: Coefficient of determination for the regression equation
- $F_{0.001, \nu_1, \nu_2}$: F statistic at the 0.1% significance level, where $\nu_1$ and $\nu_2$ are the degrees of freedom of the regression and the residuals respectively
- $T_b$: Boarding time (seconds)
- $T_a$: Alighting time (seconds)
- OAP: Number of concessionary fares
- Other: Alighting passengers other than senior citizens

All the correlation coefficients for the equations given in Tables 4.5 and 4.6 are significantly different from zero at the 0.1% significance level. The independent variables as a group affect the dependent variables at the 0.1% significance level and the coefficients for each independent variable are significantly different from zero at the 0.05% significance level. This is true for both the regression equations given in Table 4.5 so one may conclude that the equations given above provide a good fit to the data collected.

The values of the coefficients in the multiple regression equation for the alighting time
gives an indication of the relative speed of the processing of OAPs to that of 'Other' passengers. For the boarding scenario, it can be seen that even though OAPs are on average about 0.4 second slower to process than other holders of passes, they are significantly faster than those paying by cash (either by exact fare or requiring change).

A surprising outcome of calculating the average boarding time for stops where only OAPs boarded is that the average boarding time for OAPs is approximately equal to that of all the passengers (see Table 4.7). This is due to the fact that OAPs 'pay' by pass and are significantly quicker to process than those paying by cash fares. Therefore any extra time taken for any mobility handicap is compensated for by their quick method of payment. It was also observed during the survey period that many OAPs have their passes ready for inspection unlike other passengers who board the bus not quite so well prepared.

The average alighting time for OAPs was significantly larger than the average alighting time for all passengers. The multiple regression equation for the alighting time in Table 4.5 shows that the majority of the additional time required for OAPs alighting is taken up by the first OAP alighting. This reflects the difficulty many elderly people have in descending stairs and the fact that many mobility handicapped passengers will wait for the bus to stop completely before attempting to alight in order to avoid being thrown forward by the rapid deceleration.

Table 4.7 Average dead times and marginal boarding and alighting times

<table>
<thead>
<tr>
<th>Variable</th>
<th>Average</th>
<th>Std Dev (σ)</th>
<th>No. Obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boarding dead time</td>
<td>6.0</td>
<td>3.4</td>
<td>97</td>
</tr>
<tr>
<td>Alighting dead time</td>
<td>5.5</td>
<td>2.6</td>
<td>218</td>
</tr>
<tr>
<td>Dead time for no boarding or alighting</td>
<td>6.3</td>
<td>2.7</td>
<td>51</td>
</tr>
<tr>
<td>Boarding time for all passengers</td>
<td>5.5</td>
<td>3.7</td>
<td>3352</td>
</tr>
<tr>
<td>Boarding time for OAPs</td>
<td>5.3</td>
<td>4.2</td>
<td>212</td>
</tr>
<tr>
<td>Alighting time for all passengers</td>
<td>1.9</td>
<td>1.2</td>
<td>2514</td>
</tr>
<tr>
<td>Alighting time for OAPs</td>
<td>3.4</td>
<td>1.6</td>
<td>42</td>
</tr>
</tbody>
</table>

The dead time was around 6 seconds for all three different measurements of dead time, i.e. boarding dead time, alighting dead time and neither boarding nor alighting dead time.
The average boarding time for one passenger (i.e. the time taken for the boarding process divided by the number of people boarding) was found to be 5.5 seconds. The average alighting time was approximately 2 seconds. These results compare favourably with those of Jackson et al. (1977) who found that the average boarding time for a two door, one-person-operated bus is of the order of 5.5 seconds and the average alighting is 1.2 seconds and Cundill and Watts (1973) who found that the average dead time is 5.5 seconds.

Table 4.8 shows that no boarding or alighting takes place at only 19.7% of stops (as calculated from the survey data). Therefore the assumption as to whether or not the bus stops at a stop when there is no-one wishing to board or alight can be significant considering the usually high penalty for stopping. Observations from the Route 18 survey showed that drivers did not usually stop at a bus stop if there was no-one wishing to board or alight from the bus.

<table>
<thead>
<tr>
<th>Event</th>
<th>% of stops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boarding process only</td>
<td>17.9</td>
</tr>
<tr>
<td>Alighting process only</td>
<td>22.8</td>
</tr>
<tr>
<td>Simultaneous boarding and alighting</td>
<td>39.6</td>
</tr>
<tr>
<td>No boarding or alighting</td>
<td>19.7</td>
</tr>
</tbody>
</table>

4.3.2 Analysis of AVL data

Automatic Vehicle Location (AVL) systems have been used in the bus industry for several years but, so far, little use has been made of the non real-time data that these systems produce. Non real-time AVL data can only be used for analytical purposes if it is an accurate representation of events taking place in reality. When the accuracy of the data has been established, the feasibility of using this data for a variety of other purposes can be determined.
4.3.2.1 Accuracy of AVL data

When using any new data set, the first course of action is to plot the data. An example of the variation which can be found in the data is given in Figure 4.6 which shows how the speed of buses vary along one arbitrary link on an arbitrary day.

Figure 4.6 Speed of buses at Craven Park towards London (Link 9) on 9 May 1995

Inspection of Figure 4.6 shows that unusually high speeds were obtained on this link at three separate times, i.e. at approximately 0800, 1900, 2100. This data may be regarded as 'suspect'. However since the events recorded in the data have already happened: it is very difficult to extract the 'true' event. Establishing the 'truth' is especially difficult if there is conflicting information in the data, e.g. two events happen at the same time and both are equally possible. This highlights one of the main problems of using non real-time AVL data.

Conflicting information was sometimes a problem in the assignment of data to a trip. To reduce the possibility of the wrong trip being assigned to the data because of an early or late start or finish, the AVL trip data was checked for consistency i.e. if the trip was even numbered (and thus terminates in London) then all the links for that trip should be
numbered less than 28 (the number of the turning link at Kings Cross). If it was found that the bus was actually travelling in the opposite direction to the schedule then the trip was assigned to either the trip the same driver carries out before or after the assigned trip, depending on the time and location of the buses. If no trip could be confidently assigned to the data, then a trip number of 0 (i.e. a null trip) was assigned to the data.

Even though the data used was extracted from an AVL system which incorporates logic to detect and compensate for failures, analysis of the data showed that some errors still get through this ‘net’. Also, many data entries were found to be missing from the files. The system is such that the bus is polled for its positional information every 30 seconds and so every link that the bus completes should be accounted for. However this was not found to be the case. This may be due to many reasons:

- a lack of capacity on the communication channel employed
- the system being turned off for a period of time, possibly due to system development or upgrades
- positional information being lost whilst being communicated to the control centre
- beacon or transponder failure

In order to assess whether the number of errors in the AVL data decreased as time progressed due to the on-going system development, a program was written to detect the number of errors in each data file. The term ‘error’ is used here to identify:

- data entries which cannot be linked to a particular trip and therefore could not be used for estimating performance indicators of the route. This includes insufficient information given on the log card of drivers, who may have not recorded all the buses they used during the day, resulting in no trip being assigned to that data entry. In such cases no comparison with schedule can be made, although the information is still useful for real-time decision making purposes.
- data entries which indicated that the bus was travelling at over 96.5 km/h (i.e. 60 mph) which was considered unrealistic for the route in question, even in the best traffic conditions.
- data entries which caused a conflict in the progress of the bus along the route, i.e. the bus appeared to ‘jump’ backwards and forwards.

Polling is such that if the system does not accept positional information from a bus, due
to congestion within the communication channel, the bus continues to try to send this information even though it is no longer valid. Since the time recorded in the data file is the time at which the system receives this information, the bus appears to have moved backwards. Bus ‘hopping’ may also be due to a bus travelling through the overlap boundary of two radio aerial regions. The first radio aerial region extrapolates the position of the bus and sends this extrapolated information to the control centre if it loses contact with the bus for a period of time. The second aerial region actually receives position updates from the bus and sends this to the control centre too. The control centre does not check the vehicle ID when it receives a position update (to see if there is a conflict of information) and so two positions for the same bus are recorded in the data, one is the true position and one is an extrapolated position. It is impossible to detect from inspection of the data which of the two positions is the ‘true’ position and which is the extrapolated position.

As an aside, when contract monitoring comes into effect in London with Fleet Wide AVL, the bus will keep a record of its position for the whole operating day so there will be no conflict of positional information. This information will then be downloaded at the garage at the end of every working day. Data from the less reliable polling AVL system, (examples of which is currently being used in this analysis) will then only be used in cases of equipment failure at the garage. Since Fleet Wide AVL eliminates polling from the recording of positional information, London Transport Buses hope it will be more reliable.

Removal of errors from the AVL data

A computer program was written to discard suspect data from the AVL data file. A line of data (i.e. the record of the time a bus reached a given position along the route and the associated data regarding link completion time etc.) was removed so that:

- buses travelled at no more than 96.5 km/h on any given link
- the time buses reached the end of links increased as the bus travelled down the route, i.e. if a record caused the flow of time to go backwards in the trip profile, the record was removed
- if the details for a particular link in a given trip was repeated then the record which was written last to the file, i.e. had the largest clock time, was retained and the other records for that link and trip discarded. This problem occurs when the bus is crossing radio aerial boundaries as explained earlier in this
section. In the absence of further evidence, it is assumed that the ‘true’ positional information would be received later by the control centre than the extrapolated positional information.

- if two bus positions are received at the same time at the control centre, the position which indicates that the bus has travelled further down the route is kept, as it is assumed that the earlier position reports were not initially successfully polled
- the time difference between a bus completing a link and any of the nearest 5 links in either direction does not exceed 50 minutes (which is the average time it takes a bus to complete a whole trip)
- buses do not travel too fast, i.e. cover more than 9 links in less than 5 minutes which would yield speeds of over 96.5 km/h for even the shortest 9 links
- buses do not have times at positions in the middle of trips which are anomalous to the times the bus reaches other positions along the route, i.e. large deviation from the majority of trip position time.
- there is no conflict in the progress of the bus along the route, i.e. the bus does not ‘jump’ backwards and forwards with a high numbered link number appearing amongst lowered numbered links and vice versa
- links which are only used when buses turn do not appear in the middle of a trip. This is a common problem when buses passes near a beacon on a normal trip, which should only be triggered when the bus is leaving the road on which the turn takes place
- positioning information which was ‘out-of-date’ (i.e. was received much after it should have been received due to polling problems) are ignored

The average percentage of the different types of errors that are present in the two sets of data (i.e. September 1994 and May 1995) are given in Table 4.9. It should be noted that the total percentage of the data file which is useable does not reflect the total percentage which is useable for every purpose, as data which could not be assigned a trip are still included in this file and even though they form valid entries for estimating average speeds etc, they cannot be used in any schedule comparison.

The choosing of the upper limit for the maximum speed at which a bus was permitted to travel was fairly arbitrary since less than 0.1% of the data had a commercial speed (i.e. the speed of a bus which implicitly includes the time spent at stops) of between 55 km/h
and 96.5 km/h.

Table 4.9  Average percentage of unusable data in the two sets of AVL data

<table>
<thead>
<tr>
<th>Year</th>
<th>% bus speed &gt; 96.5 km/h</th>
<th>% insufficient log card data</th>
<th>% data not assigned trip</th>
<th>% trips with no data</th>
<th>% conflicting information</th>
<th>% useable lines in file</th>
<th>No. of trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>0.2</td>
<td>1.2</td>
<td>2.1</td>
<td>11.4</td>
<td>7.4</td>
<td>92.3</td>
<td>5482</td>
</tr>
<tr>
<td>1995</td>
<td>0.5</td>
<td>1.0</td>
<td>1.4</td>
<td>10.3</td>
<td>7.1</td>
<td>92.3</td>
<td>5334</td>
</tr>
</tbody>
</table>

Note: The percentages given in this table are not cumulative

In order to test whether the average number of errors in the 1994 data differed from the average number of errors in the 1995 data, a t-test on the sample means of the two sets of data was carried out. It was found that the means of the two samples were not statistically different at the 5% level for all the types of errors, therefore one can conclude that there was no improvement in the system’s ability to detect errors from September 1994 to May 1995.

Once the errors from the AVL data have been removed the data can be used for a wide range of purposes, for example:

- **timetabling**: since the AVL data is a historical record of how the route actually performs on a day to day basis, this information can be used to identify areas along the route where buses continually fail to meet the schedule or times in the day when long gaps in service regularly appear. Better schedules can then be drawn up and tested and the results of any changes to the schedule can be evaluated.

- **statistical purposes**: e.g. reliability and punctuality statistics.

- **reducing operating costs**: there may also be reductions in operating costs due to re-scheduling which reduces the fleet size and eliminates unnecessary mileage.

The following sections illustrate the uses of non real-time AVL data.
4.3.2.2 Improved scheduling

The schedule can be improved by:

- analysing the travel time profiles of buses along a route, so that areas which slow buses down considerably can be identified with the aim of campaigning for bus priority measures and/or scheduling the curtailment of some trips so that they do not pass through these areas
- identifying areas where reliability greatly deteriorates
- estimating the deviation from schedule at timing points, so that more slack time may be incorporated into the schedule to improve schedule adherence. This measure does not decrease the journey time for passengers or improve regularity but may highlight inappropriate scheduling which may put undue pressure on route controllers as they strive to achieve it.

These aids to better scheduling will be dealt with in turn in the following sections. Figure 4.7 provides an overview of the Route 18 which associates link number with timing points along the route.

Travel time profiles

The time buses spend at stops can be affected to a greater or lesser degree (excluding unusual circumstances) by scheduling, i.e. if the headway between buses increases buses will probably spend longer at stops boarding and alighting passengers if passengers arrive at the stop at random. But the time the bus spends moving between stops is very often out of the bus operator's control since it is affected by congestion, the number of signalised intersections and individual driver characteristics. Therefore if a bus operator can separate the time spent moving between stops from the time spent at stops, a stronger case can be made to the local authority for bus priority measures (such as bus lanes or priority at traffic lights etc.) along links which slow down the progress of buses significantly. The local authority can then compare the moving speed of the bus along that link after the bus priority measures have been implemented with the moving speed of the bus before priority was given, in order to assess the effectiveness of the bus priority measure.
Figures 4.8 and 4.9 show the cumulative moving travel time of buses (i.e. the total time spent moving between stops) during the midday off-peak (1000-1600) and evening peak (1600-1900) for trips originating at Sudbury and Kings Cross respectively. These travel time profiles show the speed that buses would travel at if they did not stop to pick up or let down any passengers.

When examining these graphs it should be remembered that areas along the route which have a steep gradient are more congested than areas which have a shallow gradient. Figure 4.9 shows that congestion is worse in the evening peak leaving London. It can also be seen that there is scope for improvement in bus speed (through bus priority measures etc.) along the route travelling away from central London since there is a marked difference in speeds during different times of the day. It is interesting to note that the speed along the Route 18 coming into London is fairly constant throughout both time intervals. A reason for this lack of difference in speeds during the two time intervals may be that the effective road capacity during the middle of the day is reduced by effects other than traffic flow, e.g. parking (Department of Transport, 1996b).
Areas which have a low average moving speed are congested areas and would therefore benefit from traffic management measures which give priority to buses. Figure 4.10 shows the average moving speed of buses along the whole route.

As can be seen from Figure 4.10, link numbers 10, 21, and 52 are in need of bus priority measures since the average moving speed of buses between stops on these links falls below 10 km/h during the midday off-peak. However an interesting finding from the Department of Transport (1996b) is that even in the virtual absence of traffic, the mean speed in the central area (i.e. link numbers 20 to 36) is only around 20 mph (i.e. 32.1 km/h), indicating that signal controlled junctions and a complex road network linked by mostly short sections of ‘open’ road limit the maximum overall speed that can legally be obtained. This would seem to indicate that the moving speed obtained for link number 23 is spuriously high. This may be due to the patronage at stops along this link being overestimated due to the presence of the other buses in this area which also pick up potential Route 18 passengers.

Figure 4.11 compares the average actual (commercial) travel time of buses originating
Figure 4.9 Average travel time profile of buses from Kings Cross if they did not stop to pick up passengers

![Moving travel time profile](image)

from Kings Cross and the time the buses would take if they did not pick up any passengers (i.e. the moving travel time). Whereas Figure 4.9 highlights the affects of congestion during the different times of the day, Figure 4.11 highlights the affects of passengers during one time interval (i.e. midday off-peak, 1000-1600).

As can be seen from Figure 4.11, the difference between not picking up passengers and stopping for passengers to board and alight adds an extra 25 minutes to the journey time of buses travelling towards Sudbury. Similarly, it was found that an extra 22 minutes is added to the journey time of buses travelling towards Kings Cross due to buses having to stop to pick up passengers. Therefore picking up passengers adds an extra 47 minutes to travel time of buses on the round trip between Sudbury and Kings Cross, which is nearly equivalent to the 49 minutes it would take the bus to travel from Sudbury to Kings Cross without picking up any passengers. Therefore the affect of passengers on the Route 18 bus service is to increase the time allowed for journeys between the two termini by approximately a half that which would be allowed in the absence of any passengers.
Identifying bus bunching from non real-time AVL data can be difficult because of the quantity of data involved. An example of identifying bunching for one particular link, on one particular day for the evening peak is given in Figure 4.12.

By inspection of Figure 4.12 bunching can be identified when the gradient of the graph is the steepest (a vertical line indicating two buses bunched together) as is the case around 1620. In this case it can be seen that the first bus is late and the second on time. The bunching of buses which occurs at 1730 is between two buses which are both late (hence a very short horizontal line linking the two buses).

Figure 4.13 shows another way of highlighting bus bunching from AVL data. Odd numbered trips originate in central London and travel towards Sudbury. Even numbered trips originate at Sudbury and travel towards London.

Figure 4.13 highlights the problems of gaps in the AVL data, as three of the four trips...
chosen have no data for one or more links. Also, even though creating trip profiles such as these is feasible for a small number of trips it if difficult to achieve for large numbers of trips, since the amount of data to be presented is overwhelming. Figure 4.13 also highlights the problems of starting trips from two different termini (i.e. Kings Cross and Baker Street) as buses start to bunch fairly rapidly.

Lesley (1975) suggests using a Reliability Index (R.I), which is based on the ratio of the standard deviation of observed headways to the mean headway, as a measure of irregularity. The average irregularity of the bus route, as measured by the Reliability Index, was calculated for the 1994 extrapolated weekday AVL data and the results are presented in Figure 4.14. The Reliability Index was not calculated for links which contained the Prince of Wales stop (in both directions) because of the distortion of headways caused by the change over of duties at these stops.

Figure 4.14 shows that the Route 18 is generally more irregular during the evening peak (1600-1900) than during the midday off-peak (1000-1600). This is probably due to the increase in traffic congestion experienced during the afternoon peak (which increases the
Figure 4.12  Deviation from schedule at Craven Park towards London (Link 9) between 1600-1900 on 12 September 1994

Figure 4.13  Using AVL data to highlight bunching

classification.

travel time of buses between stops) compared with the midday off-peak, as shown in
Figure 4.14. Irregularity of weekday buses (1994 AVL data)

It is interesting to note that irregularity is most severe near Sudbury (i.e. at the tail ends of the graph) and not as one would expect near Kings Cross (in the middle of the graph). This may be due to the fact that bus speeds in the centre of London are severely constrained by the volume of traffic, whereas speeds in the outer areas are more prone to be dependent on individual driver characteristics since traffic is relatively free flowing thereby increasing the variability in the speeds experienced by buses along the same segment of the route.

Lesley (1975) suggests that timing points should be stops at which the reliability deteriorates more than twice the average. An analysis of the 1994 AVL data revealed that no stops along the Route 18 met this criteria thereby indicating that the route is fairly reliable (according to Lesley’s definition).
4.3.2.3 Management statistics

One of the obvious uses of non real-time AVL data is to compile punctuality and reliability statistics to be used by the management of a bus company to assess the performance of a given route. An example of such management statistics, derived from the Route 18 AVL data, is given in Table 4.10.

Table 4.10 Weekday service monitoring statistics calculated from Route 18 AVL data

<table>
<thead>
<tr>
<th>Year</th>
<th>% of buses which arrive at timing points within ±1 minute or ±3 minutes of the scheduled arrival time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Morning Peak (0700-1000)</td>
</tr>
<tr>
<td></td>
<td>±1 min</td>
</tr>
<tr>
<td>1994</td>
<td>20.5</td>
</tr>
<tr>
<td>1995</td>
<td>23.5</td>
</tr>
</tbody>
</table>

As can be seen from Table 4.10, the Route 18 was performing more reliably in May 1995 than in September 1994 (no seasonal variation is assumed). This increased performance can also be witnessed from inspection of the percentage of buses whose deviation from schedule is greater than one headway, as given in Table 4.11.

Table 4.11 Percentage of weekday buses whose deviation from schedule exceeds the advertised headway

<table>
<thead>
<tr>
<th>Year</th>
<th>% of buses whose deviation from schedule exceeds one advertised headway (i.e. 6 minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Morning peak 0700-1000</td>
</tr>
<tr>
<td>1994</td>
<td>14.4</td>
</tr>
<tr>
<td>1995</td>
<td>11.6</td>
</tr>
</tbody>
</table>

Table 4.11 also shows that the route’s performance seriously deteriorates in the evening peak period. This is not surprising given the increase in congestion witnessed in this period which would tend to make buses more unreliable (see Section 4.3.2.2). However
a significant improvement was made in this period between September 1994 and May 1995.

### 4.3.3 Comparison of survey and AVL data

The accuracy of AVL data as a data set has been discussed in Section 4.3.2.1. However in order to use the results obtained from the analysis of this data with confidence, the accuracy of its representation of events taking place in reality has to be established. This was carried out by comparing AVL data with the Route 18 patronage survey data for trips for which both data sets were available. The results of this comparison is given below.

#### 4.3.3.1 Time at a given position

Links are specially defined in the AVL system and either end with a stop or a beacon. They do not bear much resemblance to the road network and often one road may consist of several links. It was found that the difference between the time at which the AVL system estimated buses arriving at the end of links which terminated with a stop and that recorded in the Route 18 patronage survey was on average 2.7 minutes, with a standard deviation of 1.3 minutes. The absolute difference between the times from the two sources of data was found to be 2.8 minutes with a standard deviation of 1.2 minutes, which seems to indicate that the error in times given by the AVL data and the Route 18 patronage survey data is fairly systematic, i.e. there is not an equal number of negative and positive values in the difference in the time but instead the time recorded by the AVL system usually tends to be greater than that recorded in the Route 18 patronage survey. This discrepancy may have been for a number of reasons:

- the clock used by the observer on the survey may have been 'slower' than that used by the AVL system
- the survey time was rounded down to the nearest minute
- congestion on the communication channel may have delayed the time at which positional reports were sent
- poor definition within the AVL system of when a bus actually arrives at a stop (there is no systematic method in which the system decides whether the time at which a bus completes a link which terminates at a stop includes the time taken for the boarding and alighting process). Since the time spent at
bus stops forms a fundamental part of the time take to complete a link, this would appear to be a flaw in system specification (if one of the aims of the system was to use non real-time data from the system for other purposes). For the purposes of comparison of the AVL and survey data, it has been assumed that the link ends when the bus reaches the stop (as opposed to when the bus leaves the stop).

- the time at which a bus completes a link as given by the AVL system has an associated inaccuracy of 30 seconds (assuming that the system was able to receive the information on the first poll after the event had taken place).

**Merseytravel validation survey**

Transport and Travel Research Ltd carried out a validation survey of Merseytravel’s TIMECHECKER real-time passenger information system over 5 weekdays between 4 and 8 September 1995. The times of each stage of the real-time count-down to the arrival of each bus were noted at 20 displays with the exact arrival and departure time of each bus and the time that the display cleared of this information on each occasion. Observations when the system reverted to schedule information were not included in the analysis. It was found that 59% of arrivals were within ± 1 minute of the forecast time and 86% were within ± 2 minutes for predicted time to arrivals of 1 to 5 minutes (Transport and Travel Research Ltd, 1995). Also, not surprisingly, the closer the bus got to the stop, the more accurate the predictions became.

Merseytravel also undertook an independent evaluation of the AVL system by using an observer on board the bus who noted the time the bus passed certain landmarks along the route and who estimated the speed of the vehicle at this point.

At the control centre, a controller noted all timing points that the vehicle passed from the AVL clock. The observer’s clock had been synchronised with that of the control centre, so the two time sources were compared to establish the accuracy of the AVL information i.e. where the bus was actually on the route compared with where the AVL system said it was (Transport and Travel Research Ltd, 1995). Table 4.12 provides the results of this survey.
Table 4.12 Merseytravel validation survey results

<table>
<thead>
<tr>
<th></th>
<th>Obs</th>
<th>Mean</th>
<th>σ</th>
<th>Mean of absolute values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time difference (secs)</td>
<td>203</td>
<td>2.9</td>
<td>28.8</td>
<td>16.3</td>
</tr>
<tr>
<td>Distance difference (m)</td>
<td>186</td>
<td>6.4</td>
<td>187.2</td>
<td>110.2</td>
</tr>
</tbody>
</table>


It should be noted that the stated system specification accuracy is ± 10 m (Transport and Travel Research Ltd, 1995). The large difference between the mean and absolute mean suggests that the differences between the two sources of data are not systematic, i.e. that negative and positive values cancel each other out thus producing a small mean but a larger absolute mean.

By comparing the results of the validation of the Merseytravel TIMECHECKER system and the London Transport COUNTDOWN system, it can be seen that the Merseytravel AVL system seems to provide a more accurate representation of the time at which the bus reached a given point, i.e. a absolute mean difference of 16.3 seconds as opposed to the 2.8 minutes calculated for the COUNTDOWN system. However it should be remembered that the Route 18 survey technique may have resulted in a more pessimistic view of the accuracy of the COUNTDOWN system and that the clock used in the survey was not set by the AVL system time, so this result is not conclusive.

4.3.3.2 Deviation from schedule

In order to assess whether non real-time AVL data is accurate enough for automatic monitoring of schedule adherence, the deviation from schedule (i.e. the scheduled arrival time at a given location minus the actual arrival time at that location) as recorded by the Route 18 patronage survey was compared with that given by the AVL data for each trip for which both types of data were available.

The average deviation from schedule for the whole route calculated from the Route 18 survey data alone was 1.6 minutes compared with an average deviation of -0.8 minutes given by the AVL data. It should be noted that the Route 18 survey recorded the time at which the bus arrived at the stop but the time obtained from the AVL data and used in
the comparison with schedule may include the time the bus spends at the stop (see the previous section).

Figure 4.15 highlights the difference between the average deviation from schedule at timing points as given by the Route 18 survey data and the AVL data for the weekday midday off-peak. Deviations from schedule which were greater than 30 minutes have been excluded from the calculation of the average deviation as it was felt that these large deviations were probably a result of assigning the bus to the wrong duty (see Section 4.2.2.3).

**Figure 4.15**   The difference between the average deviation from schedule at timing points as given by the Route 18 survey data and the AVL data (Weekday: 1000-1600)

In the calculation of the deviation from schedule, it was assumed that the time of scheduled arrival at the first stop at Sudbury is the same as the time of departure from the stand. Since the stand and first stop are close together (i.e. within 23 metres of each other) at Sudbury and traffic conditions along this road are generally uncongested, this is thought to be a reasonable approximation.

Similarly, at Kings Cross it was assumed that the time at which the bus completes the link
which contains the last stop of the trip is an approximation for the time the bus arrives at the stand as given in the schedule. The last stop and the stand are 123 metres away from each other but the road linking the two is generally uncongested, so this assumption is not thought to be significant. It was assumed that the scheduled arrival time at the first stop for trips originating at Kings Cross was one minute after the scheduled departure time from the stand (which gives an average bus speed of 55 km/h).

The comparison with schedule was made at the end of the link before the Prince of Wales stop in both directions (i.e. link number 16 and link number 39) because duties change at the Prince of Wales stop and so an accurate comparison with schedule cannot be made using the AVL data (since only the time at which the bus completes the link is given in this data and not the time at which it arrives at a given stop). Figures 4.16 and 4.17 show the average weekday variation in deviation from schedule derived from the Route 18 survey data alone and from the AVL data alone for the survey period.

**Figure 4.16** Average variation in deviation from schedule derived from survey data (Weekday: 1000-1600)

Both sets of data indicate that the deviation from schedule along the route is generally quite small, typically less than 1 minute, and that buses tend to arrive at their destination early, therefore indicating that there appears to be enough slack in the schedule.
It is interesting to note that in Figure 4.16, buses left Sudbury early on average but left Kings Cross late on average. It was hypothesized that this may be due to the fact that the observer used in the survey was visible to drivers leaving Sudbury which may have prompted early or on-time departure whereas the observer was not visible to drivers departing from Kings Cross until they arrived at the first stop. However Figure 4.17 shows that this is unlikely to be the case as the pattern of deviation from schedule obtained from the survey data alone is not significantly different for the pattern of deviation from schedule as obtained from the AVL data for all trips in the midday off-peak on the same days.

In Sections 4.3.1 to 4.3.2, it has been shown how the performance of the Route 18 can be analysed using the patronage survey and the AVL data in isolation. The following section describes the results of the simulation model (described in Section 4.1) which uses both data sets.
4.4 Validation of the simulation model

The amount of time it takes a bus to travel along a route can be divided into the time it spends at stops (boarding and alighting passengers) and the time it spends moving between stops. Therefore if a simulation model is to replicate the movements of buses along a route to a reasonable degree of accuracy, it is essential that these attributes of the bus service are represented correctly. The next two sections compare the estimations of patronage at stops and the moving speed of buses used in the simulation model developed with values obtained from other references, in order to validate their use in the model.

4.4.1 Patronage estimation

Since passengers generally take the first bus to arrive at the stop which will convey them to their destination, the estimation of patronage at stops which overlap with other routes becomes a complicated issue. The Route 18 is relatively fortunate in this respect since it only overlaps with other routes for 15% of the stops along the route (those being the ones which lie closest to the termini). However since little information is known about these other routes, especially with regard to patronage and timetabling information, this effect has not been considered in the estimation of patronage along the Route 18.

4.4.1.1 Comparison with survey if even headway is assumed

In order to assess whether the passenger arrival rates obtained from the extrapolated AVL data were reasonable, a ‘rough’ estimate of the passenger arrival rate was calculated using the average headway for the time of day for the same trips as were used in the calculation of the passenger arrival rate:

\[ p_e = \frac{N_{bi}}{h_e} \]  

[4.29]

where:  
\( N_{bi} \): number of boarding passengers  
\( p_e \): ‘rough’ estimate of passenger arrival rate  
\( h_e \): advertised headway for the relevant time of day

The passenger arrival rate obtained from the AVL data was generally higher than that obtained from the ‘rough’ estimation. This was due to the bunching of buses which
sometimes occurred during the Route 18 survey which meant that the headway between
the bus on which the survey was being carried out and the bus in front was significantly
less than the advertised headway. Both methods of estimating the passenger arrival rate
generally produced results which were within the same order of magnitude. The passenger
arrival rate as calculated by the AVL data was on average 2.0 passengers/hour greater
than that given by the ‘rough’ estimate over the whole route. At some stops an
overestimate of patronage was made and at some stops an underestimate was made,
therefore the absolute difference between the results obtained from the two methods of
patronage estimation were compared and it was found that the average absolute difference
between the passenger arrival rate calculated using the AVL data and the ‘rough’ estimate
was 5.3 passengers/hour, which is much less than one passenger per bus (since the
average daytime headway is approximately 6 minutes which is around 10 buses an hour).

4.4.1.2 Comparison with London Transport patronage survey

The annual patronage for each stop was calculated using the passenger arrival rates
obtained from the extrapolated AVL data. This was then compared with the estimated
route patronage in the London Transport Bus Origin-Destination (BOD) survey, as given
by Woods (1988). When this survey was carried out, the Route 18 terminated at
Farringdon and so the patronage at stops near the new terminus, Kings Cross, in the BOD
survey is larger than the expected patronage at these stops during the 1995 Route 18
patronage survey. Therefore the stop before the Kings Cross terminus was excluded from
the following analysis, as was the first stop from Kings Cross which was not on the
previous route.

It was found that the estimate of annual patronage using the passenger arrival rate
obtained from the extrapolated AVL data is approximately 1.5 passengers/hour less than
that given by London Transport’s BOD survey averaged over the whole route. The
average absolute difference between the two estimates was found to be 9.0
passengers/hour averaged over the whole route. Therefore at some stops an overestimate
of patronage was made and at some stops an underestimate was made, with the effects
of these discrepancies cancelling each other out in the averaging process. These
discrepancies were probably due to the smaller sample size of the 1995 Route 18
patronage survey which meant that averages were taken over a limited number of values.
In 1995, bus patronage for the whole of London was 3.3% lower than the level of patronage recorded during 1988 (Department of Transport, 1996a). The estimate of patronage using a combination of 1995 on-board Route 18 surveys and AVL data was found to be 6.4% lower than that of the 1988 London Transport BOD survey. The estimate using the ‘rough’ calculation was found to be 14.9% lower than that of the 1988 BOD survey. This result indicates that using the extrapolated AVL data provides a more accurate estimate of patronage over the whole route than the ‘rough’ estimate, assuming that the patronage change along the Route 18 is similar to that experienced for London as a whole between the time of the London Transport BOD survey (i.e. 1988) and the 1995 Route 18 patronage survey.

4.4.1.3 Alternative method of estimating patronage using AVL systems

An alternative method for estimating patronage is to use ticketing information, from either smartcard readers or conventional electronic ticket machines, instead of on-bus surveys. This significantly reduces the cost of obtaining the passenger arrival rate at stops but also has a few limitations:

- currently, ticketing information is recorded on a stage (group of stops) basis. If the passenger arrival rate at stops is required for modelling purposes this method would not be suitable unless ticket machines were adapted so that the number boarding at every stop was recorded. This would require greater driver input and may not succeed if drivers do not update the machine regularly. Errors are more likely to occur when the driver does not pick up any passengers and when the bus passes a bus stop without stopping. Ticket machines may be able to be updated automatically from the main AVL system but this would require a very accurate estimation of the position of the bus, e.g. a beacon at fare stage bus stops. Williams Industries and Wayfarer and currently attempting to automatically update the fare stage on ticket machines via an AVL system.

- if the ticketing information was sent, with positioning information over the data channel then the bandwidth must be large enough to accommodate the extra information which needs to be sent otherwise buses may be missed when polled leading to large gaps in the AVL data. Poultney (1996) notes that this is currently not being implemented anywhere in the country because of the significant amount of data which would need to be transferred from the
ticket machine at every poll which would increase communication costs significantly in order to maintain the same frequency of position updates. In addition to this, although origin-destination information for every fare paying passengers who state their destination can be obtained from the ticket machine, the majority of passengers do not fall into this category (as they use some form of pass) and so only boarding information is available for them. This effectively means that even if ticket information was sent via the radio channel to the control centre, the current loading of the bus could not be ascertained with any degree of certainty. Therefore operators do not see the benefit of sending ticketing information with positioning information, as the benefits do not justify the cost.

- if the system was not designed with this add on feature in mind then there may be many problems in adapting the configuration so that it will form a seamless part of the system.
- since there are more sub-systems dependent on the main positioning system there will be more associated problems should the system fail.

4.4.1.4 Limitations of patronage estimation from AVL data

Estimating the patronage at stops using AVL data is not a completely fool-proof process. However the process will be less prone to errors if the following guidelines are adhered to when estimating passenger arrival rates from extrapolated AVL data:

- the AVL data has to be accurate.
- every bus that is used on the day of surveys must be on the AVL system so that no buses are missing.
- the AVL system must be reliable so there are no gaps in the data due to congestion on the communication channel or component failure.
- ideally, the percentage of passengers who take the first bus that arrives and the percentage of passengers who wait for a particular bus should be ascertained by carrying out on-bus surveys on all routes which overlap with the route of interest on the same day as the main patronage survey is carried out. However this is probably unfeasible as the cost of carrying out such an exercise may be prohibitively large.
- patronage surveys should be carried out on several buses on the route at the same time because buses often bunch and so it is difficult to obtain a true
reflection of patronage or passenger arrival rate using a single moving observer.

As well as the problems outlined above, it should be noted that bus route patronage estimation is a complicated process since many routes overlap and it is difficult to differentiate passengers who only use a given route to arrive at their destination from those who are able to board buses from one of several routes. This problem is common to all existing methods of patronage estimation.

4.4.2 Estimation of the speed of buses

4.4.2.1 Commercial speed of buses

The commercial speed of a bus is the speed at which it operates and therefore implicitly takes into account the time spent at stops. The commercial speed of a bus can be obtained from non real-time AVL data relatively easily if the link length and the time taken to complete the link is known. Depending on the configuration of the system and the definition of links, the time taken to complete the link may be extracted from the AVL data.

The bus speeds were averaged over the Route 18 survey period for days in which both the survey data and AVL data were available. Only data which was present in the original AVL data file (i.e. data which was not the result of an extrapolation) was used in the following analysis.

The results of the comparison between the average commercial speed of buses and the average speed of general traffic as given by the Department of Transport (1994) in the daytime off-peak (when the greatest number of survey observations were made) is given in Table 4.13. The route was divided into three segments which lie in central, inner and outer London as defined by the Department of Transport:

- Central: an area of 2 miles radius centred on Waterloo Station
- Inner: an area which is 2 to 5 miles from Waterloo Station
- Outer: the rest of London.
Table 4.13 Comparison of commercial speed of buses and the general traffic speed for Inner, Outer and Central London

<table>
<thead>
<tr>
<th>Area</th>
<th>Speed in km/h for the Daytime Off-Peak: 1000-1600</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Commercial Speed</td>
</tr>
<tr>
<td></td>
<td>Survey Data(^1)</td>
</tr>
<tr>
<td>Central</td>
<td>13.1</td>
</tr>
<tr>
<td>Inner</td>
<td>16.3</td>
</tr>
<tr>
<td>Outer</td>
<td>17.8</td>
</tr>
</tbody>
</table>

1 Survey data: speed of buses obtained using only the Route 18 patronage survey data
2 Survey and AVL data: speed of buses obtained using a combination of the Route 18 patronage survey data and the associated 1995 AVL data for the same trips
3 AVL data: speed of buses obtained using weekday 1994 AVL data (19 files) and passenger arrival rates (obtained using a combination of the Route 18 survey data and associated 1995 AVL data for the same trips)
4 Source: Department of Transport (1994)

As can be seen from Table 4.13, the commercial speed of buses in central London was greater in May 1995 (when the survey was carried out) than in September 1994 (i.e. calculated from the AVL data).

4.4.2.2 Moving speed of buses

The speed of a bus as it moves between stops (i.e. the moving speed) is obtained by first calculating how long the bus actually spends moving, i.e. the time the bus spends at stops along the link whilst passengers board and alight from the bus (i.e. the dwell time) is subtracted from the total time it takes the bus to complete the link. The AVL data was used to obtain the time taken to complete the link in preference to the Route 18 survey data as the survey data only recorded time at given points rounded down to the nearest minute which proved to be too inaccurate for such a purpose.

\[
t_m = t_l - \sum_{\text{All stops on link}} S_i
\]

where:

\( t_m \): time bus spends moving between stops on link
\( t_l \): time bus takes to travel along the whole link
\( S_i \): stop time or dwell time
Extrapolated AVL data was used to obtain the headway between buses arriving at the stop which was required for the estimation of the stop time.

In order to assess whether the moving speed of buses obtained from the AVL data forms an accurate representation of the moving speeds observed in practice, the estimated moving speed of the AVL data from September 1994 was compared with the speed of buses between stops as observed during the Route 18 patronage survey period (i.e. April-May 1995) and published statistics from the Department of Transport (1994).

Figure 4.18 compares the average moving speed obtained for the weekday AVL data files in 1994 and the average moving speed obtained by subtracting the recorded time spent at stops on a link (during the survey of the Route 18) from the relevant link completion time (obtained from the 1995 AVL data for the relevant trip). The lower and upper 95% confidence limits are given for the Route 18 survey and 1995 AVL estimate of the moving speed as the number of observations from which the moving speed was obtained was sometimes quite low, due to the limited number of trips for which both AVL and survey data was available.

It was found that 76% of links in the 1994 AVL data set had an average estimated moving speed which was within the 95% confidence interval of the average moving speed observed during the 1995 patronage survey period. However for some links the 1994 data yielded a much higher moving speed. This effect is attributed to the fact the even though speeds which were in excess of 96.5 km/h were excluded from the analysis, a small number of higher speeds than would normally be expected still remained (see Figure 4.19).

Figure 4.20 shows the cumulative distribution function of the moving speeds of buses for the midday off-peak period, i.e. 1000-1600.

As Figure 4.20 shows, the maximum permitted speed used in the averaging of data (i.e. 96.5 km/h) meant that 2.5% of the data was excluded from the averaging process. A maximum permitted speed limit of 60 km/h would have excluded 5.1% of the AVL data from the averaging process.

The results of the comparison between the average moving speed of buses and the average speed of general traffic as given by the Department of Transport (1994) in the daytime
off-peak (when the greatest number of survey observations were made) is given in Table 4.14.

Table 4.14 Comparison of the moving speed of buses and the general traffic speed for Inner, Outer and Central London

<table>
<thead>
<tr>
<th>Area</th>
<th>Speed in km/h for the Daytime Off-Peak: 1000-1600</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moving Speed</td>
</tr>
<tr>
<td></td>
<td>Survey Data(^1)</td>
</tr>
<tr>
<td>Central</td>
<td>15.6</td>
</tr>
<tr>
<td>Inner</td>
<td>20.1</td>
</tr>
<tr>
<td>Outer</td>
<td>20.4</td>
</tr>
</tbody>
</table>

\(^1\) Survey data: speed of buses obtained using only the Route 18 survey data
\(^2\) Survey and AVL data: speed of buses obtained using a combination of the Route 18 survey data and the associated 1995 AVL data for the same trips
\(^3\) AVL data: speed of buses obtained using weekday 1994 AVL data (19 files) and passenger arrival rates (obtained using a combination of the Route 18 survey data and associated 1995 AVL data for the same trips)
\(^4\) Source: Department of Transport (1994)
There appears to be no significant change in the moving speed of buses in central London between September 1994 (i.e. AVL data) and May 1995 (i.e. survey data) but the moving speed of buses in inner and outer London appears to have fallen slightly during this time. This may be due to the fact that traffic on truck and principal roads in London increased by a small amount between 1994 and 1995 (Department of Transport, 1996b) which would have led to a reduction in the average moving speed of all traffic (including buses) on these roads.

### 4.4.2.3 Comparison of commercial speed and moving speed of buses

Levinson (1983) estimated that car speeds are consistently 1.4 to 1.6 times faster than bus speeds and that these ratios seem independent of year of study or type of city. The ratios of the speed of other traffic and of the moving speed of buses to that of the commercial speed of buses is given in Table 4.15.
Figure 4.20  Cumulative distribution function of moving speed of buses
(1994 Weekday: 1000-1600)

Table 4.15 Ratios of the speed of cars and buses to that of the commercial speed of
buses for Inner, Outer and Central London

<table>
<thead>
<tr>
<th>Area</th>
<th>Ratio of moving speed to commercial speed for the Daytime Off-Peak: 1000-1600</th>
<th>Ratio of traffic speed to commercial bus speed for the Daytime Off-Peak: 1000-1600</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Survey Data¹</td>
<td>Survey &amp; AVL Data²</td>
</tr>
<tr>
<td>Central</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Inner</td>
<td>1.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Outer</td>
<td>1.1</td>
<td>1.2</td>
</tr>
</tbody>
</table>

¹ Survey data: speed of buses obtained using only the Route 18 survey data
² Survey and AVL data: speed of buses obtained using a combination of the Route 18 survey data and the associated 1995 AVL data for the same trips
³ AVL data: speed of buses obtained using weekday 1994 AVL data (19 files) and passenger arrival rates (obtained using a combination of the Route 18 survey data and associated 1995 AVL data for the same trips)

The ratio for central and inner London support Levinson’s (1983) finding, however the
commercial speeds of buses in outer London is much slower than that of the rest of traffic. This indicates that either the average speed of traffic in London in these areas is greater than the average speed of traffic on this particular route or that estimation of moving speed using non real-time AVL data gives spurious results. In order to test the hypothesis that the roads along the Route 18 have an average traffic speed which is less than that experienced in the rest of outer London, the route was split into 6 sections which relate to the 6 main roads that the route passes through.

Table 4.16 compares the speed of bus movement as obtained by the AVL data and that given by the Department of Transport (1994) for the 6 sections of the route. It should be noted that the Department of Transport's traffic speed was obtained by using the floating car technique, i.e one car drives along the road and overtakes as many cars as overtake it. The speeds quoted by the Department of Transport were an average of a maximum of three such observations and in most cases were just a sole observation and so the validity of this data is in doubt but it does at least provide some sort of indication as to the average speed of traffic along these roads.

Table 4.16 Comparison of the traffic speed along 6 sections of the Route 18 and the average traffic speed for that area of London

<table>
<thead>
<tr>
<th>Area</th>
<th>Traffic speed for section (km/h)</th>
<th>General traffic speed for area of London (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 1</td>
<td>22.1</td>
<td>36.7 (Outer)</td>
</tr>
<tr>
<td>Section 2</td>
<td>12.5</td>
<td>25.4 (Inner)</td>
</tr>
<tr>
<td>Section 3</td>
<td>15.0</td>
<td>25.4 (Inner)</td>
</tr>
<tr>
<td>Section 4</td>
<td>27.4</td>
<td>25.4 (Inner)</td>
</tr>
<tr>
<td>Section 5</td>
<td>16.2</td>
<td>16.9 (Central)</td>
</tr>
<tr>
<td>Section 6</td>
<td>18.4</td>
<td>16.9 (Central)</td>
</tr>
</tbody>
</table>

Table 4.16 shows that the roads along the Route 18 do indeed have an average traffic speed which is less than that experienced in the rest of outer London. Therefore if we use 22.1 km/h as the speed of traffic in outer London, the ratio of the traffic speed to the commercial speed of buses becomes 1.2-1.3 which is closer to Levinson’s (1983) range.
Table 4.16 also shows that two of the three sections in the inner area are well below the average inner London speed which may be why the ratio of traffic speed to commercial speed of buses for the inner area was found to be at the high end of Levinson’s (1983) range i.e. 1.6. However the value given for the average traffic speed for Section 2 in Table 4.16 is suspect since it indicates that in this section of the route, buses appear to travel faster than cars! (i.e. a traffic speed of 12.5 km.h compared with a commercial speed of buses of between 16.0 and 16.3 km/h). This is not consistent with everyday observation, so one can conclude that either the AVL data is inaccurate or that the floating car observation was taken at an especially bad time when speeds were much lower than can normally be expected. It reasonable to assume that the latter is the case, as the average traffic speed provided by the Department of Transport for the daytime off-peak in this section was much less than that given for either the morning peak or the evening peak. Therefore doubt is placed on the value of using limited floating car observations, as given Table 4.16, rather than the accuracy of the aggregated AVL data.

4.4.3 Results of simulation

Since the April and May 1995 AVL data was used to calibrate the simulation model, the September and October 1994 AVL data was used to validate it. Tai (1985) observes that in the validation process the model is required to simulate the behaviour of the system under the exact conditions that prevailed and the results are compared with what actually happened. Non real-time AVL data is, therefore, a perfect tool for validation purposes, as a direct comparison can be made using the simulation model’s output file (i.e. simulated AVL data) and the original AVL data.

The model simulates a day’s operation according to the schedule and can either assume all buses ran as scheduled or only those trips which appeared in the AVL data ran (according to the schedule). This allows the best case scenario (the AVL data accounted for every bus that ran on the day) and worse case scenario (other buses ran for which there is no associated information in the AVL data) to be accounted for. What actually happened in practice probably lies somewhere in between.

Since most of the Route 18 survey was carried out in the midday off-peak (i.e. 1000-1600) observations in the other time intervals are scant due to the limited amount of AVL data received for the days on which surveys were carried out. Therefore the model will
only be representative in the 1000-1600 time interval and so the validation results presented in this section are those of this time interval.

Two variants of the model were tested, which will be termed Model A and Model B. The only difference between the two variants of the model was that in Model B, the actual moving speed of the trip was used if available, whereas in Model A the moving speed of the bus was derived from the average moving speed of buses within the relevant half an hour time interval.

In order to decide whether the two models provided an accurate representation of bus operations along the Route 18, standards were set and the output of the model (i.e. the simulated AVL file) was compared with the original AVL data to see if the output from the model met these standards. The criteria which determined if the model was valid were:

- the difference in the time taken to complete a link should be within ± 10% of that given by the AVL data (t_l test).
- the difference between the time at which a bus completes a link in the simulation and that given in the AVL data should be within ± 3 minutes (T_l test). Three minutes was chosen to be the standard since the difference between the AVL data and the Route 18 survey data was of this magnitude.
- the difference between the commercial speed of the bus in the simulation should be within ± 10% of that derived from the AVL data (v_c test)

The model was assumed to be valid if at least 90% of the data in the AVL file met all three criteria for at least 90% of the days for which AVL data was available. Table 4.17 presents the result of the validation for the midday off-peak (i.e. 1000-1600) averaged over all the useable weekday 1994 AVL data for both the variants of the simulation model developed.
Table 4.17 Percentage of AVL data which met the validation criteria

<table>
<thead>
<tr>
<th>Model</th>
<th>Trips used</th>
<th>% data passed $T_{le}$ test</th>
<th>% data passed $t_l$ test</th>
<th>% data passed $v_c$ test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model A: Average speed along links in time interval</td>
<td>AVL</td>
<td>42.8 ± 2.9</td>
<td>32.1 ± 0.8</td>
<td>32.0 ± 0.7</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>42.6 ± 2.8</td>
<td>32.1 ± 0.8</td>
<td>31.9 ± 0.8</td>
</tr>
<tr>
<td>Model B: Speed for individual trips/link</td>
<td>AVL</td>
<td>38.2 ± 1.6</td>
<td>46.1 ± 1.2</td>
<td>45.9 ± 1.2</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>38.4 ± 1.7</td>
<td>45.6 ± 1.2</td>
<td>45.3 ± 1.2</td>
</tr>
</tbody>
</table>

Table 4.17 shows that the results of the validation of the simulation indicate a very poor fit to the AVL data. None of the 17 days tested met the criteria of 90% of the data in the AVL file passing all three tests for a valid model. Therefore the model cannot, at present, be used as an aid to controller training as initially envisaged. The poor performance of the model may be due to:

- the number of passengers waiting when a Route 18 bus arrives at a stop in practice may be smaller than that calculated in the model, i.e. if a bus running on a parallel route arrived before the Route 18 bus. This would cause the time spent at stops to be overestimated in the model (since the Route 18 overlaps with other routes for the first 8 or so stops at both termini, some passengers may take the first bus to come which takes them to their destination or to a convenient transfer point).

- the time intervals over which passenger arrival rates were averaged were very large due to the lack of AVL data for the surveyed days which prevented smaller intervals being used (since averages would be taken over a small number of values). The large time intervals do not reflect the transient variation in the passenger arrival rates throughout the day (as observed by Danas, 1980).

- gaps in the AVL data trip information meant that headways used in the calculation of the passenger arrival rate were obtained from extrapolated data. Accuracy would have been increased if no gaps existed in the trip information and ‘observed’ headways were used. These gaps in the data also meant that speeds of trips on given links in Model B had to be estimated from the average speed, thus blurring the effect of using the actual speed of a given trip on a given link.
• the accuracy of some of the AVL data itself is in doubt due to the nature of the polling used. Although an attempt was made to remove ‘suspect’ data from the AVL file, some data may have remained causing anomalies which would have had repercussions on following trips.

• the maximum permitted moving speed of 96.5 km/h allowed some unnaturally high speeds to be used in the simulation. Although, these high speeds accounted for a small percentage of the speeds used, their effect would have had repercussions on following trips and the average speed calculated for a time period of half an hour (in Model A).

• the effect of the change over of duties in practice may have delayed a bus at the relief point which would not have been taken into account in the simulation model. The number of change overs in the midday peak ranged between 39 and 44 and therefore the effect of the change over of duties may have been significant.

• buses are assumed to run from their scheduled origin to their scheduled destination, therefore action by route controllers, such as turning a bus short of its destination would not have been taken into account in the simulation model. The reason why such action could not be modelled was due to the large number of gaps in the data which made it difficult to extract curtailed trips from trip data which was not recorded by the AVL system due to communication or equipment problems.

There is little difference in the results if the model is run using all the scheduled trips or only the trips present in the AVL data. This finding is surprising since it was found earlier that around 11% of the scheduled trips are missing from the AVL data file on average (see Table 4.9, Section 4.3.2.1). It was hypothesised that the number of trips missing in the midday off-peak period, which is the period of interest, is less than the average number of trips missing from the whole data set. However it was found that there was a difference of 11 trips (i.e. 7.5%) on average between the number of trips in the schedule and those that were present in the AVL data used in the validation process, so this factor would not account for the closeness in the results between the runs including all scheduled trips and only those that were present in the AVL data.

It is believed that the reason why the results from using only the AVL trips and all the schedule trips are so similar is because the passenger arrival rate along most of the Route 18 is small and so the increased time at stops due to more passengers boarding as a result

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of a missing trip is not orders of magnitude greater than that which would have occurred in the presence of the missing trip. Also bus bunching is such that two buses effectively act as one in cases where there is spare capacity on the first bus. Both these results seem to indicate that the number of buses serving the Route 18 during the midday off-peak is of the order of 10% greater than is actually required to serve the same numbers of boarding passengers. However the previous statement is made under the assumption that passengers do not have a cut off time beyond which they are no longer willing to wait for a bus.

Inspection of the average passenger waiting when all scheduled buses are in service and when the number is reduced (i.e. only those trips present in the AVL data actually run) provides a better indication as to the quality of service. The average passenger waiting time is derived from:

\[
AWT = \frac{\bar{h}}{2} \left( 1 + \frac{\text{var}(h)}{\bar{h}^2} \right) \quad [4.31]
\]

where:
- \( \bar{h} \): average headway between buses at a stop
- \( \text{var}(h) \): variance of headways

Figure 4.21 shows the average passenger waiting time as obtained from the simulation output (as calculated from the Equation 4.31) for all scheduled trips and for only trips which are present in the AVL data, for Model A on one arbitrary day.

As can be seen from Figure 4.21, the missing trips cause an increase in passenger waiting times for journeys coming into central London. However the missing trips do not produce overly large average passenger waiting times, although it should be noted that the averaging process mitigates the effect of a missing bus at the time of the missing bus which may be larger than is acceptable to the waiting passengers.
4.5 Recommendations for Improved Operations

Although the simulation model developed could not be used as a tool for controller training as initially envisaged, recommendations for improved route operations can be made from the patronage survey of the Route 18. Figure 4.22 gives a map of the Route 18 bus service in schematic format.

The following section describe observations of route performance during the Route 18 patronage survey which led to suggestions being made for improvements to the service. Although most of these recommendations are route specific, many are transferable to other routes which have similar problems.
4.5.1 Rules for driving when bunching

Drivers behave differently when they start to run off schedule. For example, some drivers who are early will wait at stops whilst others will continue to run early taking no action (or wait for controller intervention). Similarly, some drivers who are late will skip stops whilst others will only skip stops when the next bus is directly behind them.

Different driver characteristics can also exacerbate the problem of bus bunching. For example, when buses start to bunch some drivers will overtake the bus in front, thereby enabling the late bus to make up some time and regain its schedule. However this line of action causes the early bus to become even earlier than it otherwise would have been. In addition to this, controllers turn some buses short which delays drivers who have waited so that they remain on schedule, as they then find twice as many people waiting for them at stops than otherwise would have been.

**Recommendation:** The bus operating company should have a universal rule for drivers
which is explicitly explained to them so that they will know the what action to take when they start to bunch so that the effect of the variation in driver characteristics can be minimised. Also, if controllers are going to turn buses short it may be helpful if they were to inform the driver of the bus behind the turned bus so that the driver may alter his or her speed accordingly.

4.5.2 Turning buses

When turning a bus it is important to take into account the passenger loadings at the stops which the bus misses, otherwise the bus behind the turned bus could get very delayed. This often happens when buses are turned at Wembley Triangle since Wembley Central and Park Lane are both stops with heavy loadings (more so in the direction towards Baker Street).

Recommendation: If a bus is turned at Wembley Triangle, then the bus which follows it should be instructed to leave Sudbury a few minutes earlier than scheduled and the one behind it a minute earlier, as it will suffer the repercussions of the heavily loaded bus in front (e.g. if the bus in front gets full then it may have to skip stops).

4.5.3 Changes to schedule

There is very little slack in the Sunday schedule but too much slack in the Saturday and weekday evening schedule. Too much slack in the schedule can also lead to bunching as some drivers will wait at stops until they are on time whilst others will drive at the normal speed and get to their destination early. Also if buses wait at stops then they will pick up passengers which otherwise would have boarded the bus behind. This will cause the bus behind to run earlier and earlier.

When the headway falls below 6 minutes, buses are almost guaranteed to bunch as the patronage on the route is not sufficiently large enough to warrant such a small headway (especially since the smaller headway usually occurs in the evening when buses terminate at the Prince of Wales where drivers will either take their meal break or change route).

The travel time along links approaching the Prince of Wales stop from both Sudbury and Baker Street may be unrepresentative of the speed of other traffic because drivers slow
down appreciably and wait at stops coming up to the Prince of Wales as they have to reach the Prince of Wales at a certain time to change duty. This should be taken into account when analysing the data for these links and may explain the high level of variability in journey times associated with these links. It should be noted that drivers also slow down at other stops along the route or merely drive slowly to keep to schedule so that the speed of some buses will be much slower than the rest of the other traffic.

**Recommendation:** Trips which have duty changes at the Prince of Wales should be excluded from any calculation of the average speed along the link as more representative speeds will enable more accurate scheduling. Otherwise the schedule is self-perpetuating, i.e. drivers will drive at speeds to maintain schedules thereby suggesting that the schedule is a good representation of the speed of general traffic.

### 4.5.4 Departure from termini

Since the headway between buses is usually small, if drivers leave a couple of minutes early or late then the onset of bunching will occur within a few stops. This is because the stops near the start of the route from Sudbury have heavy loadings as they pass through Wembley High Street. Also, since many passengers do not travel far, the number of people boarding between Kings Cross and Baker Street Station depends heavily on the last time the Route 30 passed the stop, similarly, the number travelling between Sudbury and Wembley Triangle depends on the last time the Route 182 passed the stop. This is one of the main reasons for bunching, since these stops can be very heavily loaded if these buses have not passed the stop for a long time. This means that maintaining even headways is very difficult as both these areas are near the start of the route and so repercussions of heavy loadings will be soon felt and very often buses will bunch at Paddington or Park Lane.

**Recommendation:** Drivers should be instructed to wait for a couple of minutes if there is another bus in front and they are on time. The time spent waiting should not exceed 2 minutes when the headway is 6 minutes as this will then affect the number of people boarding the next Route 18 bus and, in the case of departure from Kings Cross, may make the bus late for its scheduled arrival at Baker Street Station.
4.5.5 Extension of route to Kings Cross on weekdays

Drivers are able to regulate their speed in outer areas of London but cannot feasibly do so in central London (i.e. between Paddington and Kings Cross) as traffic moves much more slowly along this section of the route and a slow moving bus will delay the rest of the traffic even further. Maintaining an even headway in central London is further complicated by the overlap on the route which causes alternate buses leaving central London to leave from Baker Street and Kings Cross at 12 minute headways in the expectation that when the buses from Kings Cross reach Baker Street the headway will be just 6 minutes. The erratic nature of traffic congestion in London together with the other factors mentioned earlier (i.e. the effect of the presence or absence of a Route 30 bus) means that this goal is simply very difficult to attain in reality.

**Recommendation:** It would be advisable to omit the section of the route from Baker Street Station to Kings Cross and run all buses from Sudbury to Baker Street. This will ease operational control decisions (as controllers will be able to modify departures from the one terminus without having to try and foresee the implications of that change on the bus coming from Kings Cross or leaving Baker Street) and eliminates a section of the route which is prone to heavy traffic congestion and long delays thereby enabling more trips to be made by the same drivers and hence increasing the frequency of buses on the route.

**Note:** This recommendation has been carried out in practice since all Route 18 buses now run from Sudbury to Euston.

4.5.6 Observed passenger behaviour

In the evening the patronage on the route drops significantly and most passengers prefer to stay downstairs at this time of day even when there are no seats available there and they are fit enough to go upstairs. One reason for this behaviour is that since there are more people downstairs the passengers feel more secure and fear attack upstairs. However during the day it is also noted that passengers remain standing downstairs when there are plenty of seats upstairs. This is probably due to the short distance travelled by many passengers or the assumption that the upstairs is full because of the number already standing downstairs.

**Recommendation:** It may be better to use Midi buses in the evening instead of the current
double decker buses to allow for this behaviour.

4.5.7 Reasons for large deviations in speeds between successive buses

The main shopping streets that the route passes through are too narrow to allow comfortable overtaking of buses. Therefore if a bus is stopped at the bus stop in front, the bus behind has to wait until it has finished loading and moves away from the stop before it can move itself. This is most noticeable on the roads which contain the stops: Jubilee Clock, Wembley Central, Park Lane, St. Mary’s Road and Manor Park (i.e. Harlesden and Wembley High Street).

Traffic lights can also significantly delay a bus. For example, the traffic lights between Bridge Park and Monk’s Park have a very long red time due to the large road that crosses the Harrow Road at this junction and the complexity of the signalling system employed there. Also, buses spend a significantly longer time at the traffic lights at College Park than at other lights because of the busy road encountered at this junction and the behaviour of car drivers who block the box of the junction thereby preventing buses from passing through the junction when they have the green time.

4.6 Conclusions

4.6.1 Results from the Route 18 survey

The time spent stationary at stops can be divided into 2 parts: the dead time and the time spent for passengers to board or alight (whichever is greater). The dead time was found to be approximately 6 seconds, the average time taken for one passenger to board was found to be approximately 5.5 seconds and the average time taken for one passenger to alight was found to be nearly 2 seconds. The first passenger takes on average around 3.9 seconds longer to board than subsequent passengers. Similarly, the first alighting passenger takes on average 1.6 seconds longer to alight than subsequent alighting passengers. Even though OAPs are on average about a second slower to process than other holders of passes, they are significantly faster than those paying by cash (either by exact fare or requiring change).

A surprising outcome of calculating the average boarding time for stops where only OAPs...
boarded is that the average boarding time for OAPs is approximately equal to that of all the passengers, i.e. 5.5 seconds. This is due to the fact that OAPs 'pay' by pass and are significantly quicker to process than those paying by cash fares. Therefore extra time taken for any mobility handicap is compensated for by their quick method of payment. It was also observed that many OAPs have their passes ready for inspection unlike other passengers who board the bus not quite so well prepared. However the average alighting time for OAPs was significantly larger than the average alighting time for all passengers. The majority of the additional time required for OAPs alighting is taken up by the first OAP alighting. This reflects the difficulty many elderly people have in descending stairs and the fact that many mobility handicapped passengers will wait for the bus to stop completely before attempting to alight in order to avoid being thrown forward by the rapid deceleration.

The bus occupancy was found to have no effect on the effectiveness of the boarding time model and although the number of passengers alighting was found to have some effect the regression equation, it was not regarded as being satisfactory. It is recommended that more data is collected at higher bus occupancies and higher number of passengers alighting.

4.6.2 Results derived from AVL data

Analysis of non real-time AVL data from Route 18 showed that the time at which a bus was at a given position along the route is not 100% accurate because of the method of polling and the capacity of the communication channel employed. However the time taken to complete a link and hence obtain the commercial speed of the bus was found to be fairly reliable. Therefore AVL data has to be checked for errors before it can be used for automatic monitoring of schedule adherence. When this has been carried out, the data can be used to provide reasonable estimates as to the average deviation from schedule, but it should be noted that there is a small tendency to overestimate the time at given positions, due to the nature of polling.

A new methodology which uses non real-time AVL data and on-bus passenger counts to calculate the passenger arrival rate at stops along a bus route has been used to estimate annual patronage and the speed of buses as they move between stops. Estimating the patronage at stops using AVL data is more cost-effective than conventional methods (such
as surveys at stops) but retains the benefits of accuracy and stop-specific estimates of annual patronage. Using information from on-board ticket machines and smart ticketing is more cost-effective than the method outlined in this chapter. However ticketing information may be difficult to obtain on a stop-specific basis.

The passenger arrival rate can then be used to calculate how long buses spend at stops. If the time buses spend at stops is removed from the total time it takes the bus to traverse a link, the remaining amount of time can be assumed to be the time the bus spends moving and hence the moving speed of the bus can be obtained.

It was found that estimation of patronage and the speed of buses as they move between stops using AVL data produced results which were comparable with those obtained by other methods. However the main point to note is that this new method of estimating patronage has the potential to provide a larger and superior data set than is otherwise available, at very low cost.

Although the analysis of the AVL data yielded useful results concerning the affect of passengers on the journey time and highlighted areas which could benefit from bus priority measures, the simulation model developed using the passenger arrival rate and moving speed of buses did not prove to be satisfactory. Therefore it appears that while the passenger arrival rate and moving speed of buses obtained from AVL data is useful for aggregate analysis, it is not sufficiently representative for the disaggregate modelling which was attempted. It is unclear whether the problems associated with the data used in the analysis are common to all AVL systems since data from other AVL systems were not available for comparison. However it is likely that large AVL systems which utilise more than one radio aerial range and do not have systems in place to check for multiple receipts of data from a given bus and systems which do not have sufficient communication capacity to comfortably poll all vehicles in the polling cycle, will encounter similar problems.

The benefits which can be obtained from the use of non real-time AVL data have been described in this chapter. In the next chapter the benefits which can be obtained from real-time AVL data will be discussed.
CHAPTER 5: REAL-TIME PASSENGER INFORMATION SYSTEMS

Abstract

Project managers of real-time passenger information systems were interviewed during June and July 1996 with the aim of comparing the advantages and disadvantages of each system. The costs and benefits of these systems are discussed in this chapter and guidelines for system specification of AVL and real-time passenger information systems are produced. It is shown that by assessing the needs of the user, the system which is most suited to a particular application can be specified, as there is a great deal of flexibility amongst existing systems. However in practice it was found that many users buy systems 'off-the-shelf' without fully assessing whether it meets their objectives to any great degree.
5 REAL-TIME PASSENGER INFORMATION SYSTEMS

The two main uses of real-time data from AVL systems are for bus operational control purposes and for the provision of real-time passenger information at stops. This chapter will focus on how the different technologies used to drive AVL systems affect bus operational control due to the type of information which is available to the route controller and how different real-time passenger information systems vary across the country. A review of the passenger information literature is presented as background information and the history of real-time passenger information systems is described. The effect of real-time passenger information on the perceived waiting time at stops and the behaviour of passengers is discussed in Sections 5.1.2 to 5.1.3 and the value of this information and the question of ‘who pays for it?’ is discussed in Sections 5.1.4 and 5.1.5 respectively. Finally, the question of ‘when is it necessary to implement a real-time passenger information system?’ will be addressed in Section 5.1.6.

A postal survey of bus operators and local authorities who were implementing AVL or real-time passenger information system was undertaken in 1994. The postal survey found that most buyers of AVL systems rely on the claims of the manufacturers when deciding which system to buy. Since there has been little research into AVL systems carried out by an independent researcher, the accuracy of these claims has not been verified. Therefore structured interviews were carried out in 1996 with many of the initial respondents of the pilot survey in order to assess whether the reality met the expectations of the users of AVL and real-time passenger information systems. Section 5.2 describes the methodology used in the survey and interviews, and Sections 5.3, 5.5 and 5.6 describe the respective results. A comparison of the various AVL systems currently operational in the UK based mainly on a literature review of the systems is given in Section 5.4. Guidelines for system specification are given in Section 5.7 and observations as to the relative merits of each system (obtained from on-site visits and the structured interviews carried out in June and July 1996) together with best practices are given in Section 5.8.
5.1 LITERATURE REVIEW

The extent to which bus passengers are satisfied with the service provided is usually ascertained from passenger surveys. Reliability, frequency (Butcher, 1972; De Ivey and Anson, 1995) and the uncertainty of waiting time (Chapman et al., 1976a; Khorovitch et al., 1991; Bradshaw and McGreevy, 1994; Lam, 1994) were found to be important attributes of a bus service in many surveys. Gillingwater et al. (1994) found that improving passenger information and driver behaviour were also seen as significant factors in attracting and retaining passengers. Information (either real-time or static) was of less importance to passengers than the cleanliness and comfort of buses and waiting facilities in a survey carried out by De Ivey and Anson (1995). Suffolk County Council (1995) also found that soft improvements such as friendly staff, innovative image and publicity were frequently mentioned in their passenger surveys. The difference in survey responses may be due to the varying characteristics of bus passengers and the quality of service provided in different areas. However in most surveys, passenger information has been highlighted as being an important attribute of a bus service. This is probably because comprehensive and reliable information is a prerequisite if current and prospective passengers are to make full and effective use of the services offered, irrespective of whether buses are provided on an integrated basis or in a deregulated environment (Cartledge, 1992b). Therefore high quality information should be available to travellers at all stages of their journey to inform passengers as to the options available to them and reassure them that they are in control of their journey (Blackledge et al., 1992).

The problem associated with all printed information is that in the dynamic bus environment it is difficult to keep it up-to-date and will therefore be misleading to passengers who use it thereafter (Meads, 1987; Yuen, 1988). Real-time information is up-to-date and can show day-to-day operational decisions such as cancelling buses or curtailing trip lengths. However it has the disadvantage of not being portable in the same way as maps and timetables (Meads, 1987).

Passenger information systems can operate using either scheduled travel information or real-time information which is based on AVL data. Passenger information systems are designed to convey information directly to the traveller without an intermediary and can be divided into two broad categories (Gilbert and James, 1987; Papaioannou and Reis Simoes, 1993):
• **passive information** which requires no effort on the part of the passenger but also means that the passenger has no control over the content of the information provided, e.g. VDU screens or dot matrix indicators

• **interactive information** which requires the participation of the passenger but may provide more relevant information tailored to their needs

Hall (1983) notes that if travellers are not well informed, they will benefit from passive information (i.e. maps, timetables etc.) and if travellers are not sufficiently skilled, they will benefit from interactive information.

Timetabled information is a useful tool in the planning stage of a journey, when all options are still available, however real-time information is superior when the trip has already started as it conveys the current position of the bus rather than its ideal (scheduled) position and is thus able to reinforce travel options in the course of the journey (Gilbert and James, 1987; Local Transport Today, 20 January 1994). However the full benefits and simplicity of a real-time information system cannot be achieved without good static information. Therefore real-time passenger information should be complementary to good static information, rather than replacing it (Gilbert and James, 1987; Meads, 1987; Cassidy and White, 1995). In some cases the volume of printed material may be reduced as the use of new technology spreads.

Axhausen (1993) observes that real-time passenger information systems are a service of the system operator to existing or potential customers. For potential customers the aim is to advertise the service and encourage the spontaneous purchase of the service by making the availability of the service clear and by reducing the perceived waiting time. For existing customers the aim is to reassure them about the expected service and to retain their loyalty through an obvious display of interest in the concerns of the user. An image effect of modernity and high technology is an useful extra.

Warman and Sheldon (1985) report that passengers reservations about the concept of real-time passenger information relate to the perceived likely cost to the customer, the robustness of the display at the stop to withstand vandalism (a concern which Atkins (1994) observes appears to be unfounded) and the ability of the system to take account of the effects of the heavy traffic conditions.
5.1.1 History

Real-time passenger information has been around for many years in various formats. A brief history of the development of these various schemes is given below. Only schemes which have been discontinued will be discussed below, since current schemes are described in more detail in Section 5.6.

5.1.1.1 ERICA

Suen (1981) describes ERICA (Easy Rider Information with Computerized Assistance) which was implemented by Mississauga Transit, Ontario, Canada in the late 1970s and was the first telephone-based real-time passenger information system in the world: a manual demonstration of the concept began in December 1975 on a route which had a headway of 15 minutes in the peak and 30 minutes in the off-peak. Initially a large mechanical slide rule was used to adjust the schedule performance of buses to their actual performance as each bus report was transmitted via radio. The slide rule was replaced with a computer in April 1976 and the automatic voice response system took over from telephone operators in October 1977.

Passengers keyed in a telephone number which represented the bus route and stop, and a computerised voice provided them with the time of arrival at that stop of the next 2 buses over the telephone. The automatic telephone response system was based on an odometer and radio-based AVL system in which the computer polled each bus every 30 seconds to obtain its current wheel count since the odometer was last reset. The odometer reset was carried out by the driver because a beacon-based AVL system failed to pass an acceptance test. The driver was alerted by means of indicator lights and a buzzer if he was ahead of schedule, had forgotten to reset the odometer or if he was called by the route controller.

Suen (1981) reports that 50% of passengers departing from their home used ERICA due to the ease of access to a phone, however this figure fell to 10% on return trips. 47% of passengers used the system frequently, with a further 23% being occasional users.

The real-time aspect of ERICA was discontinued after 3 years due to operational difficulties and maintenance problems with the on-vehicle equipment.
5.1.1.2 BUSCO

The first real-time passenger information system for buses in the UK was trialled by London Transport between 1984 and 1986 on the Route 36 and utilised the BUSCO (Bus Communications and Control System) AVL system and LED displays at stops (Whitley, 1984; Yuen, 1988; London Transport, 1993a; Wileman, 1995). The BUSCO system used odometers and inductive loops in the road (situated principally at terminals, turning points, garages and where the routes divide and merge) to locate buses (Whitley, 1984; Yuen, 1988). Positional information was stored on-board the bus and buses were polled once a minute using a radio data channel (Wileman, 1995). A one line display was used to show the destination and arrival time of the next two buses, however the equipment was expensive and the system made heavy use of the London Buses’ radio channels which led to its termination (Balogh, 1993).

5.1.1.3 HEWORTH

BUSCO was followed by the Heworth Interchange Bus Station system which was implemented by the Tyne and Wear PTE and utilised VDUs at the bus station which advised passengers as to the next four departures to each destination served by transponder bearing buses and gave a full route profile for the next bus. Bus delays were shown in red and normal operations in green (Gilbert and James, 1987). The AVL system utilised microwave roadside beacons and on-bus transponders. Beacons transmitted a continuous signals which buses would respond to when they passed by, transmitting their identity (which is set by thumb wheels within the unit) to the beacon. The transponders were powered from the bus’ electrical system and did not transmit a signal until they received a stimulus from a beacon. The beacons were polled by the control centre using British telecom lines (Cowell et al., 1988).

5.1.1.4 TRUST

CENTRO (the West Midlands Passenger Transport Executive) implemented their real-time passenger information system called TRUST (TRacking Using Satellite Technology) in the summer of 1994 under the DRIVE II QUARTET (Quadrilateral Advanced Research in Telematics for Environment and Transport) Blueprint project (CENTRO, 1993). The project produced a real-time passenger information system for enquiry office staff,
optimum route software, an at-home information system and on-street and at-stops displays (Holmes, 1994). The system was based on GPS vehicle tracking technology due to the flexibility it offered. Since bus routes in the Birmingham area were prone to change often, beacon-based AVL systems were regarded as too inflexible (Holmes, 1994).

TRUST was switched off in 1995 due to erroneous information being displayed at stops as a result of a combination of drivers failing to input the correct information into the system, non-fitted buses running along the route and buses equipped with GPS receivers operating on a parallel route to the trial route with the on-bus equipment switched on (Middlebrook, 1995; Transport and Travel Research et al., 1995). CENTRO has put out an invitation to tender for a new real-time passenger information system in Birmingham which is expected to be commissioned in January 1997.

5.1.2 Effect of real-time passenger information on perceived waiting time

Forsyth and Silcock (1985) note that passengers are required to be in a constant state of preparedness to board and so cannot use waiting time at stops for useful activity. Furthermore, attention to the passage of time generally results in the wait appearing to be longer than it actually is, with stress, fatigue and frustration contributing to the magnitude of this effect (Axhausen, 1993; Atkins, 1994). Therefore real-time passenger information systems should have a reassuring effect and reduce the perceived waiting time (Harding, 1994; Reed, 1995).

Results from a study on the London Underground support this hypothesis, as they show that the factor by which passengers over-estimate the time they have to wait is 1.2 in the absence of real-time information but only 1.05 when expected arrival times are displayed (Forsyth and Silcock, 1985; ECMT, 1989). Butcher (1972) reports the overestimation of waiting time as being nearer the two mark which agrees with the traditional weighting of waiting time as being twice that of in-vehicle time in many studies. This perceived reduction in waiting time has also been found for bus users in studies in Liverpool (57%), (Merseytravel, 1995), Heworth (23%), (Cowell et al., 1988) and London (65%) (Atkins, 1994; Wileman, 1995; Johnson, 1996).

London Transport carried out passenger surveys on the Route 18, which was the trial route for London’s COUNTDOWN system, during July 1993. At this time service
reliability was marginally worse than the previous year (Wileman, 1995), therefore the perceived improvement in reliability by 64% of passengers surveyed was thought to be attributable to COUNTDOWN (Atkins, 1994).

5.1.3 Effect on passenger behaviour at stops

It has been hypothesised that passengers may switch to an alternative mode if the wait shown is deemed to be too long (Jabez, 1993b; Atkins, 1994; Local Transport Today, 20 January 1994). However Atkins (1994) argues that bus information provision is likely to have a fairly neutral effect on overall bus use since:

- when a short wait is indicated, a walk journey might be diverted to bus
- when a long wait is indicated, passengers may walk or use another mode

Middlebrook (1995) supports Atkins argument in noting that in Southampton 13% of passengers who were informed of a long wait by the real-time passenger information system (STOPWATCH) left the stop and of this 13%, 38% walked the whole journey, 30% walked to the next stop, 18% went to a nearby shop, 7% took a taxi and 7% were unaccounted for. Warman and Sheldon (1985) surveyed passengers on London Transport’s trial route (No. 36) and found that about 75% of respondents were prepared to wait when the display showed a wait of up to 10 minutes before the next bus before seeking an alternative, for a service which was scheduled to run every 6 minutes. This higher figure (25%) of passengers who left the stop in London may be accounted for by the greater mode choice available in London, since the concentration of bus routes in the capital is greater than in Southampton, so switching from one bus route to another bus route is a reasonable alternative (as is catching a tube).

Forsyth and Silcock (1985) found that unquantifiable benefits of real-time passenger information systems were reductions in the levels of stress, better informed opportunities to exercise choice of: route, whether to board a crowded vehicle or wait for the next one and whether to make practical use of the waiting time, e.g. visit a nearby shop. Atkins (1994) notes that for waiting time to be used in diversionary activities, passengers must be confident that the information presented is accurate. In surveys carried out on the Route 18, only 82% of passengers said that the accuracy of the information was acceptable (Atkins, 1994). Lam (1994) adds that inaccurate information may lead to negative perceptions of the system or even worse to incorrect travel decisions being made.
by passengers (Schweiger et al., 1994).

5.1.4 Value of real-time information

London Transport (1993b) report that passengers put a high value on real-time passenger information. This value has been quoted as being between 10p and 12p per journey by various authors (Balogh, 1993; R Smith, 1993; Local Transport Today, 20 January 1994) following stated preference work with 240 respondents, after the Route 36 trial in London (Axhausen, 1993). More complex information (e.g. about seat availability) was valued at 44% of the fare (Axhausen, 1993; Atkins, 1994). The fully developed COUNTDOWN system yielded even higher values of 20p and 26p per journey in later surveys on the Route 18 (Atkins, 1994).

Merseytravel (1995) revealed that passengers attribute an average valuation of 9p to the information provided by their real-time passenger information system TIMECHECKER which was equivalent to 16% of the average fare.

However before these values are used in any financial appraisal of the system, it should be noted that there may be some bias present in the value put on information as passengers tend to overstate the system’s worth intentionally in order to increase the chances of the system being extended and that there may also be a difference between what passengers say they are willing to pay and what they are actually willing to pay (Lam, 1994).

5.1.5 Paying for information

Some researchers hypothesise that with a small generation of passengers, information systems are able to show a good rate of return and pay for themselves over a reasonable period (Gilbert and James, 1987; Cowell et al., 1988). For example, Peter Jones (Local Transport Today, 28 September 1995) estimates that, at worst, a 10% increase in patronage is required to cover the costs of STOPWATCH.

The cost of extending COUNTDOWN to a quarter of London’s network which would encompass 100 routes, 2000 vehicles and 4000 busiest stops (R Smith, 1993) is estimated as being between £40-£50 million spent over the next 7 to 10 years (Balogh, 1996a).
this kind of investment it is unclear if the gains in patronage possible through real-time passenger information are larger than those possible through a similar investment into other service improvements, e.g. improved service reliability or speed improvement through bus priority measures (Axhausen, 1993). This point was also echoed by Dr Laurie Pickup when he identified the current trend of implementing new technology in the bus industry by saying that the industry has primarily been technology led and in some cases operators have opted for expensive state-of-the-art equipment without fully assessing the benefits it may bring. He believes that the introduction of less sophisticated technology could, in many places, be both cheaper and easier to install and would be more effective (Jabez, 1993b). Even though real-time passenger information seems like an expensive option, Nelson and Hills (1992) are quite correct in noting that the investment required for real-time information systems is paltry compared to that of, say, building an urban motorway which costs many millions.

Holmes (1994) raises the question of who should pay for the provision of real-time passenger information in a deregulated environment. Since the costs involved in installing and maintaining such equipment are high, this question is non-trivial. If real-time passenger information encourages bus use and reduces car use, then society as a whole benefits (through a reduction in congestion, pollution, etc). But this is not the case for most of the systems in operation at present. Even if patronage did increase, the bus operator would be the main beneficiary of this increase through increased revenue and so should be expected to contribute to the cost of the system. However in a competitive bus environment, which is financially constrained, the incentive to do so is limited. Also, in a deregulated environment, it is difficult to stop ‘free-loaders’ who have not paid for the system running along the same route and benefiting from the extra patronage (Holmes, 1994).

In their paper, 'A Bus Strategy for London', the Department of Transport (1991a) advised that operators should be able to buy into real-time passenger information technology or develop their own system when London was deregulated. However many researchers (Majumdar, 1992; Balogh, 1993; R Smith, 1993; Lam, 1994) hypothesised that the incentive for operators to invest in such systems is weak if they wish to run the service for only a trial period and is often financially out of the question (Cahm, 1990; ETSU, 1993).

Much of the research into the effects of real-time passenger information in a deregulated
environment was carried out before any schemes were commissioned in deregulated areas. The bus operating environment outside London has much greater stability now than previously expected and so there has been some contribution afforded by bus companies involved in real-time passenger information schemes, usually in the form of new buses. However, in most cases, it is the public sector who pays for the majority of real-time passenger information systems costs.

5.1.6 Implementing real-time passenger information

With small fleet sizes and low frequency routes reliability can usually be maintained relatively easily (Lam, 1994), therefore the implementation of real-time passenger information would not be cost-effective and would be superfluous, since on low frequency routes: passengers do not tend to arrive at random (Seddon and Day, 1974). In cases such as these, it would be better to use conventional information (e.g. timetable information) even if it is conveyed by an electronic means (Gilbert and James, 1987). Research conducted by MVA found that static electronic information was most useful to irregular visitors of the system but paper timetables tended to suffice for the majority of people (85%) who were already familiar with the services on offer (Local Transport Today, 20 January 1994).

Therefore AVL and real-time passenger information systems are most useful and of greatest benefit on high frequency, high demand routes through urban areas where the effects of congestion, accidents and unstable demand make a reliable bus service more difficult to achieve. Lam (1994) observes that although real-time passenger information tends to reduce the negative effects of unreliability, it is still second best to the alternative of improving reliability. He argues that passengers would rather be able to depend upon a reliable service than depend upon being notified of an unreliable service and goes on to predict that the effects of real-time passenger information will gradually fade once passengers continue to observe a poor service. Therefore AVL should be used to improve reliability as much as possible and then the remaining unreliability can be dealt with by the real-time passenger information system. However if reliability is very good then the real-time passenger information becomes superfluous and is rarely used (Lam, 1994). This point is illustrated by Cassidy and White (1995) when they describe the experiences of the River Bus real-time passenger information system (which has since been discontinued).
Meads (1987) argues that high profile real-time passenger information can do more good in the eyes of the public than, for example, behind the scenes improvements in operating and engineering technology. However Baggaley (1984) warns against abandoning tried and tested techniques simply because they are old. He notes that in many fields the adoption of new technology has all too frequently increased costs without producing commensurate benefits.

5.2 Methodology

The main aims of this research are to identify the capabilities of AVL systems, potential areas of exploitation for AVL data and the pitfalls associated with this technology.

The aim of identifying the capabilities of AVL systems was achieved by a series of interviews with project managers of real-time passenger information systems in the UK and bus route controllers, who were identified after an initial postal survey. The interviews provided a valuable insight into the problems associated with using this technology which were not immediately obvious before implementation. Although problems with individual systems have sometimes been documented, there has been no broader comparison of systems. It was clear from the interviews that this would be a useful task to carry out.

Assessment of the capabilities and pitfalls of AVL technology was made by use of a pilot postal questionnaire (mainly in April 1994) and a series of face-to-face interviews with members of organisations who were using real-time data from AVL systems (which were carried out during June and July 1996).

5.2.1 Postal survey

A questionnaire relating to the use of Automatic Vehicle Location systems amongst bus operators and local authorities was posted to a number of relevant organisations, who were identified from a literature review, articles in newspapers and the trade press. The questionnaire was changed slightly for bus operators and local authorities to reflect the different requirements of the two types of organisations.

The questionnaire which was sent to local authorities is given in Appendix B. Completed questionnaires were returned by the organisations listed in Tables 5.1 and 5.2. Three bus
operators and five local authorities failed to respond to the questionnaire. One bus operator and three local authorities replied to the request for information with a letter explaining that they had no AVL system. Of the local authorities which failed to respond only one (Surrey County Council) is currently implementing a real-time passenger information system and one (West Yorkshire PTE) is considering doing so. Go-Ahead Gateshead failed to respond to the questionnaire but it was later discovered that they did not have an AVL system at that time.

The questionnaire’s main aim was to obtain information regarding the preferred technology, accuracy and costs of the AVL systems which were being implemented and to identify areas which users felt needed more research.

5.2.2 Interviews

Information gathered from the pilot survey led to the development of a second questionnaire which was used as the basis of interviews with bus operators and project managers of real-time passenger information systems in the UK. There was also a slight difference between the questionnaire used in interviews with bus operators and that which was used in interviews with transport planning authorities. The questionnaire used in the interviews with project managers can be found in Appendix C.
Table 5.1 Completed questionnaires returned by transport planning authorities

<table>
<thead>
<tr>
<th>Transport planning and local authorities</th>
<th>Date of questionnaire completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merseytravel</td>
<td>21 March 1994</td>
</tr>
<tr>
<td>Hampshire County Council</td>
<td>8 April 1994</td>
</tr>
<tr>
<td>London Transport</td>
<td>11 April 1994</td>
</tr>
<tr>
<td>Nottinghamshire County Council</td>
<td>11 April 1994</td>
</tr>
<tr>
<td>Strathclyde PTE</td>
<td>13 April 1994</td>
</tr>
<tr>
<td>Hertfordshire County Council (proposal described in the questionnaire was later rejected)</td>
<td>14 April 1994</td>
</tr>
<tr>
<td>Berkshire County Council</td>
<td>19 April 1994</td>
</tr>
<tr>
<td>Lancashire County Council</td>
<td>25 April 1994</td>
</tr>
<tr>
<td>CENTRO</td>
<td>1 August 1994</td>
</tr>
<tr>
<td>Suffolk County Council</td>
<td>31 August 1995</td>
</tr>
<tr>
<td>Maunsell and Partners (consultants to Suffolk County Council)</td>
<td>28 September 1995</td>
</tr>
</tbody>
</table>

Table 5.2 Completed questionnaires returned by bus operators

<table>
<thead>
<tr>
<th>Bus operator</th>
<th>Manufacturer</th>
<th>Technology</th>
<th>Date of questionnaire completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>CentreWest (London) - visited in person</td>
<td>Mark IV SLE</td>
<td>Beacon/Transponder</td>
<td>15 March 1994</td>
</tr>
<tr>
<td>PMT Ltd (Stoke-on-Trent)</td>
<td>Terrafix</td>
<td>GPS</td>
<td>17 March 1994</td>
</tr>
<tr>
<td>London United</td>
<td>GEC Marconi</td>
<td>Beacon/Transponder</td>
<td>24 March 1994</td>
</tr>
<tr>
<td>Armchair Passenger Transport (London)</td>
<td>GEC Marconi</td>
<td>Beacon/Transponder</td>
<td>6 April 1994</td>
</tr>
<tr>
<td>R and I Buses (London)</td>
<td>Datatrak</td>
<td>Radio navigation</td>
<td>8 April 1994</td>
</tr>
<tr>
<td>Leaside Buses (London)</td>
<td>Mark IV SLE</td>
<td>Beacon/Transponder</td>
<td>21 October 1994</td>
</tr>
</tbody>
</table>
5.2.2.1 Real-time passenger information systems

All the known real-time passenger information systems which had been commissioned in the UK before the 1 August 1996 were visited in turn. The timetable for these visits is given in Table 5.3.

Table 5.3 Visits made to real-time passenger information installations in the UK

<table>
<thead>
<tr>
<th>Transport planning and local authorities</th>
<th>Date of visit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strathclyde PTE</td>
<td>17 June 1996</td>
</tr>
<tr>
<td>Tyne and Wear PTE</td>
<td>25 June 1996</td>
</tr>
<tr>
<td>CENTRO</td>
<td>26 June 1996</td>
</tr>
<tr>
<td>Nottinghamshire County Council</td>
<td>1 July 1996</td>
</tr>
<tr>
<td>Merseytravel</td>
<td>2 July 1996</td>
</tr>
<tr>
<td>Hampshire County Council</td>
<td>4 July 1996</td>
</tr>
<tr>
<td>Suffolk County Council</td>
<td>22 July 1996</td>
</tr>
<tr>
<td>Berkshire County Council</td>
<td>1 August 1996</td>
</tr>
<tr>
<td>Surrey County Council</td>
<td>2 August 1996</td>
</tr>
<tr>
<td>London Transport Buses</td>
<td>9 September 1996</td>
</tr>
</tbody>
</table>

The real-time passenger information system in Birmingham was operated by CENTRO from September 1994 until January 1996 (when it was switched off).

Lancashire County Council were about to start installing their system, which is based on Peek Traffic’s Bus Tracker, in Blackburn at the end of August 1996 but were uncertain as to the progress that could be made during the period of this research. In April 1994, Lancashire County Council completed the pilot questionnaire sent to them in the anticipation that their real-time passenger information system would be ‘on-line’ by the summer of 1994. However two years later they find themselves in approximately the same situation, as a direct result of the problems that occurred when Peek Traffic acquired GEC Marconi’s Bus Tracker which caused a delay of many months for several real-time passenger information implementations. Therefore Lancashire County Council returned the follow-up questionnaire by post, instead of an interview being carried out on-site. The
Norwich system was also in its trial stages at the end of July 1996 and the real-time passenger information component was not fully functional. Therefore a questionnaire was sent to Norfolk County Council for completion. Unfortunately Norfolk County Council failed to return the questionnaire sent to them. However a brief description of the Norwich system can be found in Section 5.4.8. West Yorkshire PTE are currently considering implementing real-time passenger information on the Leeds Super Bus route but have not yet decided upon a preferred system.

5.2.2.2 Bus operational control

In order to assess whether the AVL technology itself affects bus operational control, visits were made to bus companies who were known to be using different AVL systems. Table 5.4 gives the timetable for these visits and the AVL system and technology used by each operator visited.

The only beacon and tag AVL system currently operational in the UK is that used by Strathclyde PTE. However the bus operators in Glasgow did not have AVL workstations in their garages at the time of the visit to Strathclyde PTE so no visit was made to any bus operator's premises.

Table 5.4 Visits made to bus operators

<table>
<thead>
<tr>
<th>Bus operator</th>
<th>Manufacturer</th>
<th>Technology</th>
<th>Date of visit</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMT Ltd (Stoke-on-Trent)</td>
<td>Terrafix GPS</td>
<td>24 June 1996</td>
<td></td>
</tr>
<tr>
<td>Go-Ahead Group North East (Gateshead)</td>
<td>Peek Traffic Beacon/ Transponder</td>
<td>25 June 1996</td>
<td></td>
</tr>
<tr>
<td>Armchair Passenger Transport (London)</td>
<td>GEC Marconi Beacon/ Transponder</td>
<td>27 June 1996</td>
<td></td>
</tr>
<tr>
<td>MTL London Northern</td>
<td>Mark IV SLE Beacon/ Transponder</td>
<td>3 July 1996</td>
<td></td>
</tr>
<tr>
<td>Reading Transport</td>
<td>Peek Traffic Beacon/ Transponder</td>
<td>1 August 1996</td>
<td></td>
</tr>
</tbody>
</table>
5.3 RESULTS OF THE POSTAL SURVEY

In April 1994 a postal survey was sent to organisations which were implementing AVL systems. At this time most systems were in the commissioning or trial stages of development, with only 3 (out of 15) AVL systems over a year old. Therefore the responses obtained from this survey were, in the main, expectations of the users. These expectations were usually based on information provided by the supplier of the AVL system.

The main findings of the postal survey were in relation to the criteria used to decide on system technology and manufacturer.

5.3.1 Criteria for choosing technology

7 out of the 15 respondents (9 local authorities and 6 bus operators) had chosen the GEC Marconi Bus Tracker system (which is now owned by Peek Traffic). The reasons for choosing this system included an attractive offer of a demonstration by the manufacturers, the ease of maintenance of a beacon-based system, the fact that it was proven technology used in the UK, an acceptable level of accuracy and good value for money. Another operator who used a beacon-based system by a different manufacturer gave similar reasons for their choice.

4 respondents had chosen a GPS-based AVL system because of the flexibility in route choice, ease of extension, relatively low cost of operation, low capital cost and potential for development and enhancement.

R and I Buses was the only respondent to use a radio navigation-based system, i.e. Datatrak. The reasons for this choice were similar to those given by users of GPS-based systems and included flexibility of the system and the independence of any roadside infrastructure.
5.3.2 Criteria for choosing manufacturer

The criteria for choosing which manufacturer won the contract to install and maintain the system were similar to those of system choice, i.e. cost, track record, proposals for innovation and development, compliance with the tender specification, price, type of technology, consultants recommendation and potential interface with other systems (e.g. Urban Traffic Control).

5.3.3 System evaluation

Evaluation of the success of the implementation of the AVL system was mainly carried out by:
- market research (on-bus surveys)
- monitoring whether there had been a reduction in lost milage
- monitoring whether there had been an increase in reliability
- assessing the perceived accuracy of the system by users, i.e. bus route controllers and passengers
- monitoring whether there had been an increase in patronage

Section 5.6.7 shows to what extent these measures have been achieved. In general, perceived accuracy is relatively high amongst passengers but perception of the accuracy of positional information varies between route controllers who use different systems.

5.3.4 Expansion

Respondents generally had no intention of expanding their AVL systems to include extra features such as consoles in driver’s cabs which showed the number of minutes ahead or behind schedule. However linking the system to bus priority at traffic lights was frequently mentioned as being planned for future implementation. It should be noted that, so far, Hampshire County Council are the only authority to have actually implemented this feature.
5.3.5 Paying for the system

Most respondents felt that bus operators should be responsible for paying for the on-bus equipment and any additional equipment used in their own control centres, and that local authorities should be responsible for the provision and maintenance of roadside infrastructure (e.g. beacons) and any real-time passenger information infrastructure, such as bus stop displays.

5.3.6 Running costs

Gillingwater (1995) estimates that the running costs of AVL systems are about 10% of the initial capital cost. However Middlebrook (1995) estimates running costs to be approximately 15% of capital cost and that the running costs for TRUST were of the order of £2500 per week. The postal survey found that running costs for all systems (except Datatrak) were approximately 10% of the capital costs. The annual running cost for the Datatrak system was approximately half of the capital cost, as the bus operator had to pay a subscription cost for the use of the navigation network.

5.4 Comparison of different AVL systems currently operational in the UK

Before the relative merits of individual AVL systems can be assessed, it is important to understand how each system works. Sections 5.4.1 to 5.4.8 summarises the available literature which describes AVL systems which are currently operational in the UK.

5.4.1 Peek Traffic - Bus Tracker

Radio beacons (each with their own unique transmission code) are positioned along the route and continuously transmit on UHF, covering a distance of between 30-100 m. These transmissions are received by a radio receiver incorporated into the on-board computer on the bus and allow the correction of any errors which have accumulated at the odometer level (Rivett, 1996).

Each bus sends data (i.e. bus ID, route, code of last beacon passed and odometer reading) in the form of a telegram to the control centre via the bus’ radio system. Peek Traffic (1995) claim that Bus Tracker has been designed to use existing vehicle radios (since its
data transmission is not detectable by users of the radio system) and add that there is no
impact on normal voice operations. However Blackledge (1994) found that once a speech
call is initiated by the driver, data communication is no longer possible and therefore a
separate data radio needs to be installed if the speech radio is used to any great degree
in order to obtain regular position updates.

The beacons are powered solely by battery (providing a battery life of a minimum of 7
months) or by a combination of a ni-cad battery connected to a trickle charger. The latter
provides an extended battery life of up to 2 to 3 years but is only available for those
beacons located at bus stops (Blackledge, 1994; Merseytravel, 1995).

If Bus Tracker is used for real-time passenger information then two computers are
provided. One of the machines controls the AVL system and the other the real-time
passenger information system (Blackledge, 1994). Since message transmission to the
displays is one way, fault reporting is provided at the bus stop via an altered beacon code
which includes a fault code, which is then transmitted to a passing bus for relay back to
the control centre.

Bus Tracker can be linked to an Urban Traffic Control Centre (UTCC) to give bus
priority at traffic lights depending to how ahead or behind schedule the bus is. Priority
can also be given at isolated junctions by using tags, loops, etc.

5.4.2 Mark IV SLE - COUNTDOWN

The Mark IV SLE system is the AVL system on which the London real-time passenger
information system, COUNTDOWN, is based. The COUNTDOWN system is a beacon
and transponder type system which uses an odometer to measure distance and battery
powered microwave beacons to reset the odometer. When a bus passes a beacon it stores
the beacon’s code in the on-board microprocessor and relays this information, together
with the odometer reading since the bus last passed a beacon, to the control centre when
polled (London Transport, 1992; R Smith, 1993). Beacons only transmit their identity to
a bus when it passes by and only recognise buses travelling in one direction. When the
batteries in the beacons start to run down this fact is picked up by buses and relayed to
the control centre. Transponders are fitted to the near side of the bus and can be used to
operate the on-board ‘next stop’ display (London Transport Buses, 1996).
Reliability of the system seems to be satisfactory with an average of 1% or less of buses having failed equipment and a further 1% dropping out during a given service day (Balogh, 1996a). Atkins (1994) notes that some concern was expressed about the reliability of the radio system which was perceived to be the weakest link in the SLE system. This finding was echoed by Wileman (1995) who investigated how the COUNTDOWN AVL system was perceived by bus route controllers. Her main findings were that:

- there was considerable difficulties in using the radio system, i.e. in logging a bus to the system, sending and receiving speech calls
- the radio system would often fail in the peak period (when it was needed most) due to more buses being on the system than it was appropriate
- controllers perception of the accuracy of information given by the system was poor and not relied upon. Common problems encountered included:
  - buses shown on the screen in the wrong location
  - buses freezing on the screen
  - predictions being unrealistic
  - system crashing

Data from the COUNTDOWN system was used in the development of the simulation model described in Section 4.1.

5.4.3 Terrafix - BICCS

Vehicle position, which is derived from the navigation system and direction, speed and bearing data taken from in-vehicle dead reckoning sensors, are computed by the on-board computer and transmitted to the AVL control centre as a grid reference using the in-vehicle radio communication system. The on-board unit also sends status and pre-coded messages as well as allowing free text messages to be sent and received via an illuminated keypad (M. Smith, 1993; Terrafix Ltd, 1993).

The vehicle position is updated every second on-board the bus but update at the control centre can be at longer intervals since the polling rate depends on the number of buses in the fleet and the communication system used (M. Smith, 1993). Radio communication can be achieved via existing voice channels, although a dedicated data channel is recommended for larger fleet sizes (M. Smith, 1993; Weardon, 1993).
An ordnance survey map is used to present information on the bus number, position, direction and speed. The system is able to interface with a number of Geographical Information System (GIS) mapping software (Terrafix Ltd, 1993).

5.4.4 GEC Marconi - Star-Track

The GPS-based Star-Track system uses a GPS receiver, a communications modem and a powerful data processor to establish vehicle position. The data processor can be interfaced with a wide range of on-board sensors and terminals e.g. automatic passenger counting systems, ticketing systems, passenger information systems. All data (e.g. position (which is calculated twice a minute), ticket information and data messages for communication with the control centre) are collected and processed on-board the vehicle and are then transmitted to the control centre (M. Smith, 1993; Gallagher, 1995). An odometer can also be incorporated for information on speed and distance travelled.

Gallagher (1995) notes that position location can be obtained on either a pre-set time basis (e.g. every 1 minute), a pre-set distance basis (e.g. every 200 metres) or on an event-driven, exception reporting basis (which is usually the preferred option). The control centre can re-programme and override the pre-set poll rate and can handle up to 200 vehicle telegrams in 10 seconds (M. Smith, 1993).

Star-Track can store information relating to special events that affect normal running patterns, such as football matches etc, and take these into account when making its various predictions which are usually based on traffic patterns learnt over a period of time (Pearce, 1994).

5.4.5 Securicor - Datatrak

The Datatrak system has been described in Section 2.3.1. The vehicle sends data (using the time-slot polling method) in a 30 ms data packet, containing position, speed, direction and status, to a network of receivers or base stations on a dedicated UHF data channel. The frequency of position updates is dependent on the number of vehicles in the fleet, unless emergency conditions occur when vehicle position updates occur frequently and a vehicle identity code is included in the transmission. Regional base stations are sited to ensure at least two of them receive the transmission from a vehicle. On receipt of a data
package, they incorporate the vehicle identity before passing the information in encrypted form to the control centre for distribution to the bus company via dedicated landline (Smith et al., 1994). The information received from up to 32 base stations is checked for errors before being displayed on a computer generated map. The system is fully automatic and does not require any initialisation prior to daily use or driver input (Securicor, 1994). Balogh (1993) states that the accuracy of Datatrak is not high enough to use this technology as the basis of a real-time passenger information system.

The running costs of Datatrak are quite high (i.e. monthly usage charge of £10 per vehicle to £113 per vehicle depending on usage). However the locators are fairly cheap, i.e. of the order of £500 per vehicle. Datatrak is capable of monitoring a vehicle’s position every 1.68 seconds but costs decrease significantly if position is checked every 108 seconds (Jabez, 1993c)

5.4.6 Williams Industries - BusNet

William Industries Ltd (1994) describe their system as follows: the prediction software is built into every display and traffic signal priority controller which has been fitted with similar radio modems to those on buses. Position information is received by default by ‘listening’ to the radio frequency (RF) communications between the base station and the bus. The bus stops displays do not usually acknowledge messages sent to them but can do so if desired by sending a receipt of the message received back to the base station on the re-broadcast channel. The control centre just has to manage the acknowledgement of the bus status, which it broadcasts back to the bus.

Time-slot polling using the Time Division Multiplex (TDM) mechanism is employed for bus status transmission. As there is no need to request a bus status, a bus operating in an area with poor communications to the base station can be managed by installing a passive radio station within the area. The passive radio station receiver listens to the status message transmitted by nearby buses that would otherwise be obscured from the main base station and transfers these via landline to the control centre. Differential corrections can also be sent to the bus to provide accuracies of 5-10m.

A system status LED on-board the bus will flash if there is a problem with the acknowledgement sent from the control centre so that the driver will know that the on-
vehicle equipment is not working correctly.

5.4.7 GEC Marconi - Tele-Tag

Tele-Tag is a line-of-sight microwave tagging system based on radio technology, operating in the licence exempt band. The tag is a semi-passive unit with a unique identification code (ID) and extended battery life which is attached to the bus, either on the outside of the bus or on the inside of the windscreen. When a bus enters the Interrogator's (or beacon's) field of view it is 'woken-up' by the signal. The incoming signal is then modulated by the tag and reflected back. The reflected signal now contains that bus' unique ID number and is received and decoded by the Interrogator. The tags can be configured to relay data from on-board sensors such as ticket machines. To avoid excessive power consumption, once a tag has completed sending its code it returns to the dormant state until removed from the Interrogator’s field of view.

The Interrogator consists of essentially two units, an internal processor module which provides the unit's intelligence and the Radio Frequency (RF) module with its associated transmit and receive antennas, providing the fundamental tag detection process. The Interrogator maintains an internal database of all tag ID numbers, which vehicle they are fitted to and when they were last seen by the Interrogator. The Interrogator also issues data messages to the tag and can switch on/off internal relays, e.g. for the control of traffic lights.

There are two channels of communication to the outside world, one via a modem (internal or external) and the other via a serial data link. This enables remote and local communications with other Interrogators and/or a control and monitoring system. As well as an internal processing unit, the Interrogator has a real-time clock which is used as a time-stamp of when the Interrogator sees a tag. The Interrogator is able to ignore repeated Tag-seen messages sent from the RF module for periods of time as would be the case when a vehicle draws up besides an Interrogator. The Tag-seen ignore time can also be customised. Interrogators can be polled at regular intervals from the control centre or send information on an exception reporting basis (e.g. when a bus passes). The position of a bus is only known when it passes an interrogator. Tele-Tag's capture distance is up to 9m and capture speed is up to 70 mph (Gallagher, 1995).
5.4.8 Siemens Traffic Control

Crawshaw and Shaw (1995) describe an AVL system, unique to the UK, which is manufactured by Siemens Traffic Control and is based on traffic control loops and transponders which give priority at traffic lights. When a bus passes a loop, this information is sent back to the control centre and buses which are running behind schedule are given priority, overriding the SCOOT system which is in place. This system is being used in Norwich to provide real-time passenger information in the form of the predicted arrival time of buses at four stops along a route.

5.5 Comparison of bus operational control facilities

The bus route controller interacts with the AVL system in four ways:

- obtains an overview of the relative position of buses along the route
- uses other information provided by the system (such as fault information, adherence to schedule etc.)
- modifies the schedule and route when necessary
- uses the information which is kept as a record of the daily bus operations

Each of these aspects of bus route controller interaction with the AVL system will be discussed in the following sections in light of observations and information gathered during interviews (which took place in June and July 1996) with bus route controllers who use different systems.

5.5.1 Display environment

An AVL system should have a user-friendly interface to encourage use of the system by route controllers (many of whom are not computer literate and are used to conventional methods of route control, such as radio contact with inspectors positioned along the route). The quality of the route map displayed in the control room is important because it determines to what extent the controller can visualise the position of buses along the route and how quickly buses can be located in order to make control decisions. The user-interface for the Datatrak, Peek Traffic, Mark IV SLE and GPS-based systems are described below. GPS-based systems have been classed together because the display environment does not vary much between manufacturers of different systems.
5.5.1.1 Datatrak

The Datatrak map shows only a limited part of the route and so does not reduce the workload of the controller by any great degree, as there has to be frequent radio contact between the controller and the drivers in order to obtain a ‘complete picture’ of the state of the bus network. However the high quality ‘A-Z’ street map is extremely useful when buses have to be re-routed at short notice because the controller can view bus positions and the complete road network simultaneously. The system has the facility to view all buses on one map but no road names or other reference points are given and the display appears cluttered and confusing.

5.5.1.2 GPS-based systems

Generally the ordnance survey maps accompanying GPS systems are not as legible as that accompanying the Datatrak system but cover a much larger area showing most, if not all, the route. The screen shows the location of buses, the fleet number, route number and direction of travel. Usually three or more maps of different scales are provided with the system.

The Terrafix system utilises a second terminal which provides the time at which each bus was last polled and the name of the last timing point which was past at the time of polling, together with the current time.

The Williams Industries system has the ability to show the route as a straight line enabling several routes to be clearly displayed on the operator’s terminal at one time. All the mapping options can be animated with bus stops and landmarks (Williams Industries Ltd, 1994).

5.5.1.3 Peek Traffic - Bus Tracker

The Peek Traffic Bus Tracker map is of an extremely high quality but cannot be manually edited. The schematic map is clear and shows the location of features along the route such as parks, roundabouts etc. Figure 5.1 illustrates a typical Bus Tracker map. The display shows vehicles that are bunching, can track a vehicle and list the buses which were logged-on to the system at the last poll. An example of the Bus Tracker vehicle list...
facility is given in Figure 5.2. The operator is able to instigate manual polling of individual or all vehicles on the route but is only able to do so occasionally. User-friendly menu-driven applications ensure ease of system operation.

5.5.1.4 Mark IV SLE - COUNTDOWN

The Mark IV SLE system utilises line maps to show route details. Buses are colour coded according to their destination, and routes which share common sections are marked on the screen. Turning points and inaccurate information inputted by the driver are highlighted by the system thereby enabling the controller to identify errant drivers. The progress of individual buses can be monitored by the use of timing boxes which show when the bus past timing points along the route. These timing boxes also give the scheduled arrival time of buses at these points so a comparison can be made with schedule (see Figure 5.3).

5.5.1.5 Summary

GPS-based AVL systems and Datatrak do not have very user-friendly displays and do not allow the whole route to be seen easily on one screen, with the result that controllers still continue to use conventional methods of route control, such as voice radio contact with drivers and roadside inspectors, instead of making more use of the information given by the AVL system. Peek Traffic’s Bus Tracker and Mark IV SLE’s COUNTDOWN systems were deemed to be the most user-friendly systems in terms of layout of information presented to the operator and clarity of route map.

Although schematic maps do not provide detailed road information they have the advantage of simplicity and allow bunching to be identified quickly. However route maps which incorporate the road network aid the controller in re-routing buses in cases of emergency diversions.
Figure 5.1 Peek Traffic's Bus Tracker: control room display
## Figure 5.2 Peek Traffic's Bus Tracker: example of a vehicle list

<table>
<thead>
<tr>
<th>FLEET</th>
<th>(run) BOARD NO (car)</th>
<th>ROUTE</th>
<th>STATUS</th>
<th>LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>403</td>
<td>707</td>
<td>4</td>
<td>O.K.</td>
<td>HARRISONS WAY APP SUMMERS ROAD</td>
</tr>
<tr>
<td>404</td>
<td>701</td>
<td>1</td>
<td>O.K.</td>
<td>DALE STREET NORTH JOHN STREET</td>
</tr>
<tr>
<td>405</td>
<td>706</td>
<td>1</td>
<td>O.K.</td>
<td>AWAITING TRIP</td>
</tr>
<tr>
<td>406</td>
<td>709</td>
<td>4</td>
<td>O.K.</td>
<td>UPPER DUKE STREET HOPE STREET</td>
</tr>
<tr>
<td>407</td>
<td>704</td>
<td>1</td>
<td>O.K.</td>
<td>AWAITING TRIP</td>
</tr>
<tr>
<td>408</td>
<td>702</td>
<td>1</td>
<td>O.K.</td>
<td>VICTORIA STREET CUMBERLAND STREET</td>
</tr>
<tr>
<td>410</td>
<td>703</td>
<td>1</td>
<td>O.K.</td>
<td>JERICHO LANE APP JERICHO FARM CLOSE</td>
</tr>
<tr>
<td>411</td>
<td>710</td>
<td>3</td>
<td>O.K.</td>
<td>NO CURRENT TRIP</td>
</tr>
<tr>
<td>412</td>
<td>705</td>
<td>1</td>
<td>O.K.</td>
<td>PRESCOTT ROAD SUNBEAM ROAD</td>
</tr>
<tr>
<td>413</td>
<td>708</td>
<td>4</td>
<td>O.K.</td>
<td>LORD STREET</td>
</tr>
</tbody>
</table>

Courtesy of Merseytravel
Figure 5.3 Mark IV SLE’s COUNTDOWN: control room display

Courtesy of LT Buses
5.5.2 Information available to the route controller

The COUNTDOWN system is the only one in the country which displays early/late information to the route controller. Those who use the COUNTDOWN system find this feature to be extremely useful but for other route controllers, who do not have this facility, opinion was divided as to whether or not this feature would be of benefit to them (as some controllers argue that they know the timetable well enough to decipher early/late information purely from the position of the buses on the route map).

Controllers who use the Terrafix system expressed an interest in obtaining an updated position of a bus when its driver logged a call with the control centre, or maybe highlighting the time that the bus was last polled, instead of the present situation of time stamping when the call was received.

Peek Traffic's Bus Tracker provides a daily record of: the trip number, route number, stop number, the time at which the AVL system projects the arrival of the bus at that stop, scheduled arrival time at that stop and actual bus arrival time at that stop. However this information is only provided on a bus basis for the current trip and next trip and is not written to file.

Although, in some cases, it was found that the introduction of AVL did not reduce the workload of the route controller most controllers were generally quite happy with their AVL system. This was due to the fact that controllers tended to compare how routes were monitored before the advent of AVL and the present situation, instead of making a comparison with how routes could be controlled with a better AVL system. There was also a distinct lack of knowledge amongst route controllers of the type of features which are available on the AVL market at the moment.

One manager of a bus garage bemoaned the fact that the AVL system gave a false sense of security to the route controllers (in that the route was being monitored without their intervention) and suggested that if some active input from the controllers was required (e.g. when a bus passed a particular point on the route) this would bring their attention to the screen and help ‘keep them on their toes’.
5.5.3 In-cab displays

In-cab displays add to the cost of the AVL system and are only useful if the bus service is headway controlled. Since most bus routes outside London are registered on a schedule basis, the operator has a duty to try and maintain the schedule as opposed to trying to maintain an even headway. Therefore in-cab displays are usually dismissed as being an unnecessary cost, as drivers are aware of their schedule and so providing the number of minutes ahead or behind schedule would just be superfluous to their needs. Also, some bus operators felt that this sort of tool puts additional pressure on the already stressed drivers and doubted whether some drivers would use it, even if it was there.

If a move were made towards headway-based operations then in-cab displays would be quite an attractive proposition. However headway-based route control brings with it a unique set of problems concerning meal breaks and duty change overs which have to be carefully considered before this type of operational control is implemented.

5.5.4 Ease of modifying routes and schedules

Since bus operations are dynamic by nature, routes and schedules can change frequently (especially in a deregulated environment) therefore it is essential that routes and schedules held within the AVL system are able to be easily modified by the bus operator. Unfortunately this is not the case with Peek Traffic’s Bus Tracker system which requires that modification of the system’s route description and scheduling software be carried out by Peek Traffic, at a cost of approximately £11,000 per alteration.

The Williams Industries GPS-based system allows routes to be added and altered fairly easily since the map overlay showing the bus routes is derived from positions extracted from buses travelling along the route. A number of route description tables are kept for each route. The oldest route tables are replaced by the newest ones, so the system is quick to learn route changes caused by diversions or operational requirements. The Mark IV SLE system also allows easy modification of the route by the user since the route is displayed as a line map as opposed to the schematic diagram which the Peek Traffic system utilises. Balogh (1996a) reports that a new route can be added to the COUNTDOWN system in two man-weeks.
5.5.5 Information kept on file

The sort of information which is stored to file differs from system to system. For example, the two dimensional tracking systems such as Datatrak, Terrafix and Williams Industries keep all bus operations for an individual day in a replay file which can be ‘played back’ on the route map in ‘fast motion’. The Terrafix system also keeps a log of vehicle calls and emergency calls. Replay files are useful for controller training purposes and can provide evidence of when buses actually passed certain points on the route in case of passenger complaints. However since no data is actually written to an ASCII file, bus speeds between points along a route and locations where bus bunching is prone to occur cannot be obtained, so the data cannot be used for scheduling purposes beyond what is achievable by visual inspection of the route’s performance.

Data which Peek Traffic’s Bus Tracker writes to file include: the name of the beacon, the time at which the bus passed the beacon, route number and bus number (on a vehicle number/trip basis). This is the best format in which to have AVL data as there is no interpolation of the data. However the fact that an individual file is created for each duty (board number) every day rather than on a whole day’s operation basis means that file handling becomes more tedious in any statistical analysis to be carried out at a later date. Additional software can be purchased from Peek Traffic to allow journey times and punctuality statistics to be collated on a route and monthly basis (an example of such an output is given in Figure 5.4). Although this analysis is useful, it is calculated using both good and bad data (see Section 4.3.2.1) and therefore will provide misleading results. It is far better to carry out the same process separately using the basic AVL data which can be checked for mistakes before being processed.

The Mark IV SLE system records a whole day’s operation on one file in the following format:

- Route number
- Link number
- Time when the bus was first polled after it had completed the link
- Predicted travel time of the bus along the link
- Time the last three buses took to travel along the link
- Default travel time for system initialisation purposes
- Radio identification number
Alarms, comprehensive technical monitoring files and the time at which buses passed timing points can also be downloaded to disk.

The GEC Marconi Tele-Tag system records the stop number, the projected arrival time at the stop, how the projected arrival time deviates from the scheduled arrival time at the stop (e.g. + 2 minutes) and the actual arrival time at the stop, for the whole operating day. This data can also be used to test the efficiency of the prediction algorithm. Similar information is available from the Williams Industries AVL system, i.e. actual time bus arrived at a stop and punctuality statistics. The Williams Industries system also keeps a record of the bus number, location and time at location, which can be used to generate a speed profile of the bus travelling along the route.

The GEC Marconi Star-Track system keeps a comprehensive record of the bus company's daily activities which includes: duty and trip number, time stamp of actual arrival time at a virtual beacon, the time when messages were created and received, position of bus, speed, bearing and (since the system is event-driven) the reason for the exception report.
Fig. 5.4 Peek Traffic’s Bus Tracker: punctuality statistics

<table>
<thead>
<tr>
<th>ROUTE</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>JOURNEY START</td>
<td>Aigburth Vale</td>
</tr>
<tr>
<td>JOURNEY FINISH</td>
<td>Broadgreen Hospital</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>EARLY</th>
<th>%</th>
<th>LATE</th>
<th>NO OF BUSES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-5</td>
<td>-3</td>
<td>OK</td>
<td>+3</td>
</tr>
<tr>
<td>Aigburth Vale</td>
<td>0</td>
<td>0</td>
<td>63</td>
<td>27</td>
</tr>
<tr>
<td>Brunswick Business Park</td>
<td>0</td>
<td>24</td>
<td>73</td>
<td>1</td>
</tr>
<tr>
<td>Whitechapel</td>
<td>19</td>
<td>16</td>
<td>54</td>
<td>9</td>
</tr>
<tr>
<td>Wavertree Rd / Dryden Rd</td>
<td>6</td>
<td>13</td>
<td>65</td>
<td>8</td>
</tr>
<tr>
<td>Broadgreen Hospital</td>
<td>7</td>
<td>13</td>
<td>56</td>
<td>9</td>
</tr>
</tbody>
</table>

Courtesy of Merseytravel
The introduction of real-time passenger information systems around the country has been swift and the market is still expanding. Five years ago, London Transport were the only organisation experimenting with this type of technology. Today, there are about a dozen organisations who have real-time passenger information systems which are currently 'online'. But, has this rapid uptake of new technology been a success and are there any lessons to be learnt?

In order to answer these questions, most of the planning authorities who have implemented real-time passenger information systems in the UK and some bus operators who have AVL systems were interviewed. The results of these interviews are summarised in the following sections. Only three of the six bus companies visited will be included in the comparisons that follow, i.e. PMT, Armchair Passenger Transport and MTL London (ex-R and I Buses), since the other three bus companies were participating in real-time passenger information systems and so information regarding these systems was already supplied by the local authorities responsible for these schemes: Go-Ahead Group North East is involved in the Newcastle real-time passenger information scheme, MTL London Northern runs routes on COUNTDOWN in London and Reading Transport are participating in the Berkshire County Council initiative in Reading.

5.6.1 Technology

6 out of the 11 real-time passenger information systems visited were based on the Peek Traffic (ex-GEC Marconi) beacon and transponder Bus Tracker AVL system. The reasons for the popularity of this system, is that beacon and transponder technology is perceived to be proven technology (since London Transport have been experimenting with this type of technology for more than a decade). Technology which has been implemented successfully elsewhere is perceived to be relatively low risk. However of all the systems visited, most problems were incurred with those using the Peek Traffic system and in some cases resulted in the real-time passenger information system not being switched on until over two years after commissioning.

The reason for this long delay before implementation was due to the sale of GEC Marconi’s Bus Tracker system to Peek Traffic in 1995 which resulted in many ex-GEC
Marconi staff who developed the system leaving the new company. In addition to this, on buying the Bus Tracker system, Peek Traffic discovered that each Bus Tracker system sold was unique to the organisation buying it and even though the basic structure of the system was the same, small differences made it virtually impossible to carry out successful upgrades over all systems. Therefore Peek Traffic decided to 'go back to the drawing board' and develop a generic system which would replace the old GEC Bus Tracker system across the country. However this process took some time to carry out and the result was the delay in the implementations of many real-time passenger information schemes.

London Transport are the only organisation in the country to have implemented the French made Mark IV SLE system. The main reason why this system was not considered by other parties was due to its high cost. MTL London (ex-R and I Buses) are the only London bus company using the Datatrak system. However Datatrak’s future in London looks bleak as it is not compatible with London Transport’s Band III radio system (which is a necessary requirement for the COUNTDOWN real-time passenger information system) and Balogh (1995) warns that compliance with COUNTDOWN may become mandatory for future contract awards in London.

Strathclyde PTE are the only organisation to have based their real-time passenger information system on the GEC Marconi Tele-Tag system which utilises tags on buses and interrogators (beacons) at bus stops. The main reasons for Strathclyde PTE choosing this technology is that it does not require two-way radios to be fitted to buses (this is an important consideration since only a minority of buses in Glasgow are thus equipped and the cost of fitting the remaining buses with radios was prohibitively large). As it is envisaged that the real-time passenger information scheme will be expanded to cover the whole of Glasgow, it was necessary that the on-vehicle costs were low. Strathclyde PTE were willing to pay up to £200 for on-bus equipment but the tags only cost around £30.

GPS technology was tried successfully in Birmingham and is currently being implemented in Ipswich and Nottingham. GPS has a reputation of having poor system performance in urban areas, but organisations which have implemented GPS-based systems in the UK have not found this claim to be justified. The market share of GPS in the UK is much lower than that of North America: Lam (1994) reports that out of the 28 agencies in North America who have implemented AVL systems, 25% use beacon-based systems and 50% utilise GPS-based systems. In the UK, only 3 out of the 11 real-time passenger
information systems visited were based on GPS technology.

5.6.2 Age and Coverage

London Transport launched COUNTDOWN on the Route 18 in November 1992 and continued testing the system until March 1993. The Route 18 was chosen as the trial route because it had little overlap with other routes (so the effects of the trial could be isolated) and is subject to traffic congestion in Central London and in suburban centres (such as Wembley) therefore providing testing conditions for journey time predictions (Atkins, 1994). COUNTDOWN was later expanded to other routes in North and West London and should be available at a quarter of London’s busiest bus stops within the next 7 to 10 years (Balogh, 1996a).

STOPWATCH, Hampshire County Council’s real-time passenger information system, was officially launched in October 1993 (Brown, 1993) and is part of the ROMANSE (ROad MANagement System for Europe) initiative which is under the umbrella of the DRIVE II (Dedicated Road Infrastructure for Vehicles in Europe) SCOPE project (Blackledge, 1994). The main objectives of ROMANSE are to influence travel behaviour by the dissemination of accurate, timely, traffic and travel information. As bus location information is incorporated into the Urban Traffic Control system, it is possible to modify signal timings to give buses priority at traffic lights (Tarrant, 1994). Multi modal trip planning information is available via public access terminals sited throughout Southampton.

MerseyTravel’s SMART TIMECHECKER was launched in April 1994 and incorporated the following features (Burley and James, 1993; James, 1993, 1994; Merseytravel, 1995):

- low floor bus
- specially designed and improved infrastructure
- unique branding and livery
- special driver training
- associated bus priority and traffic management measures

Since 1994, the number of towns and cities which have real-time passenger information systems has risen considerably, with the only gap between system implementation being due to the problems encountered with the Bus Tracker system previously described in
Section 5.2.2.1. Therefore the question of a superior technology emerging after a system has been implemented has not really been faced but it is a question which will undoubtedly have to be addressed at some time in the future.

London has by far the largest and most extensive real-time passenger information system. This is a function of its age and also the fact that it is the capital city and is provided with copious amounts of funding from central government. Most of the schemes outside London are on a corridor basis with stops equipped with real-time passenger information usually showing the predicted arrival times of buses from more than one route. The varying levels of coverage of real-time passenger information systems in the UK are described in Table 5.5.

5.6.3 Accuracy

In the 1994 postal survey, Hampshire County Council reported the accuracy of their AVL systems as being ±100m. In the more recent interview undertaken in July 1996 the positional accuracy of the system had increased to 20-30m. This reflects the improvements made in the prediction software and also the overcoming of 'teething problems' (i.e. anomalies in the system which previously undermined accuracy: for example, the saturation of the radio channel by other users which restricted the efficiency of the polling process).

London Transport Buses estimate that to obtain a level of location accuracy of less than 20m, beacons should be positioned every 300-500m. This implies that the odometers used in London have an accuracy of between 4-6% of distance travelled since re-initialisation instead of the 1-3% previously quoted in Section 2.1.

Table 5.6 summarises the preferred technology, age and accuracy of the real-time passenger information systems currently operational in the UK.

There does not seem to be any correlation between the accuracy of the system and the type of technology used or even the system supplier.
Table 5.5 Coverage of real-time passenger information systems in the UK (Cont’d on next page)

<table>
<thead>
<tr>
<th>Town/City</th>
<th>Workstation</th>
<th>Buses</th>
<th>Beacons</th>
<th>Stops</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RTPI</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birmingham (Sept '94-Jan '96)</td>
<td>1</td>
<td>50</td>
<td>-</td>
<td>5</td>
<td>1 telephone enquiry service 5 hand held terminals</td>
</tr>
<tr>
<td>Blackburn</td>
<td>4</td>
<td>70</td>
<td>45</td>
<td>40</td>
<td>-</td>
</tr>
<tr>
<td>Glasgow</td>
<td>10</td>
<td>520$^i$</td>
<td>90</td>
<td>57</td>
<td>1 off-route display</td>
</tr>
<tr>
<td>Heathrow</td>
<td>3</td>
<td>11</td>
<td>28</td>
<td>9</td>
<td>-</td>
</tr>
<tr>
<td>Ipswich</td>
<td>1</td>
<td>8</td>
<td>-</td>
<td>22</td>
<td>8 on board buses 4 off-route displays 1 telephone enquiry service</td>
</tr>
<tr>
<td>Liverpool</td>
<td>1</td>
<td>12</td>
<td>32</td>
<td>50</td>
<td>12 on board buses 10 off-route displays 2 talking bus stops</td>
</tr>
<tr>
<td>London</td>
<td>17</td>
<td>1300</td>
<td>650</td>
<td>394</td>
<td>62 on board buses 2 talking bus stop</td>
</tr>
<tr>
<td>Newcastle</td>
<td>1</td>
<td>22</td>
<td>40</td>
<td>9</td>
<td>-</td>
</tr>
<tr>
<td>Nottingham</td>
<td>1</td>
<td>68</td>
<td>-</td>
<td>28</td>
<td>-</td>
</tr>
<tr>
<td>Reading</td>
<td>3</td>
<td>20</td>
<td>15</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>Southampton</td>
<td>3</td>
<td>115</td>
<td>50$^{ii}$</td>
<td>46</td>
<td>Bus priority at signalized 5-6 junctions 3 talking bus stops</td>
</tr>
</tbody>
</table>

Note: $^i$ In brackets, $^ii$ in italics
<table>
<thead>
<tr>
<th>Town/ City</th>
<th>Workstation</th>
<th>Buses</th>
<th>Beacons</th>
<th>Stops</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVL systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Armchair</td>
<td>1</td>
<td>36</td>
<td>26</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MTL London (ex-R and I Buses)</td>
<td>1</td>
<td>40</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PMT</td>
<td>2</td>
<td>150</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Typically only 180 buses will be on the system at any one time*

*Typically only 40 buses will be on the system at any one time*
Table 5.6 Summary of size and costs of real-time passenger information systems in the UK (Cont’d on next page)

<table>
<thead>
<tr>
<th>Town/ City</th>
<th>Name of RTPI system</th>
<th>AVL system</th>
<th>Technology</th>
<th>On-line since</th>
<th>No. of stops with displays</th>
<th>Total Cost (AVL + RTPI)</th>
<th>Accuracy (Interview)</th>
<th>Accuracy (Quoted)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RTPI</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birmingham</td>
<td>Trust</td>
<td>GEC Marconi (Star-Track)</td>
<td>GPS</td>
<td>Sept 1994-Aug 1996</td>
<td>5</td>
<td>£400,000</td>
<td>100m</td>
<td>25-40m i</td>
</tr>
<tr>
<td>Blackburn</td>
<td>TimeTravel</td>
<td>Peek Traffic (Bus Tracker)</td>
<td>Beacon/Transponder</td>
<td>Oct 1996-Jan 1998</td>
<td>45</td>
<td>£500,000</td>
<td>30m</td>
<td>10m ii</td>
</tr>
<tr>
<td>Glasgow</td>
<td>BusTime</td>
<td>Peek Traffic (GEC Marconi - Tele-Tag)</td>
<td>Interrogator/Tag</td>
<td>Apr 1994-Dec 1994</td>
<td>40</td>
<td>£595,000</td>
<td>10m</td>
<td>-</td>
</tr>
<tr>
<td>Heathrow</td>
<td>TimeTracker</td>
<td>Peek Traffic (Bus Tracker)</td>
<td>Beacon/Transponder</td>
<td>Oct 1994-Dec 1994</td>
<td>10</td>
<td>£100,000</td>
<td>10m</td>
<td>-</td>
</tr>
<tr>
<td>Ipswich</td>
<td>BusNet</td>
<td>Williams Ind. (BusNet)</td>
<td>GPS</td>
<td>Oct 1994-Dec 1994</td>
<td>15</td>
<td>£270,000</td>
<td>10m-20m</td>
<td>50m iii</td>
</tr>
<tr>
<td>Liverpool</td>
<td>SMART - TimeChecker</td>
<td>Peek Traffic (Bus Tracker)</td>
<td>Beacon/Transponder</td>
<td>Apr 1994-Dec 1994</td>
<td>25</td>
<td>£500,000</td>
<td>15-25m</td>
<td>10m ii</td>
</tr>
<tr>
<td>London</td>
<td>Countdown</td>
<td>Mark IV SLE</td>
<td>Beacon/Transponder</td>
<td>Nov 1992-Dec 1993</td>
<td>394</td>
<td>£6 million</td>
<td>10m</td>
<td>10m iv</td>
</tr>
<tr>
<td>Newcastle</td>
<td>TruTime</td>
<td>Peek Traffic (Bus Tracker)</td>
<td>Beacon/Transponder</td>
<td>Apr 1996-Dec 1997</td>
<td>9</td>
<td>£120,000</td>
<td>10m-20m</td>
<td>10m ii</td>
</tr>
</tbody>
</table>
### Table 5.6 Summary of size and costs of real-time passenger information systems in the UK (Cont’d)

<table>
<thead>
<tr>
<th>Town/ City</th>
<th>Name of RTPI system</th>
<th>AVL system</th>
<th>Technology</th>
<th>On-line since</th>
<th>No. of stops with displays</th>
<th>Total Cost (AVL + RTPI)</th>
<th>Accuracy (Interview)</th>
<th>Accuracy (Quoted)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RTPI</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nottingham</td>
<td>NextBus</td>
<td>Williams Ind. (BusNet)</td>
<td>GPS</td>
<td>July 1994</td>
<td>28</td>
<td>£250,000</td>
<td>15m</td>
<td>50m&lt;sup&gt;iii&lt;/sup&gt;</td>
</tr>
<tr>
<td>Reading</td>
<td>TimeLine</td>
<td>Peek Traffic (Bus Tracker)</td>
<td>Beacon/ Transponder</td>
<td>July 1995</td>
<td>5</td>
<td>£165,000</td>
<td>100m</td>
<td>10m&lt;sup&gt;ii&lt;/sup&gt;</td>
</tr>
<tr>
<td>Southampton</td>
<td>Stopwatch</td>
<td>Peek Traffic (Bus Tracker)</td>
<td>Beacon/ Transponder</td>
<td>Oct 1993</td>
<td>46</td>
<td>£500,000</td>
<td>5m-10m at beacons, 20m-30m elsewhere</td>
<td>10m&lt;sup&gt;ii&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>AVL systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Armchair</td>
<td>-</td>
<td>GEC (Bus Tracker)</td>
<td>Beacon/ Transponder</td>
<td>Nov 1991</td>
<td>-</td>
<td>1st route free</td>
<td>5m</td>
<td>10m&lt;sup&gt;ii&lt;/sup&gt;</td>
</tr>
<tr>
<td>MTL London</td>
<td>-</td>
<td>Securicor (Datatrak)</td>
<td>Radio navigation</td>
<td>Feb 1993</td>
<td>-</td>
<td>£90,000</td>
<td>50-100m</td>
<td>50m&lt;sup&gt;v&lt;/sup&gt;</td>
</tr>
<tr>
<td>PMT</td>
<td>-</td>
<td>Terrafix (BICCS)</td>
<td>GPS</td>
<td>Oct 1992</td>
<td>-</td>
<td>£330,000</td>
<td>10m</td>
<td>20-50m&lt;sup&gt;vi&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

5.6.4 Communication

In general the communication channel employed in an AVL system is the limiting factor for system expansion since, for reasons of cost, most users only have sufficient communication capacity to meet their short term needs. For example, in Southampton the upper polling limit on the Band III radio channel employed is 6 veh/sec, therefore to obtain vehicle position updates at least every 30 seconds no more than 180 buses can be logged on to the system at any one time. The polling cycle depends on the number of buses in the fleet. For example, in the Terrafix system it takes 1.5 second for each bus to send its positional information, therefore 20 buses can be polled every 30 seconds or 40 buses can be polled every minute. Hence, a trade-off must be made between the number of buses which can be logged on to the system (i.e. capacity for expansion) and how often buses are polled (which affects the accuracy of the system).

Table 5.7 summarises the method of communication used in the various systems being implemented around the country and illustrates the need to have a higher rate of position updates if information from AVL systems is to be used for real-time passenger information purposes. The polling rate of buses in AVL systems which provide real-time passenger information at bus stops is typically every 15-30 seconds, whereas position updates for bus operational control purposes are obtained approximately every 100-200 seconds. In general time-slot polling and exception reporting allow more buses to be logged on to the system than would be possible for sequential polling as more efficient use is made of the available communication channels. However it is interesting to note that nearly all the non-Peak Traffic AVL systems (with the exception of London) have opted for the more efficient communication protocols (i.e. Birmingham and Glasgow have opted for exception reporting based AVL, whilst Ipswich and Nottingham have utilised time-slot polling). This may indicate the preference of suppliers, since the GPS-based systems of Ipswich and Nottingham are manufactured by Williams Industries and the Birmingham and Glasgow systems are based on GEC Marconi products. Nearly all the real-time passenger information systems in the UK use radio paging to convey predicted arrival time information to displays at bus stops. London is currently the notable exception (as the Birmingham system is no longer operational).
<table>
<thead>
<tr>
<th>Town/ City</th>
<th>Polled/ Event-driven P/E</th>
<th>Polling rate of each bus/ Definition of event</th>
<th>Comm. Network</th>
<th>Capacity of comm. channel</th>
<th>Effective capacity of current system (bus)</th>
<th>Driver input Y/N</th>
<th>Integration with schedule Y/N</th>
<th>Central/ Decentral. C/D</th>
<th>Comm. with stop</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTPI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birmingham</td>
<td>E</td>
<td>Event: bus reaches virtual beacon (but bus polled if does not send information when expected)</td>
<td>RAM Mobile Data</td>
<td>-</td>
<td>200</td>
<td>Y</td>
<td>N</td>
<td></td>
<td>C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Multi-drop landline</td>
</tr>
<tr>
<td>Blackburn</td>
<td>P</td>
<td>15-20 secs</td>
<td>-</td>
<td>-</td>
<td>200</td>
<td>N</td>
<td>Y</td>
<td></td>
<td>C</td>
</tr>
<tr>
<td>Glasgow</td>
<td>E</td>
<td>bus passes radio interrogator (usually at stops)</td>
<td>RAM Mobile Data</td>
<td>-</td>
<td>520</td>
<td>N</td>
<td>Y</td>
<td></td>
<td>C</td>
</tr>
<tr>
<td>Heathrow</td>
<td>P</td>
<td>30 secs</td>
<td>RAM Mobile Data</td>
<td>-</td>
<td>N</td>
<td>Y</td>
<td>C</td>
<td></td>
<td>Paging</td>
</tr>
<tr>
<td>Ipswich</td>
<td>P</td>
<td>60 secs</td>
<td>Band III radio</td>
<td>5 veh/sec</td>
<td>No limit</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td>D</td>
</tr>
<tr>
<td>Liverpool</td>
<td>P</td>
<td>15 secs</td>
<td>Band III radio</td>
<td>-</td>
<td>120</td>
<td>N</td>
<td>Y</td>
<td></td>
<td>C</td>
</tr>
<tr>
<td>London</td>
<td>P</td>
<td>30 secs</td>
<td>Band III radio</td>
<td>10 veh/sec</td>
<td>800</td>
<td>Y</td>
<td>N</td>
<td></td>
<td>C</td>
</tr>
</tbody>
</table>
Table 5.7 Communication channels and capacity of AVL systems (Cont’d)

<table>
<thead>
<tr>
<th>Town/ City</th>
<th>Polling rate of each bus/ Event-driven P/E</th>
<th>Comm. Network</th>
<th>Capacity of comm. channel</th>
<th>Effective capacity of current system (bus)</th>
<th>Driver input Y/N</th>
<th>Integration with schedule Y/N</th>
<th>Central./ Decentral. C/D</th>
<th>Comm. with stop</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTPI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newcastle</td>
<td>P</td>
<td>15 secs</td>
<td>-</td>
<td>180</td>
<td>N</td>
<td>Y</td>
<td>C</td>
<td>Paging</td>
</tr>
<tr>
<td>Nottingham</td>
<td>P</td>
<td>60 secs</td>
<td>Band III radio</td>
<td>60 \text{ii}</td>
<td>\text{Y}^\text{ii}</td>
<td>Y</td>
<td>D</td>
<td>Paging</td>
</tr>
<tr>
<td>Reading</td>
<td>P</td>
<td>15 secs</td>
<td>-</td>
<td>999</td>
<td>N</td>
<td>Y</td>
<td>C</td>
<td>Paging</td>
</tr>
<tr>
<td>Southampton</td>
<td>P</td>
<td>15 secs</td>
<td>Band III radio</td>
<td>120</td>
<td>N</td>
<td>Y</td>
<td>C</td>
<td>Paging</td>
</tr>
</tbody>
</table>

| AVL Systems      |                                           |               |                            |                                          |                  |                             |                        |                 |
| Armchair         | P                                         | 180 secs      | 0.2 veh/sec               | 36                                       | N                | N                           | -                      | -               |
| MTL London       | P                                         | 101 secs      | Datatrak                  | -                                        | N                | N                           | -                      | -               |
| (ex-R and I Buses)|                                           |               |                            |                                          |                  |                             |                        |                 |
| PMT              | P                                         | 225 secs      | 0.7 veh/sec               | 180                                      | N                | N                           | -                      | -               |

\text{i} The effective capacity of the Williams Industries systems is dependent on the polling rate, e.g. for a 60 second polling cycle the effective capacity is about 300 buses (Williams Industries Ltd, 1994).

\text{ii} The trip details are obtained directly from the ticket machine on-board the bus.

\text{iii} In Nottingham, the radio licence limits the capacity of the system to 60 buses. However the Williams Industries system has a capacity of 300 for the polling rate used (Williams Industries Ltd, 1994).
5.6.5 Displays

The type of signs used at stops to display predicted arrival times of buses are fairly similar across the country. Three line LED displays with scrolling facility, typical size: 1000mm x 220mm x 200mm, such as that shown in Figure 5.5, are the norm. Some Peek Traffic Bus Tracker systems utilise small 365mm x 215mm x 115mm, graphical LCD flat plate displays. The main advantages of these small LCD displays are that they can be pole mounted (and so do not require a bus shelter to be fitted at the stop) and since they cost about half as much (and require less power) than a large LED display, more displays can be purchased within a given budget.

The Nottingham system utilises a flat plate LCD display which shows a graphic route map together with predicted arrival time information. Even though Nottingham has the only display of this type in the country, displays which provide the actual position of a bus have been used in Nice (France) with great success (Gilbert & James, 1987). However the Nice system does not provide any predicted arrival time information.

The main disadvantage of using flat plate LCD displays is that the contrast ratio is not as large as that of LED displays. This makes these signs particularly difficult to read in bright sunlight. Another disadvantage of LCD is that the crystals melt at high temperatures and fill the display surface with solid colour (usually black or yellow).

Dot matrix LCD displays offer a much better contrast ratio and greater clarity of information presented than their flat plate counterparts. Transflective LCD displays have a very high contrast ratio but are more expensive than LED displays of equivalent size.

5.6.6 Costs

The real-time passenger information systems currently on-line in the UK vary a great deal in terms of costs. The cheapest system (Heathrow) is of the order of £70,000 for information at 9 stops (using small LCD displays) along one route and the most expensive is of the order of £6 million which provides information at 394 stops and currently covers 34 routes (London). The total costs of the real-time passenger information systems visited were given in Table 5.6.
Figure 5.5 Three line LED display

10 NEXT BUS APPROACHING
10 GLEN EYRE

12min

Courtesy of Hampshire County Council
The cost of a real-time passenger information system is heavily dependent on the communication channels employed for the transfer of information between buses, signs and the control centre, and the basic structure of the system. In addition to this, the price of components which are similar in nature can vary considerably from manufacturer to manufacturer. Peter Cook, Location and Control Division manager for GEC Marconi, notes that when a system integrator (i.e. the organisation who coordinates and integrates the various components (e.g. displays, on-bus equipment) of the AVL system which are supplied by different companies) is involved in a real-time passenger information scheme the price of the basic components is increased in order to cover the cost of the integration service provided. He argues that costs are at a minimum if components are bought directly from the manufacturer.

Tables 5.8 and 5.9 give the approximate capital and running costs of components of a real-time passenger system. It is difficult to comprehend how the price of some components (e.g. GPS receivers) can vary by a factor of 6 between suppliers. As some suppliers do not provide a detailed breakdown of costs, this discrepancy may never be resolved. Therefore it is necessary for users of AVL systems to obtain a complete breakdown of costs for all system components, which separates installation costs from the cost of the component.

The pilot survey carried out two years ago showed overwhelming support for the idea that bus operators should fund the on-bus equipment and control room expenditure side of real-time passenger information systems and transport planning authorities should fund the on-street infrastructure, such as displays etc. This finding was echoed in *Transport Telematics* (1996). It is interesting to note that this sharing of financial outlay has already happened in Southampton and Newcastle, with contributions from operators in other schemes being in the form of new vehicles for branded schemes, e.g. Ipswich and Nottingham. This financial contribution from operators is in contrast to the expectations of previous researchers who hypothesised that there would be no financial contributions towards real-time passenger information systems from bus operators in a deregulated environment (see Section 5.1.5).
Table 5.8 Capital cost of components of AVL and real-time passenger information systems

<table>
<thead>
<tr>
<th>Component</th>
<th>Capital Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base station hardware</td>
<td>£4000 - £10285</td>
</tr>
<tr>
<td>Base station software</td>
<td>£10100</td>
</tr>
<tr>
<td>Software describing route</td>
<td>£2500</td>
</tr>
<tr>
<td>Software for AVL system calibration</td>
<td>£10000</td>
</tr>
<tr>
<td>Data radio</td>
<td>£600 per bus</td>
</tr>
<tr>
<td>Speech radio</td>
<td>£500 per bus</td>
</tr>
<tr>
<td>Radio channel</td>
<td>£875</td>
</tr>
<tr>
<td>Band III radio channel</td>
<td>£20000</td>
</tr>
<tr>
<td>Radio base/decoder</td>
<td>£12100</td>
</tr>
<tr>
<td>Modem</td>
<td>£300-£500</td>
</tr>
<tr>
<td>Pager</td>
<td>£200</td>
</tr>
<tr>
<td>Pager system</td>
<td>£6945</td>
</tr>
<tr>
<td>Passive tag</td>
<td>£20 if buy from supplier</td>
</tr>
<tr>
<td></td>
<td>£33 if use system integrator</td>
</tr>
<tr>
<td>Intelligent tag with serial port</td>
<td>£30</td>
</tr>
<tr>
<td>GPS receiver</td>
<td>£100-£600</td>
</tr>
<tr>
<td>On bus transponder</td>
<td>£650</td>
</tr>
<tr>
<td>Beacon</td>
<td>£500</td>
</tr>
<tr>
<td>Active beacon/interrogator</td>
<td>£1715-£2500</td>
</tr>
<tr>
<td>3 line LED display</td>
<td>£1500-£4700</td>
</tr>
<tr>
<td>Small graphic LCD</td>
<td>£1200-£2350</td>
</tr>
<tr>
<td>Transreflective 3 line LCD display</td>
<td>£4500</td>
</tr>
<tr>
<td>LED display on board buses</td>
<td>£1500-£4000</td>
</tr>
<tr>
<td>Installation</td>
<td>£4600</td>
</tr>
<tr>
<td>Training</td>
<td>£1000</td>
</tr>
<tr>
<td>Landline</td>
<td>£800-£4440</td>
</tr>
<tr>
<td>Beacon data licence/ telecoms</td>
<td>£130</td>
</tr>
</tbody>
</table>
Table 5.9  Running cost of components of AVL and real-time passenger information systems

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>£3000 per year per bus company</td>
</tr>
<tr>
<td></td>
<td>£20000-£35000 per year with AVL supplier</td>
</tr>
<tr>
<td>Beacon</td>
<td>£50-75 per year leased</td>
</tr>
<tr>
<td>Landline</td>
<td>£1000-£1500 per year</td>
</tr>
<tr>
<td>Pager channel for up to 100 signs</td>
<td>£250 per year</td>
</tr>
<tr>
<td>Band III radio licence (for up to 60 vehicles)</td>
<td>£1000 per year</td>
</tr>
<tr>
<td>Public radio system</td>
<td>£25 per mobile per month</td>
</tr>
<tr>
<td>Private radio system</td>
<td>£30-40 per channel per mobile</td>
</tr>
<tr>
<td>RAM Mobile data</td>
<td>0.1p per 56 bytes transferred (about £25 per mobile per month)</td>
</tr>
<tr>
<td>Peek Traffic to change schedule in system</td>
<td>£11000 per change</td>
</tr>
<tr>
<td>Beacon licence</td>
<td>£50-100 per year</td>
</tr>
<tr>
<td>Radio channel for up to 125 interrogators</td>
<td>£100 per year</td>
</tr>
<tr>
<td>Aerial licence</td>
<td>£3000 per year</td>
</tr>
</tbody>
</table>

However the expectations of previous researchers has been met to a greater or lesser degree in other real-time passenger information installations. For example, CENTRO received no financial contribution from the bus operators involved in the TRUST scheme and Lancashire County Council paid for AVL equipment to be fitted to the minimum number of buses required to operate the route involved in the real-time passenger information scheme plus 50% spare allocation, with the bus operator paying for the on-bus equipment of any additional buses which were fitted beyond this number (Harding, 1994). Other transport planning authorities, notably London Transport Buses, are also following this approach.

5.6.7  Benefits

The benefits of AVL are often quoted as being cost-savings (due to staff reductions, more efficient utilization of resources), improved scheduling, increased service reliability and increased patronage. The following sections discuss to what extent these expected benefits have been realised in the real-time passenger information systems operational in the UK.
5.6.7.1 Staff reductions

One of the expected benefits from the introduction of AVL was the reduction in roadside inspectors. Table 5.10 shows to what extent the bus companies interviewed have made such reductions.

Table 5.10 Reduction in number of roadside inspectors after the introduction of AVL

<table>
<thead>
<tr>
<th>Bus operator</th>
<th>AVL Only /RTPI</th>
<th>Number of roadside inspectors before AVL</th>
<th>Number of roadside inspectors after AVL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armchair Passenger Transport (London)</td>
<td>AVL</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Go-Ahead Group North East (Gateshead)</td>
<td>RTPI</td>
<td>-</td>
<td>Same as before</td>
</tr>
<tr>
<td>MTL London (ex-R and I Buses)</td>
<td>AVL</td>
<td>-</td>
<td>Fewer than before</td>
</tr>
<tr>
<td>MTL London Northern</td>
<td>RTPI</td>
<td>6</td>
<td>2¹</td>
</tr>
<tr>
<td>PMT Ltd (Stoke-on-Trent)</td>
<td>AVL</td>
<td>33</td>
<td>3</td>
</tr>
<tr>
<td>Reading Transport</td>
<td>RTPI</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

¹ Although the number of roadside inspectors has reduced the number of route controllers has increased from 2 to 3

Table 5.10 shows that reductions in the number of roadside inspectors have been made in organisations whose AVL systems are not linked to any real-time passenger information system. This is due to the fact that the cost of the AVL system had to be justified in the bus companies which initiated the purchase of the system (as opposed to companies who were offered a partnership with a transport planning authority) and a reduction in personnel seemed to be the best way of meeting this objective. Also the bus companies which took the initiative in buying AVL systems were prepared to change their operating procedures as a result of their investment and so were more pro-active in nature. PMT made the greatest reduction in staff but it seems likely that the number of roadside inspectors they had before were being used inefficiently. Also, the cost of their system was quite substantial (i.e. £330,000), so a greater cost-saving on manpower needed to be achieved. PMT was the only bus company of the three companies which were not linked
to a real-time passenger information system, which paid the full price for its system.

MTL London Northern also made substantial manpower savings with the introduction of their AVL system but a financial contribution was made to the system in the form of equipping more buses than was needed to run the real-time passenger information route, which may have prompted some cost-saving action.

5.6.7.2 Patronage increase

Middlebrook (1995) and R Smith (1993) argue that patronage increases witnessed in real-time passenger systems around the country are a result of a package of complementary measures, such as new low floor buses, branding of services and new shelters which provide a more pleasant waiting environment. For example, Ipswich’s system lead to a 44% patronage increase, of which 74% had previously travelled by car (Suffolk County Council, 1995). Merseytravel (1995) also report that a large (25%) passenger generation was recorded on Liverpool’s SMART routes which have implemented similar measures.

Dublin Buses also report a 25% increase in demand (Tyler, 1995, 1996), half of which was generated from previous car users as a result of the introduction of new buses, new bus stops, better routing, high frequency services, staff training and bus priority at junctions (but notably no real-time passenger information). An increase in patronage was also witnessed in Belfast when high quality vehicles were provided on a route to give a faster, more comfortable and frequent service (Bradshaw and McGreevy, 1994).

Traffic management measures such as the Red Routes in London, which prohibit the stopping of vehicles during the peak periods and only allow severely restricted parking in the off-peak, have also led to an increase in patronage due to the reduced in-vehicle time afforded to buses (Bradshaw and McGreevy, 1994). However for routes such as these to be successful, they must be rigorously enforced which can be quite costly. Red Routes have also sparked much controversy, as local shopkeepers claim that they are losing trade (as a direct result of these routes) to out of town shopping areas where customers may drive to and park their cars with ease.

There are many factors which affect bus patronage (e.g. an increase in employment in the area, change in the socio-economic mix, change in car-ownership) therefore it is difficult
to quantify exactly what percentage of any increase in patronage is directly attributable to the real-time passenger information system. However it is clear that passenger perceptions of the bus system have generally improved as a direct result of the information provided.

Since a high valuation was put on the information provided in London (see Section 5.1.4), it is reasonable to expect a correspondingly large patronage increase. However this increase was not forthcoming (Atkins, 1994; Local Transport Today, 20 January 1994). Balogh (1996a) notes that the 1.5% passenger generation (Local Transport Today, 1 August 1996) that has occurred since the introduction of COUNTDOWN in London (which was not accompanied by any other complementary measures) has been difficult to determine as statistically significant. However London Transport still believe that the investment can be justified on purely social benefit grounds (Freeman, 1972; Local Transport Today, 20 January 1994). Interestingly enough, the Heworth real-time passenger information system also did not produce any evidence of patronage generation (Burley and James, 1993). Both these findings are in line with the hypothesis made by Khorovitch et al. (1991) who predicted that real-time passenger information would not lead to greater customer use.

Atkins hypothesises that COUNTDOWN may have been perceived as inaccurate due to temperamental behaviour in its early development stages and this may be the cause of the lack of an increase in patronage (Local Transport Today, 20 January 1994). This highlights the importance of presenting correct information at stops, as passenger confidence is very difficult to restore once it has been lost.

Atkins (1994) observes that an increasing use of buses by existing passengers is most influenced by personal circumstances and changes in travel needs, rather than service information provision. He adds that it will take some time for non-users to become acquainted with the system and consider switching from their current mode.

Most real-time passenger information systems are based on high frequency routes. However Mississauga Transit implemented a real-time telephone information system called ERICA in Mississauga, which provided information at home (or work etc.) on a low frequency route. This resulted in an 13.7% increase in patronage on one of the routes covered by the system, with all routes covered experiencing more patronage gains than
routes not covered (Suen, 1981). This may be due to the fact that the majority of users phoned from home as the service had a low frequency (and hence arrivals at the stop are most likely timed to coincide with a particular bus) and also because an extended waiting time due to unreliability is significantly less inconvenient when the wait takes place at home.

A comfortable waiting environment could explain the large patronage increases which have accompanied the real-time passenger information systems which promoted the use of off-route displays, i.e. Ipswich and Liverpool. The Glasgow system which also uses off-route displays is still in its early stages so patronage information is not currently available.

Winfield (1981) observes that it is often forgotten that the people who use bus services frequently change (e.g. through moving home or changing their job or buying a car) and although a regular passenger is confronted with the product on every journey, an irregular passenger will only be aware of it if other arrangements fail. He stresses the importance of ensuring that non-passengers are made aware of the public transport services available to them. It may be that the key to increased bus use is to advertise the services on offer to non-users, via off-route displays in shopping areas and supermarkets or by simply sending timetables and route information to every household in the area (e.g. via a supplement in a free paper) as was the case in Stoke-on-Trent and Ipswich.

A 3% patronage increase was recorded by the Potteries-based company, PMT, who advertised the introduction of their AVL system highlighting the improved passenger security aspects of the system (via the driver’s panic alarm) and promising improved reliability of service. PMT hypothesise that passengers now feel safer travelling on their buses since they know that the police can be called quickly in case of incidents. This hypothesis is supported by the fact that the number of cases of reported assault and verbal abuse of drivers reduced significantly after advertising the introduction of the AVL system. PMT’s AVL system is not linked to any real-time passenger information system so the increase in patronage can be assumed to have been generated as a direct result of their advertising campaign.
5.6.7.3 Increased reliability

R and I Buses (now known as MTL London) and Armchair Passenger Transport found that reliability increased significantly after the implementation of their AVL system and that this was accompanied by a patronage increase. Neither system is linked to a real-time passenger information system. However MTL London Northern found that neither reliability nor patronage changed significantly after the introduction of their AVL system, even though some of their routes were part of the COUNTDOWN real-time passenger information project.

5.6.7.4 Advertising

Some of the cost of an AVL system can be recouped by selling advertising space (Gilbert and James, 1987) on the next stop indicators on board the buses, for example:

<table>
<thead>
<tr>
<th>NEXT STOP</th>
<th>GLOUCESTER ROAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alight here for</td>
<td>Sainsburys</td>
</tr>
</tbody>
</table>

Anderson (1993b) recommends that advertising should only be considered on displays where there is sufficient space for both simultaneous advertising and passenger information (e.g. on the VDUs used in the River Bus real-time passenger information system) or where the information is not time-critical. In fact, the constantly changing advertisements on the River Bus real-time passenger information system were used as a deliberate ploy to bring passenger’s attention to the display (Cassidy and White, 1995). Alternatively displays at stops could be used for advertising relative to a geographical area when arrival information is not needed, i.e. after the last bus at night (Holmes, 1991). The capacity of real-time media is immense and so care must be taken not to present too much information to the user who may find it confusing (Anderson, 1993a).

None of the systems visited were currently advertising on-board buses but London Transport Buses are contemplating such a move.
5.6.7.5 Other benefits

None of the bus operators visited were currently using non real-time AVL data to improve scheduling or to optimise fleet usage. However most operators used the AVL data to check passenger complaints of late arrival or early departure at certain points along the route. Go-Ahead North East are currently contemplating using non real-time AVL data, which showed slow bus speeds along certain links, as supporting evidence for the introduction of bus priority measures.

5.6.7.6 Summary

The expected benefits of using AVL technology in the bus industry for real-time passenger information purposes were: improved reliability of service due to greater information available to route controllers, an increase in patronage due to the value passengers place on the real-time passenger information provided and an improved quality of service offered. Table 5.11 shows to what degree these expectations have been met. Information regarding patronage and reliability statistics were not obtained from all organisations visited, as some organisations were not actively monitoring such statistics whilst others were still in the trial stages of system implementation.

In Birmingham and Southampton, the percentage of respondents who claimed that they would use the bus services more often as a result of the real-time passenger information provided, fell significantly between the before and after surveys. This would seem to indicate that the prior expectations of passengers regarding the benefits of the real-time passenger information system were not being met when the system was actually installed. Another interpretation could be that before the system was implemented passengers overstated their expected use of bus services in order to ensure that the idea would be realised. However once the system was in place, the incentive to overestimate the expected use of service was no longer present and so more realistic answers were obtained.

It is interesting to note that systems which produced an increase in reliability of service were ones in which the operator had a financial stake in the AVL system or the real-time passenger information scheme, which provided an incentive for the operator to ensure that some productivity gains were obtained. Significant patronage increases were observed in
real-time passenger information schemes which implemented a package of complementary measures to improve bus services. However patronage gains were also recorded by bus companies who were not involved in any real-time passenger information scheme but who experienced an increase in reliability. Inspection of Table 5.11 shows that schemes which failed to improve reliability of service also failed to produce major patronage increases. However reliability was perceived to have improved in London but this was not accompanied by a large patronage increase. This seems to suggest that either perceived reliability does not affect travel behaviour or that passengers overstate perceived reliability in surveys and that actual reliability is a more representative indicator of travel behaviour.

Only 24% and 41% of respondents in Birmingham and Nottingham respectively perceived a reliability increase. Therefore the operational benefits of AVL do not appear to have been realised in these systems. By inspection of the available statistics, it appears that the Liverpool’s SMART TIMECHECKER has been the most successful (from the passenger perspective of perceived reliability and increased patronage) real-time passenger information implementation in the UK. Although Merseytravel claim to have witnessed a 600% patronage increase on the SMART routes, James (1994) qualifies that this increase was only witnessed on two of the four routes and that the annualized patronage figures from February to December 1994 showed an increase from 350,500 passengers a year to over two thirds of a million passengers a year.
Table 5.11 Perceived and actual benefits of AVL and real-time passenger information

<table>
<thead>
<tr>
<th>Town/ City</th>
<th>% Passengers who perceived reliability increase</th>
<th>Actual reliability increase Y/N</th>
<th>Patronage increase</th>
<th>% Passengers who claim they will/do use buses more</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RTPI</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birmingham (Sept '94-Jan '96)</td>
<td>24%</td>
<td>N</td>
<td>0%</td>
<td>25% (before) 1% (after)</td>
</tr>
<tr>
<td>Blackburn</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Glasgow</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>60% (before)</td>
</tr>
<tr>
<td>Heathrow</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>&gt; 0% (before)</td>
</tr>
<tr>
<td>Ipswich</td>
<td>-</td>
<td>Y</td>
<td>44%</td>
<td></td>
</tr>
<tr>
<td>Liverpool</td>
<td>73%</td>
<td>-</td>
<td>600%</td>
<td>97% (after)</td>
</tr>
<tr>
<td>London</td>
<td>64%</td>
<td>N</td>
<td>1.5%</td>
<td>&gt; 0% (after)</td>
</tr>
<tr>
<td>Newcastle</td>
<td>-</td>
<td>Y</td>
<td>-</td>
<td>29% (before)</td>
</tr>
<tr>
<td>Nottingham</td>
<td>41%</td>
<td>-</td>
<td>-</td>
<td>16%&lt;sup&gt;i&lt;/sup&gt; (after)</td>
</tr>
<tr>
<td>Reading</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Southampton</td>
<td>&gt; 0%</td>
<td>-</td>
<td>&gt; 0% in off-peak only</td>
<td>16% (before) 5% generated&lt;sup&gt;ii&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>AVL systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Armchair</td>
<td>-</td>
<td>Y</td>
<td>&gt; 0%</td>
<td></td>
</tr>
<tr>
<td>MTL London (ex-R and I Buses)</td>
<td>-</td>
<td>Y</td>
<td>&gt; 0%</td>
<td></td>
</tr>
<tr>
<td>PMT</td>
<td>-</td>
<td>Y</td>
<td>3%</td>
<td>&gt; 0% (after)</td>
</tr>
</tbody>
</table>

Note: > 0% and < 0% indicate that an un-quantified change was observed in a positive and negative manner respectively

<sup>i</sup> Source: Gillingwater (1995)

<sup>ii</sup> Source: Transport Telematics (1996)
5.7 Guidelines for System Specification

Once an AVL system has been commissioned it may prove to be quite costly to ‘add on’ features which were not part of the original specification, such as bus priority at traffic lights. Therefore it is important to ‘get it right’ the first time. However this can be more difficult than initially anticipated as there are many factors to be considered.

Scorer (1993) suggests that when specifying an AVL system the required call rate, call set up time, call success rate and data reliability should be considered. Previous specifications for tender for AVL systems included the following useful guidelines (MerseyTravel, 1993; West Midlands Travel Ltd, 1994; Centro, 1996):

- breakdown of expansion costs should be included in the tender
- all components must be type approved and meet relevant standards or codes of practice
- if a bus is taken out of service this information should be conveyed immediately to the control centre
- vibration, resonance, interference and noise from the on-bus AVL equipment should be documented

From their 20 years experience of using a beacon-based AVL system Dublin Bus (1993) recommend that:

- status messages from drivers should be time stamped
- it should be possible to highlight a bus and view the last couple of messages received from that bus and their reception time
- beacons should be used at garages to reset odometers as the bus leaves the garage, with an alarm sounding if a bus leaves the garage without validating that the odometer has been reset
- the odometer should be linked to an intelligent unit which holds fare stages in its memory and prompts the driver (both visually and audibly) to update the fare stage at the relevant location along the route
- if the bus is not signed-on it should be highlighted in a separate section of the screen in a different colour to indicate that it has left the garage without signing on. (This feature is currently available in the Mark IV SLE system).

This section outlines other important factors which need to be considered before an AVL
system is specified. The main function of the AVL system is of paramount importance. A system which is acceptable for bus operational control may not be suitable for the provision of real-time passenger information purposes. Therefore the extra factors which need to be considered when specifying a real-time passenger information system will also be outlined together with guidelines for specification of displays to be used at bus stops. These guidelines were formulated as a result of the interviews carried out with project managers and bus route controllers during June and July 1996.

5.7.1 AVL system

5.7.1.1 Main function of the AVL system

The principal use of the system’s data is very important in deciding the system specifications. If the AVL system is to be used for real-time passenger information then accuracy is paramount and can result in large amounts of money spent on communication in order to achieve the desired level of accuracy. However if the main function of the AVL system is to be for bus operational control then the degree of accuracy required is reduced and a cheaper, less advanced system can be installed.

5.7.1.2 Choice of suitable technology

AVL technology can be split into two categories depending on where the ‘intelligence’ is located in the system: bus-based systems and road-based systems. Bus-based technologies include GPS, radio navigation and beacon and transponder systems whilst the only road-based AVL system used in the UK at the moment is the beacon and tag system used in Glasgow. The location of the ‘intelligence’ of an AVL system is dependent on the operational constraints imposed on the owner of the system. Choosing where to site the ‘intelligence’ of the system has a direct impact on the type of communication channel which needs to be employed. For example, road-based systems do not require any radio or data transfer equipment on board the bus and so have the utmost flexibility in type of communication channel employed (although, in practice, landlines may prove to be prohibitively expensive). If the intelligence is on-board the bus, the choice of communication lies mainly between mobile data network providers and trunk private mobile radio. However suitable integration with other systems, such as the COUNTDOWN real-time passenger information system in London, may limit the choice
of supplier.

With beacon-based systems it is necessary to liaise with relevant departments to ensure that beacons are not removed in the routine maintenance of street furniture (e.g. lampposts).

5.7.1.3 Accuracy of positional information

The accuracy of the positional information has a direct impact on cost since, in general, the greater the level of accuracy the higher the cost of the system. All participants in the interviews named accuracy as being one of their prime concerns when considering which AVL system to buy.

Accurate information is not only important for real-time passenger information (where it may actively misinform a passenger who may then make the ‘wrong’ travel decision) but it is also important for real-time bus operational control. For example, controllers may turn a bus which appears to be moving slowly only to discover later that the information presented to them was incorrect and that the bus was actually much further along the route than they had previously thought. The whole premise of Automatic Vehicle Location is to represent what is happening on the streets to the controller, if this information is inaccurate then the controller will try to optimise their version of what is happening rather than the actual situation. If inaccuracies in positioning information are systematic then the resulting effect will mean that buses are shifted a few minutes one way or the other. However random one-off inaccurate positioning information can be very disruptive. For this reason it would be wise to validate the system (i.e. check that the system produces positions that are very close to those actually experienced by the bus in practice) in its trial stages and before it is considered fully functional.

The positional accuracy of buses on the screen in the control room can be of the order of 100m, even though the actual accuracy of the location of a bus in the system is significantly less than this. This is a factor to be considered when specifying the scale of the map of the route for the control room screens, as a compromise has to be achieved between legibility and the accuracy required in order to make sensible control decisions. In most cases the accuracy required to make control decisions is significantly less than would be required for most other purposes, e.g. real-time passenger information.
The results of the 1994 postal survey undertaken as part of this research showed that the accuracy of AVL systems can be undermined by two buses being too close together, a bus being stationary too long, a bus not being seen by two beacons or the non-polling of buses when they are not proceeding according to the prediction algorithm.

5.7.1.4 Re-initialisation of bus position

Odometers need to be re-initialised at points along the route in order to correct the errors which build up as the bus travels along the route. There are a number of ways in which this can be achieved (Khorovitch et al., 1991; Elkins, 1993a; M. Smith, 1993; Engels and Bonara, 1995):

- **Physical location**: The odometer is reset to zero as it passes a beacon whose exact location is known.
- **Logical location**: Each stop reached triggers the door-opening signal. The position is determined by the number of stops made. Door opening may not be an accurate representation of stops if doors are opened at places other than at stops (Goodchild and Fairhead, 1993) and buses skip some stops (Engels and Bonara, 1995). Update of fare stages or zones can also be used (Finn, 1992).
- **Mixed location**: This uses information from both physical location and logical location sources so that the number of location beacons is reduced.

Physical locationing is the most accurate method of re-initialisation but also the most expensive.

5.7.1.5 Communication

The communication channel employed is probably the most expensive component of any AVL system. Band III radio or RAM Mobile Data seems to be the most popular methods of communication between buses and the control centre. Even though the use of existing channels, such as trunk radio, would reduce the infrastructure cost it may be necessary to make use of a dedicated data channel if the voice radio is in constant use for communication between the driver and the control centre. It has been found that using voice and data communication on one channel results in relatively infrequent updates of vehicle positions. In addition to this, when problems occur on the route (e.g. accidents,
road closure) voice contact with the control centre increases and there is a corresponding reduction in the frequency of position updates. However it is exactly at times such as these that vehicle location information is most valued. The operator should also ensure that no licensing agreements are being breached in using voice radio for the transmission of data.

Engels and Bonara (1995) note that the communication system can often limit accuracy since it determines the refresh interval at the control centre. If vehicle positions are updated using a polling mechanism then the frequency of polling has to be determined and the communication channel employed should have sufficient capacity to enable all buses to be polled within a reasonable amount of time. Alternatively exception reporting can be used. This has the advantage of reducing the amount of communication between bus and the control centre but, correspondingly, there is a lack of information as to the exact whereabouts of the bus between position reports.

5.7.1.6 System time

The system time in GPS systems is automatically synchronised between components to the order of one millisecond. Ideally AVL systems not based on GPS technology should obtained, or at least initialise, their system time from a single, accurate, external source, such as the National Physical Laboratory time signal in Rugby. Internal clocks on personal computers are notorious for inaccurate time keeping and so should not be used as the basis of system time.

The definition of local time is important for AVL systems, especially if checks are to be made with the scheduled arrival time at certain locations (e.g. exception reporting if the bus is earlier or later than a pre-specified value) or if non real-time data from the AVL system is to be used for timetabling or performance monitoring purposes.

System time becomes critical if the method of communicating with buses is such that there is no ‘handshaking’ between the main control centre and the bus (e.g. the bus sends its positional information at a predetermined time as is the case in the time-slot polling systems). However systems which use this type of communication protocol are usually based on GPS technology.
5.7.1.7 User-friendliness

AVL systems should have a simple, user-friendly interface. The information presented to the user should be easy understandable and should not be presented in a cluttered or confusing manner, if the system is to be accepted by those who use it. The quality of the route map displayed in the control room is important for operational control reasons. AVL systems which do not allow the whole route to be seen on one screen increase the workload of the controller and encourage greater use of the voice radio. A guide to the type of control room maps accompanying various systems is given in Section 5.5.1.

5.7.1.8 Information stored to files

When specifying a system careful consideration must be given to exactly what information is required from the system (i.e. what information will actually be used by the user) and the best format in which to store this information. Since AVL systems do not work perfectly all the time, information should be retained in the most unprocessed form possible (i.e. time bus passes a certain location) as opposed to the predicted time of arrival at certain points along the route.

5.7.1.9 Physical characteristics of the route

The layout of the route may rule out some technologies (such as GPS) which do not perform well in a closed environment. Similarly, a lack of suitable infrastructure may prevent the use of beacon-based systems. The current state and position of existing infrastructure should be considered when deciding on the technology on which the AVL system is based, e.g. in Newcastle there were incidences of corrosion in lampposts and so the lampposts had to be tested in order to ascertain whether they were in a fit state to have beacons attached to them. Also the source of power for AVL equipment should be considered. Local authorities may be able to use existing street light electrical supplies to power beacons and displays at stops, otherwise a separate power supply may need to be installed which could prove to be costly.

5.7.1.10 Capital and running costs

Capital and running costs are probably the most important factors in deciding the supplier
of an AVL system. The size of the bus fleet to be fitted may be a deciding factor in the type of technology used since large fleets require that on-bus equipment costs are at a minimum in order to make the system affordable. Costs may also be incurred if staff have to be re-trained as a result of the implementation of an AVL system.

5.7.1.11 Maintenance

Durability

The reliability of components should be high in order to keep maintenance costs to a minimum. In particular, equipment on buses must be durable and robust enough to survive the harsh bus environment especially vibration, interference from voice radio, dirt, violent movements, heat, cold and water resistance (if positioned outside the bus).

Fault reporting

Faulty components should be quickly identified without the need of regular manual checks which can be time consuming. Therefore automatic and reliable fault reporting is essential, e.g. the AVL system should produce a daily log of faulty components with the appropriate action to be taken for each failure. Faults should also be prioritised in order of importance to enable a swift response to failures. The person responsible for the system should be clearly identified to all those involved in the day-to-day running of the service so that there is one ‘port of call’ for all problems.

In-house maintenance

The user should be aware of how severe a fault must be before it warrants intervention from the supplier to carry out maintenance: for example, some suppliers use security screws to mount displays at stops but do not provide the local authorities with the appropriate screwdriver to remove these screws, with the result that the local authority is not able to carry out even the most basic of maintenance tasks (such as cleaning the inside of displays which may become dirty due to diesel fumes etc.) without calling out the supplier.

Keeping maintenance in-house may prove to be more cost-effective for a local authority
or bus company, if sufficiently skilled people are already available. However in order to carry out in-house maintenance there needs to be easy access to components and available spare parts.

*External maintenance contracts*

The level of support and maintenance from the supplier should be ascertained prior to purchasing the system. If a maintenance contract is to be awarded to the supplier then the guaranteed lifetime of components, replacement costs, lead times (which may depend on the location and availability of sub contractors) and call out charges should be agreed upon prior to any contract being awarded (with appropriate penalty clauses for failure to comply with the terms and conditions of the contract). Keeping the number of contractors to a minimum may reduce lead times for maintenance as there are fewer channels to go through. Lead times can be quite significant as Merseytravel (1995) reports that battery replacement times for critical beacons is two working days and is five working days for other beacons (for beacons supplied by Peek Traffic). This is a significant amount of time for beacons to be unavailable especially beacons which clear signs at bus stops. It has also taken Merseytravel over a year to obtain a replacement destination blind for one of their SMART branded buses since there were no spares made in the initial production run. Therefore it is essential that the provision of spares parts is included in the specification for tender.

5.7.1.12 Computer manuals

Support from the supplier should extend beyond the installation stage and fully comprehensive manuals describing the system and maintenance procedures should be supplied with the system. Nottinghamshire County Council regarded the manuals they received with their system as being too complicated and incomprehensible, whilst Surrey County Council regretted the absence of manuals accompanying their AVL system.

5.7.1.13 Flexibility

Routes and schedules change relatively frequently (especially in deregulated areas). Therefore routes and schedules held in the AVL system should be able to be easily modified by following clear and simple instructions (and without supplier intervention).
Changes such as these should be easy to implement by personnel with a limited amount of computer literacy, as it cannot be assumed that the person who oversees system installation will remain with the company indefinitely. The time required to perform these changes should be at an absolute minimum. This may result in a trade-off between the attractiveness of routes displayed on the control room screen and the flexibility of the AVL system. GPS-based systems have an advantage in being able to ‘learn’ the route as the bus carries out its daily operation, so temporary diversions are automatically accounted for in the system’s route tables (Williams Industries Ltd, 1994).

Weissenberger et al. (1995) observe that technology is changing in directions of increasing performance and lower cost and although general technological trends can be forecast with some confidence, there is uncertainty about many details. Government policies are also extremely difficult to predict especially with regards to standards, capital financing, operation and maintenance costs, regulation and tax policies. Therefore flexibility is essential to achieve a compromise between two undesirable extremes: total lack of structure and guidance on one hand, and complete specificity of design on the other.

5.7.1.14 Potential for expansion

Even though it may not be financially feasible to use all the features that AVL systems currently offer, provision should be made for easy modular expansion so that if and when funding is available for future expansion, all components of the current system can be utilised with the only additional cost being that of the extra components (with possibly an upgrade of the communication channel employed). Therefore standard protocols should be used wherever possible. Using standard protocols has the added benefit of encouraging competition between suppliers when the system is expanded so that a monopoly situation does not arise.

On-bus equipment should be easily transferable between buses so that the AVL system does not impede the modernisation of the bus fleet. If bus priority is to be introduced at a later date then the AVL system must be compatible with the Urban Traffic Control system.
5.7.2 Real-time passenger information system

In addition to the factors outlined in the previous section, the following attributes should be considered when specifying an AVL system which is to be used as the basis of a real-time passenger information system.

5.7.2.1 Accuracy of information

Accurately predicting the arrival time of a bus, is fundamental to any real-time passenger information system. However due to the vagaries of congestion, traffic signals, variable passenger demand and different characteristics of individual drivers, this is an exceedingly difficult process. Cassidy (1995) highlights the problems of prediction algorithms when he quotes a bus controller as saying:

"Prediction inaccuracies are no reflection on the technology. You are asking a machine to think like 50 individual people. A machine does not allow for people with a poor attitude problem, someone having a bad day etc."

Cassidy (1995)

Despite these problems, some sort of prediction has to be made and, for the information to be useful, this prediction should be relatively accurate. Most real-time passenger information systems utilise a weighted prediction algorithm in which the previous travel time of the last three buses is weighted in order to provide some sort of balance between average journey times and transient variation (Jabez, 1993c). Therefore this sort of algorithm is not suitable for low frequency routes since the time difference between the third last bus and the current bus would be too great to reflect current conditions (R Smith, 1993, Balogh, 1996a). An example of a weighted predictive algorithm is given by the COUNTDOWN system which calculates the predicted travel time of a bus using the following model (Sayers et al., 1994; Fisher, 1995):

\[
LTT_i = 0.25 \cdot LTT_{i-1} + 0.25 \cdot ATT_{i-1} + 0.25 \cdot ATT_{i-2} + 0.25 \cdot ATT_{i-3}
\]

where:
- \(LTT_i\): predicted travel time of bus \(i\)
- \(ATT_i\): actual travel time of bus \(i\)
Sayers et al. (1994) attempted to improve this algorithm using statistical analysis. However they could not find a time series model which predicted link travel times more accurately than the existing model, but they did find that exponential smoothing has an advantage over the current model in that it offers a small improvement in predictive accuracy and is based on fewer terms (i.e. the last travel time and the last predicted travel time). They add that the evenness of performance between the quite diverse models tested is probably due to the variation within each link and the great differences between links. They recommend that a search for a better predictor should therefore concentrate on traffic effects and attempt to forecast congestion.

Even if the predictive algorithm gave perfect results, the information shown at stops could still be inaccurate due to a number of reasons (Balogh, 1993):

- there could be problems with the communication with the stop
- buses which turn short may still appear on displays downstream of the turning point
- timings (on the COUNTDOWN system) are not revised upwards even if there has been a delay
- if a bus broke down the driver is supposed to log out of the system so that the bus would disappear from the screen. If the driver complied, then the system appears to be temperamental to waiting passengers; if a driver fails to comply, the bus appears stuck in time and will mislead passengers arriving at the stop.

Gillingwater (1995) notes that all transport authorities have encountered the same problems with predicting near to layover points (i.e. buses only register on the system after they pass the first beacon after the turning point or are seen to be moving, by which time it is merely a matter of seconds until they arrive at the first stop thus providing virtually no warning to the waiting passengers of their imminent arrival). The causes of incorrect information displayed at signs at stops, based on the COUNTDOWN beacon and transponder AVL system, are given by Balogh (1996a) in Table 5.12.
Table 5.12 Causes of incorrect information displayed at signs at stops

<table>
<thead>
<tr>
<th>Problem</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sign not working at all</td>
<td>Failure of power supply</td>
</tr>
<tr>
<td></td>
<td>Failure of internal shelter wiring</td>
</tr>
<tr>
<td>Sign saying 'Information not available'</td>
<td>Failure of communications to sign</td>
</tr>
<tr>
<td>Bus appears without a forecasts</td>
<td>Failure of bus AVL and/or radio</td>
</tr>
<tr>
<td></td>
<td>Non-fitted bus used on the route</td>
</tr>
<tr>
<td>Little or no forecast before bus arrival</td>
<td>Driver has not keyed in destination and sign just beyond turning point</td>
</tr>
<tr>
<td>Bus arrives before forecasts says 'due'</td>
<td>Incorrect distance configuration</td>
</tr>
<tr>
<td></td>
<td>Temporary loss of communication to sign or bus</td>
</tr>
<tr>
<td>Forecast stays on ‘due’ when bus departs</td>
<td>Longer or missed polling cycle</td>
</tr>
</tbody>
</table>

Source: Balogh (1996a)

Once passenger confidence has been lost in a real-time passenger information system it is very difficult to regain, therefore it is essential that the system is working correctly and is producing reliable and accurate information before it is switched 'on-line' and is available to the general public. The accuracy of the predicted arrival time information should be highest when passengers are able to compare the information the system provides with their own observations (e.g. clearing a bus from the display, showing that a bus is 'due' or that its arrival at the stop is less than, say, 2 minutes away).

Clearing buses from the display as they leave the stop is very important because not doing so will actively misinform passengers, especially if passengers arrive at a stop to see that a bus will be arriving in one minute (when in fact it has already left the stop) and let other buses pass as they wait for it to arrive. Clearing a bus from the sign can be achieved by:

- the door opening signal (but this is prone to error if the bus passes a stop without opening the door)
- infra-red communication between the display and the bus
- a beacon positioned shortly after the stop
- a ‘time out’ in which the system displays the bus being ‘due’ for a given period of time, say, one minute before it automatically removes the bus from
the display. If the bus fails to appear within the specified time limit, then it may seem that the bus 'appeared from no-where' to new passengers arriving at the stop after the 'time out' but before the arrival of the bus.

If the travelling public do not trust the information provided, they will not make use of it and the system will be redundant. Warman and Sheldon (1985) suggest that if there is genuine uncertainty about the arrival time of the next bus or if the system is not working properly, this should be conveyed to the passengers at the stop so that more confidence is placed in the system when it is functioning properly. Of course, this measure will only be successful if failure of the system or inaccurate predictions are the exception and not the rule.

For central controlled real-time passenger information, the communication time between the control centre and displays at stops is also important in determining the level of accuracy of the information presented to the waiting passengers.

5.7.2.2 Driver input

All real-time passenger information systems are susceptible to the problem of an incorrect fleet or board number being entered into the system which results in misleading information being presented to passengers at stops. Obtaining board numbers from ticket machines (as in the Williams Industries system) reduces this problem considerably as ticket machine information tends to be fairly reliable, since inputting trip information into the machine is a necessary part of the driver's working day and does not form an additional task which may be forgotten. Alternatively control centres can input driver or trip information into the system or obtain updates automatically from the operator's garages via landline.

The Mark IV SLE system suffers from the problem that if a bus passes from one radio aerial region to another, information inputted by the control centre is lost. Therefore to ensure continuous trip information, service number details must be held on the bus itself and be entered by the driver.

AVL systems which do not require any driver input reduce the probability of incorrect information being presented on the displays at stops due to drivers not updating the
information on their on-bus units or entering incorrect or outdated information. However the drawback of having a system which does not require driver input is that changes to the service and bus breakdowns etc. have to made via central control and may be omitted if the route controller is busy. If trip information is to be obtained from the operator then to ensure correct and timely input of information into the AVL system, the process of inputting this information should form a usual part of the controller's day and not be an extra task which the controller may forget to carry out on occasion.

Information gathered from the interviews carried out as part of this research revealed that operators who have a financial stake in an AVL or real-time passenger information system are more likely to ensure that buses which are fitted with location equipment are assigned to the correct route and also encourage drivers to enter the correct information into the system.

5.7.2.3 Integration with schedule

In an uncertain world integration of AVL systems with the bus route schedule is desirable. The scheduled information can be used as a fall-back mechanism if the prediction algorithm fails (e.g. at stops close to turning points), if communication between buses and the control centre is not functioning or if non-fitted buses run along the route.

Peek Traffic's Bus Tracker system gives the scheduled arrival time of non-fitted buses which are running along the route by displaying the word 'Estimated' (as opposed to the destination of the bus) on the display at stops, however this may be interpreted as a real-time forecast by the passenger at the stop who may not be aware of the difference in terminology. If the distinction between scheduled information and real-time predicted information is not clear to passengers at stops then passenger confidence in the system may be affected.

Definitive words such as 'scheduled' or 'timetabled' are more appropriate in presenting timetable information to the waiting passenger. If a clock time is displayed instead of the predicted number of minutes until arrival, the distinction between scheduled information and real-time information is clearer but the clock time must be accompanied by a clock on the display which shows the current real-time. Tyne and Wear PTE and Merseytravel feel that providing a real-time clock at stops may make the passenger more aware of
inadequacies in the service (i.e. early or late bus) especially if the stop is equipped with a paper schedule which could be used to make a comparison with the information displayed and could have a negative impact on the passenger’s perception of reliability of the service.

Some systems, such as Bus Tracker, default to the timetable if there is doubt as to accuracy of system information, e.g. a bus does not register passing two beacons or has not covered a minimum distance in a given period of time. In contrast, the Mark IV SLE system removes the offending bus. This may cause passengers at stops to miss a bus if they choose to carry out a diversionary activity if the time shown until the arrival of the next bus is deemed long enough. In addition to this if a bus is removed from the system because it is moving too slowly, the route controller may not be aware of a particular bad area of traffic congestion and will take no remedial action. The alternative action is simply to count-down to the arrival of a bus which then does not appear.

5.7.2.4 Map or predicted arrival time information

When a prediction for the arrival time of a bus is made, an expectation is formed in the passenger’s mind which may or may not be fulfilled. A way to circumvent this problem is to show the passenger the current position of the bus along the route and allow them to make up their own mind as to when it will arrive at the stop. The latter methodology has two major drawbacks:

- an assumption is made that the passenger is familiar with the route and travel times of buses between specific segments of the route
- the display technology for these kinds of map is currently poor and requires low to medium lighting levels, good eyesight, close proximity to the display and a minimum height requirement.

Therefore the predicted arrival time of a bus should be given to passengers in preference to information regarding the actual location of the bus.

5.7.2.5 Real-time count-down to arrival or event-driven count-down to arrival

Some systems count-down the time to arrival of a bus in real-time between predicted arrival time updates (e.g. Peek Traffic’s Bus Tracker) whereas others only reduce the
expected wait time when they have received updated vehicle positions or prediction
estimates (e.g. Williams Industries and GEC Marconi Tele-Tag).

In London, new route profiles are sent every 30 seconds to all stops regardless of whether
the profile has changed or not. This method of sending information to bus stops is more
expensive than a system which utilises event-based count-downs to arrival of buses at
stops or alternatively counts down in real-time according to a route profile gathered from
previous experience of buses with updated route profiles only sent if the count-down starts
to become inaccurate (i.e. utilise computation power first and then communicate if
necessary since Engels & Bonara (1995) note that computing costs are currently lower
than communication costs).

Counting down in real-time has the advantage of presenting a smooth reduction in waiting
time to the passenger at the stop but is prone to announce the arrival of a bus which has
broken down further up-stream or has turned short of its destination en-route to the stop
(until a pre-defined time without communication has elapsed in which case the offending
bus will be removed from the display) and for routes with high travel time variability will
show many ‘corrections’ to the information presented.

Event-based count downs can show estimates which are ‘jerky’ (in that one system minute
is not equivalent to one real-time minute) and may knock passenger confidence in the
system especially when the predicted time to arrival is small and the difference between
say, a two minute, estimated waiting time which reduces to due after a few seconds is
obvious. However event-driven count downs have the benefit of being more conservative
in their estimation of arrival, therefore providing an opportunity for buses which have
broken down to be removed from the display if they are observed to be stationary for
longer than a user-defined period of time.

5.7.2.6 Communication

Radio paging is much more cost-effective than landlines for sending information to
displays at stops but requires good radio reception at all stops. Similarly, distributed
control is more cost-effective than centralised control and time-slot polling or exception
reporting is more cost-effective than sequential polling, as communication between the
control centre and stops is at a minimum.
In general the more stable the operating environment, the simpler the AVL system should be. If the variability of running times between stops is large then frequent updates of bus positions will need to be obtained in order to update the arrival time estimates at stops, which will increase the communication costs. It should be noted that the predictive accuracy of real-time passenger information systems which use the travelling time of previous buses is severely reduced when there is a sudden and short disruption to service.

5.7.2.7 Power requirements for displays at stops

Electrical cabling may have to be installed to power the displays at stops. Local authorities may be able to power displays using a combination of street lighting and rechargeable batteries. In addition to the powering of displays from street lights, siting bus stops near street lights has the added advantage of reducing the need to provide separate lighting for the stop as the area will be well lit by the street lighting. Well-lit bus stops can help combat the fear that some passengers have about waiting for a bus at night.

5.7.2.8 User-configurability

The real-time passenger information system should allow user-defined messages to be displayed at stops and groups of displays should be able to be configured to show a given message. Each display needs to have some computer memory to allow it to automatically download user-defined messages (e.g. "Routes 10, 15 and 23 also serve this stop") which need to be sent to the display every day. Messages should be sent to displays by the AVL system on start-up and should not have to be inputted by the control centre daily (as is the case in Reading).

5.7.2.9 Clarity of information

Static information should be available at all stops, as it is essential for educating and reassuring first time users so that they might know where to access the network and how to use it (and who would also benefit greatly by finding buses easy to use and would therefore be inclined to use them again). Reference should be made to the static information so that the first time user is able to choose the correct bus from the real-time information presented to them and can refer to the information when the display is not functioning properly.
The relevance of each column of the display at stops should be explained to passengers, possibly by means of a separate poster about the real-time passenger information system, so that the information presented is simple for the passenger to understand. If the last line of the display is to be used for alternately scrolling information between two or more buses, then the arrival order of buses should be given otherwise the information will be confusing and the arrival time of buses will appear to oscillate.

5.7.2.10 Information content

It is important to consider what sort of information the passenger actually needs and whether the information presented meets this need in an easily understandable way, e.g. how far away should the bus be before predicted arrival time information is given and how many buses should be shown on the display. Currently arrival information is, typically, provided for up to 15-30 minutes before the bus is predicted to arrive at the stop.

Real-time information reduces uncertainty about the arrival time of the next bus at the stop. However the usefulness of this information is severely reduce if there is uncertainty in in-vehicle travel time. Therefore if details about conditions which deviate from the norm are provided at the stop, such as "Traffic congestion in Wembley is delaying buses by approx. 10 minutes", then the passenger will be able to make a much more informed choice about whether to travel by a particular bus on a given day. Even though this may mean a lost trip for the operator on some occasions, the passenger will be more favourably disposed to use the bus on another occasion which may result in an overall increase in trip frequency. As well as providing useful information, passengers may actually have a better opinion of the bus operator as they will be able to differentiate a bad service due to events outside the operator’s control, such as traffic congestion, from a poor service due to undisciplined staff. Also passengers will be more forgiving if the real-time passenger information provided is not 100% accurate as they will be aware of the unusual circumstances causing the inaccuracy.

5.7.2.11 Integration with audio unit at stop

Elkins (1993a) notes that, in general, visual information is preferable to audio information as it provides continuous information to passengers waiting at stops. Audio information
can be provided using either digitised or synthesised speech. Digitised speech reproduces words recorded by a person in a studio and has a large cost associated with the studio recording time required to set up the speech unit. All the words likely to be used must be known in advance and any additions will require further studio time and the necessary distribution of a large amount of data. Synthesised speech is completely computerised and requires no studio recording time and is hence more cost-effective. It is totally flexible since it is able to speak any text without prior knowledge or pre-recorded data. However the audible quality of synthesised speech is currently less clear than that of digitised speech (Williams Industries Ltd, 1994).

Visually impaired passengers can be provided with infra-red key fobs which activate audio information at stops. A system of restricted distribution of key fobs was used in the schemes implemented in Southampton and Liverpool in preference to a push button at the stop (which is implemented in London) because the amount of noise intrusion to nearby residents and the risk of misuse by other passengers is minimal if only a those who need to use this facility are able to do so. Key fobs in Southampton were distributed by the local society for the blind.

5.7.2.12 On-board next stop displays

Next stop displays on-board buses are only useful to a small fraction of bus passengers since most passengers are regular bus users and do not require the information as they are familiar with the route. In addition to the purchase, installation and maintenance costs of these displays, if incorrect information is presented confidence in the whole system will be jeopardised. Therefore next stop displays should only be used in areas with a high proportion of infrequent bus users, such as routes which pass through tourist areas, galleries, hospitals, etc.

Merseytravel were having problems with their next-stop displays at the time of the interview since, although the position of the bus was known to the AVL system to a reasonable degree of accuracy, the next stop shown on the on-board display was inaccurate. As a result Merseytravel switched off the displays on-board the buses until this problem could be rectified. Obtaining the next stop information from the on-bus equipment (as opposed to the control centre) may alleviate this problem for bus-based AVL systems.
5.7.3 Displays for real-time passenger information

From the interviews with organisations implementing real-time passenger information systems in the UK carried out in June and July 1996, the following factors were mentioned as important considerations when specifying displays for a real-time passenger information system at bus stops:

- vandal-resistance: there should be no joints and security screws should be employed
- robustness
- resistance to heat and sunlight: this is especially important for LCD displays
- resistance to ingress of dirt and water during cleaning
- anti-reflective screen
- number of lines static and scrolling: Scrolling right to left is recommended by National Institute of Blind (McGarth, 1996)
- contrast ratio: LCD displays tend to go black in hot weather thus losing contrast completely
- legibility
- character size: the lettering of the display should be large enough for passengers to read at a reasonable distance away from the sign (e.g. 5 metres)
- highlighting of information: this can be through flashing or scrolling
- positioning of the display: passengers should be able to view the display with minimal change to their usual waiting patterns
- viewing angle and distance
- reliability
- replacement costs
- ease of access for maintenance
- safety features
- compatibility with shelter
- compatibility with any branding scheme of the real-time passenger information route
- processing power: displays should have the facility to keep messages in a local memory
- user-configurability
- capital and running costs
- ease of interface with AVL system
• colour of characters: red is the most popular character colour in the UK
• message verification and fault reporting
• energy consumption

5.8 **BEST PRACTICE AND EVALUATION OF REAL-TIME PASSENGER INFORMATION SYSTEMS IN THE UK**

Table 5.14 gives the current best practices for real-time passenger information systems in the UK obtained as a result of the interviews carried out with local authorities and bus companies given in Table 5.13.

Table 5.15 shows the positive and negative aspects of each system visited in the interviews carried out in June and July 1996. It can be seen that the Williams Industries BusNet system and the GEC Marconi Tele-Tag system seem to have more strong points than other systems. It is interesting to note that both these companies are defence orientated and so are used to making high specification equipment. The criticism levelled at Williams Industries was that they provided computer manuals which were too complicated for the user to understand and generally expected too much technical knowledge from their users (i.e. the local authorities). This may reflect the fact that they are not orientated towards civilian customers. The Liverpool and Southampton implementations of the Peek Traffic Bus Tracker system also have many points in their favour. It should be noted that both these implementations have been successful in obtaining generous funding from the European Union which other Bus Tracker users have not had the privilege of. London Transport have also benefited from generous funding, however their system has many weaknesses. In fairness to London Transport, it has to be said that they did much pioneering research into AVL systems and were the ‘guinea pigs’ for the rest of the country as they led the way in real-time passenger information systems with COUNTDOWN. Therefore many of the other systems have benefited from their experience and have also benefited from the delay in implementation, as the technology became more common and ‘teething’ problems were resolved.
Table 5.13 Real-time passenger information systems and bus operators visited during June and July 1996

<table>
<thead>
<tr>
<th>Town/ City</th>
<th>AVL system</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RTPI</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birmingham (Sept '94-Jan '96)</td>
<td>GEC Marconi (Star-Track)</td>
<td>GPS</td>
</tr>
<tr>
<td>Blackburn</td>
<td>Peek Traffic (Bus Tracker)</td>
<td>Beacon/ Transponder</td>
</tr>
<tr>
<td>Glasgow</td>
<td>Peek Traffic (GEC Marconi - Tele-Tag)</td>
<td>Interrogator/ Tag</td>
</tr>
<tr>
<td>Heathrow</td>
<td>Peek Traffic (Bus Tracker)</td>
<td>Beacon/ Transponder</td>
</tr>
<tr>
<td>Ipswich</td>
<td>Williams Industries (BusNet)</td>
<td>GPS</td>
</tr>
<tr>
<td>Liverpool</td>
<td>Peek Traffic (Bus Tracker)</td>
<td>Beacon/ Transponder</td>
</tr>
<tr>
<td>London</td>
<td>Mark IV SLE</td>
<td>Beacon/ Transponder</td>
</tr>
<tr>
<td>Newcastle</td>
<td>Peek Traffic (Bus Tracker)</td>
<td>Beacon/ Transponder</td>
</tr>
<tr>
<td>Nottingham</td>
<td>Williams Industries (BusNet)</td>
<td>GPS</td>
</tr>
<tr>
<td>Reading</td>
<td>Peek Traffic (Bus Tracker)</td>
<td>Beacon/ Transponder</td>
</tr>
<tr>
<td>Southampton</td>
<td>Peek Traffic (Bus Tracker)</td>
<td>Beacon/ Transponder</td>
</tr>
<tr>
<td><strong>AVL systems</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Armchair</td>
<td>GEC Marconi (Bus Tracker)</td>
<td>Beacon/ Transponder</td>
</tr>
<tr>
<td>MTL London</td>
<td>Securicor (Datatrak)</td>
<td>Radio navigation</td>
</tr>
<tr>
<td>PMT</td>
<td>Terrafix (BICCS)</td>
<td>GPS</td>
</tr>
</tbody>
</table>
Table 5.14 Best practice of real-time passenger information and AVL technology in the UK (Cont’d on next page)

<table>
<thead>
<tr>
<th>Best practice</th>
<th>Alternative</th>
<th>Town or AVL system with best practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modular system</td>
<td>Integrated system</td>
<td>All systems - ease of expansion dependent on communication channel</td>
</tr>
<tr>
<td>Inexpensive on-bus equipment</td>
<td>Expensive on-bus equipment</td>
<td>GEC Marconi (Tele-Tag)</td>
</tr>
<tr>
<td>Exact bus positions stored to file (e.g. time bus</td>
<td>Extrapolated bus positions stored to file</td>
<td>Peek Traffic (Bus Tracker)</td>
</tr>
<tr>
<td>passed beacon)</td>
<td></td>
<td>GEC Marconi (Tele-Tag)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Williams Industries (BusNet)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GEC Marconi (Star-Track)</td>
</tr>
<tr>
<td>GPS system timing</td>
<td>Computer system timing</td>
<td>Williams Industries (BusNet)</td>
</tr>
<tr>
<td>Trip information inputted by control centre</td>
<td>Driver input</td>
<td>Peek Traffic (Bus Tracker)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GEC Marconi (Tele-Tag)</td>
</tr>
<tr>
<td>Integration with schedule, with default to schedule</td>
<td>No reference to schedule</td>
<td>Peek Traffic (Bus Tracker)</td>
</tr>
<tr>
<td>if accuracy of information presented is in doubt</td>
<td></td>
<td>GEC Marconi (Tele-Tag)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Williams Industries (BusNet)</td>
</tr>
<tr>
<td>Clear route map in control centre</td>
<td>Ordnance survey map</td>
<td>Peek Traffic (Bus Tracker)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GEC Marconi (Tele-Tag)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mark IV SLE</td>
</tr>
<tr>
<td>GPS-based ‘learning’ of changes to route</td>
<td>Supplier modification of route</td>
<td>Williams Industries (BusNet)</td>
</tr>
</tbody>
</table>
### Table 5.14 Best practice of real-time passenger information and AVL technology in the UK (Cont’d on next page)

<table>
<thead>
<tr>
<th>Best practice</th>
<th>Alternative</th>
<th>Town or AVL system with best practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distributed processing of information</td>
<td>Centralised processing of information</td>
<td>Williams Industries (BusNet)</td>
</tr>
<tr>
<td>Fault reporting from components with a daily log</td>
<td>No fault reporting</td>
<td>Peek Traffic (Bus Tracker)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mark IV SLE</td>
</tr>
<tr>
<td>Radio paging communication between control centre</td>
<td>Landline</td>
<td>Peek Traffic (Bus Tracker)</td>
</tr>
<tr>
<td>and stops</td>
<td></td>
<td>GEC Marconi (Tele-Tag)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Williams Industries (BusNet)</td>
</tr>
<tr>
<td>Real-time clock displayed at stops</td>
<td>No clock displayed at stops</td>
<td>Williams Industries (BusNet)</td>
</tr>
<tr>
<td>Event-based count-down to arrival of buses</td>
<td>Real-time based count-down to arrival of buses</td>
<td>GEC Marconi (Tele-Tag)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Williams Industries (BusNet)</td>
</tr>
<tr>
<td>Event-driven position updates (e.g. exception</td>
<td>Polling of buses</td>
<td>GEC Marconi (Tele-Tag)</td>
</tr>
<tr>
<td>reporting)</td>
<td></td>
<td>GEC Marconi (Star-Track)</td>
</tr>
<tr>
<td>Time-slot polling</td>
<td>Sequential polling</td>
<td>Williams Industries (BusNet)</td>
</tr>
<tr>
<td>Predicted number of minutes to arrival of buses at</td>
<td>Current position of bus displayed on a</td>
<td>All systems - Nottingham does both</td>
</tr>
<tr>
<td>stops</td>
<td>route map</td>
<td></td>
</tr>
<tr>
<td>User-defined messages stored in display memory or</td>
<td>Messages downloaded daily</td>
<td>Mark IV SLE</td>
</tr>
<tr>
<td>sent to display on start up</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comprehensive static information</td>
<td>No static information</td>
<td>All systems</td>
</tr>
</tbody>
</table>
Table 5.14 Best practice of real-time passenger information and AVL technology in the UK (Cont’d)

<table>
<thead>
<tr>
<th>Best practice</th>
<th>Alternative</th>
<th>Town or AVL system with best practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low floor buses, new shelters, branding of route: New bus shelters should blend in with the surrounding architecture if they are to be accepted by the local community</td>
<td>Use existing vehicles and infrastructure</td>
<td>Ipswich</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liverpool</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nottingham</td>
</tr>
<tr>
<td>Key activated audio information at stops</td>
<td>Push button audio information at stops</td>
<td>Liverpool</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Southampton</td>
</tr>
<tr>
<td>Powering of display from street lighting and rechargeable batteries</td>
<td>Powering of displays from mains</td>
<td>Nottingham</td>
</tr>
<tr>
<td>Positioning of shelter near street lights</td>
<td>Shelters positioned in dimly lit places</td>
<td>Nottingham</td>
</tr>
<tr>
<td>Comprehensive maintenance policy with manufacturer with deferral of payment until specified accuracy is achieved</td>
<td>No maintenance policy agreed</td>
<td>Glasgow</td>
</tr>
</tbody>
</table>
Table 5.15 Advantages and disadvantages of real-time passenger information systems and AVL systems currently operational in the UK (Cont’d on next page)

<table>
<thead>
<tr>
<th>Town/ City</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RTPI</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birmingham (Sept '94-Jan '96)</td>
<td>Bus positions written to file</td>
<td>Driver input</td>
</tr>
<tr>
<td></td>
<td>Event-driven position updates</td>
<td>Low positional accuracy</td>
</tr>
<tr>
<td></td>
<td>Event-driven count-down at stops</td>
<td>Use of landline</td>
</tr>
<tr>
<td></td>
<td>Telephone enquiry service</td>
<td>Small number of signs equipped</td>
</tr>
<tr>
<td>Blackburn</td>
<td>Bus positions written to file</td>
<td>Expensive to modify route</td>
</tr>
<tr>
<td></td>
<td>No driver input</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Integration with schedule</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radio paging to sign</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fault reporting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clear route map</td>
<td></td>
</tr>
<tr>
<td>Glasgow</td>
<td>Bus positions written to file</td>
<td>Position between interrogators not known</td>
</tr>
<tr>
<td></td>
<td>No driver input</td>
<td>No on-bus radios</td>
</tr>
<tr>
<td></td>
<td>Integration with schedule</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radio paging to stops</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fault reporting</td>
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<tr>
<td></td>
<td>Clear route map</td>
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</tr>
<tr>
<td></td>
<td>Event-driven position updates</td>
<td></td>
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<tr>
<td></td>
<td>Event-driven count-down at stops</td>
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<tr>
<td></td>
<td>Inexpensive on-bus equipment</td>
<td></td>
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<tr>
<td></td>
<td>Accurate clear down at stops</td>
<td></td>
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<tr>
<td></td>
<td>Off-route display</td>
<td></td>
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<tr>
<td>Town/ City</td>
<td>Advantages</td>
<td>Disadvantages</td>
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<tr>
<td><strong>RTPI</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heathrow</td>
<td>Bus positions written to file</td>
<td>Expensive to modify route</td>
</tr>
<tr>
<td></td>
<td>No driver input</td>
<td>No computer manuals</td>
</tr>
<tr>
<td></td>
<td>Integration with schedule</td>
<td>Small LCD displays</td>
</tr>
<tr>
<td></td>
<td>Radio paging to signs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fault reporting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clear route map</td>
<td></td>
</tr>
<tr>
<td>Ipswich</td>
<td>Bus positions written to file</td>
<td>Driver input</td>
</tr>
<tr>
<td></td>
<td>Integration with schedule</td>
<td>Unclear route map</td>
</tr>
<tr>
<td></td>
<td>Radio paging to signs</td>
<td>Complicated computer manuals</td>
</tr>
<tr>
<td></td>
<td>Event-driven count-down</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Decentralised control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time-slot polling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Real-time clock at stops</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Easy route update</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Door trigger clears sign</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Off route displays</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Telephone enquiry service</td>
<td></td>
</tr>
<tr>
<td></td>
<td>New low floor buses</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Branded route</td>
<td></td>
</tr>
</tbody>
</table>
Table 5.15 Advantages and disadvantages of real-time passenger information systems and AVL systems currently operational in the UK (Cont’d on next page)

<table>
<thead>
<tr>
<th>Town/ City</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RTPI</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liverpool</td>
<td>Bus positions written to file</td>
<td>Expensive to modify route</td>
</tr>
<tr>
<td></td>
<td>No driver input</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Integration with schedule</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radio paging to signs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fault reporting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clear route map</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Off-route displays</td>
<td></td>
</tr>
<tr>
<td></td>
<td>New low floor buses</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Branded route</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Key fob audio bus stops</td>
<td></td>
</tr>
<tr>
<td>London</td>
<td>Fault reporting</td>
<td>Driver input</td>
</tr>
<tr>
<td></td>
<td>Clear route map</td>
<td>Landline</td>
</tr>
<tr>
<td></td>
<td>Relatively easy route update</td>
<td>Extrapolated data written to files</td>
</tr>
<tr>
<td></td>
<td>User-defined messages on start up</td>
<td>Expensive</td>
</tr>
<tr>
<td></td>
<td>Extensive system</td>
<td>Push button audio stop</td>
</tr>
<tr>
<td></td>
<td>High polling rate</td>
<td></td>
</tr>
<tr>
<td>Newcastle</td>
<td>Bus positions written to file</td>
<td>Expensive to modify route</td>
</tr>
<tr>
<td></td>
<td>No driver input</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Integration with schedule</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radio paging to signs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fault reporting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clear route map</td>
<td></td>
</tr>
</tbody>
</table>

251
<table>
<thead>
<tr>
<th>Town/ City</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RTPI</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nottingham</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bus positions written to file</td>
<td>Driver input</td>
</tr>
<tr>
<td></td>
<td>Integration with schedule</td>
<td>LCD-based route maps at stops</td>
</tr>
<tr>
<td></td>
<td>Radio paging to signs</td>
<td>Unclear route map at control</td>
</tr>
<tr>
<td></td>
<td>Event-driven count-down</td>
<td>Complicated computer manuals</td>
</tr>
<tr>
<td></td>
<td>Decentralised control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time-slot polling</td>
<td></td>
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<tr>
<td></td>
<td>Real-time clock at stops</td>
<td></td>
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<tr>
<td></td>
<td>Easy route update</td>
<td></td>
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<tr>
<td></td>
<td>Door trigger clears sign</td>
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<tr>
<td></td>
<td>New low floor buses</td>
<td></td>
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<tr>
<td></td>
<td>Branded route</td>
<td></td>
</tr>
<tr>
<td>Reading</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bus positions written to file</td>
<td>Expensive to modify route</td>
</tr>
<tr>
<td></td>
<td>No driver input</td>
<td>User-defined messages downloaded daily</td>
</tr>
<tr>
<td></td>
<td>Integration with schedule</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radio paging to signs</td>
<td></td>
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<tr>
<td></td>
<td>Fault reporting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clear route map</td>
<td></td>
</tr>
</tbody>
</table>
### Table 5.15: Advantages and disadvantages of real-time passenger information systems and AVL systems currently operational in the UK (Cont’d)

<table>
<thead>
<tr>
<th>Town/ City</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RTPI</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southampton</td>
<td>Bus positions written to file</td>
<td>Expensive to modify route</td>
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<tr>
<td></td>
<td>No driver input</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Integration with schedule</td>
<td></td>
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<tr>
<td></td>
<td>Radio paging to signs</td>
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<tr>
<td></td>
<td>Fault reporting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clear route map</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Key fob audio bus stops</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bus priority at traffic lights</td>
<td></td>
</tr>
<tr>
<td><strong>AVL systems</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Armchair</td>
<td>No driver input</td>
<td>Expensive to modify route</td>
</tr>
<tr>
<td></td>
<td>Clear route map</td>
<td>Low polling rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No information written to files</td>
</tr>
<tr>
<td>MTL London (ex-R and I Buses)</td>
<td>No driver input</td>
<td>High running costs</td>
</tr>
<tr>
<td></td>
<td>High quality road map</td>
<td>Limited section of route shown</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No ASCII files kept</td>
</tr>
<tr>
<td>PMT</td>
<td>No driver input</td>
<td>Low polling rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cluttered route map</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No ASCII files kept</td>
</tr>
</tbody>
</table>
5.9 CONCLUSIONS

Peek Traffic have a large market share of the AVL UK bus market because of their high market profile and ‘complete’ package approach (as they also act as system integrators for many systems). However there has been a tendency for many local authorities and bus operators to follow the lead of high profile initiatives, such as STOPWATCH and TIMECHECKER, without fully assessing the relative benefits of all systems on offer. Therefore, there was a clear need for an investigation into the types of technologies currently available.

Bus deregulation outside London has put some constraints on transport planning authorities, such as authorities are no longer allowed to own any vehicles which run on commercial routes. Since commercial routes tend to be those which have the largest patronage and are therefore the natural choice for any envisaged real-time passenger information system, this political constraint has implications on the type of technology that can be used as the source of vehicle location since many location technologies are bus-based.

In order to circumvent this problem, some local authorities have formed ‘quality partnerships’ with bus operators. If an authority did not want to form such a partnership, then the natural solution would be to have the intelligence of the AVL system under their control (i.e. on the roadside) if they were interested in implementing a real-time passenger information system in their area. Having a system such as the GEC Marconi Tele-Tag system is ideal in this respect as the on-bus equipment is inexpensive (i.e. about £20 for a basic model) and so many more buses can be fitted than are actually required for the real-time passenger information scheme, allowing the operator greater flexibility in bus allocation and also increasing the probability of a fitted bus running on the desired route.

The disadvantage of the Tele-Tag system is that it ‘fixes’ the route (as interrogators act as beacons) but it should be noted that real-time passenger information itself fixes the route as the cost of installing and removing displays far outweighs that of moving an interrogator. In addition to this, the bus position is only known when a bus passes an interrogator and not between interrogators, so for accurate prediction of arrival time at stops the variation in running times between buses should be small.
If a bus operator has contributed towards the cost of a real-time passenger information system through a ‘quality partnership’ with the local authority they may want to use the AVL system for purposes other than the provision of passenger information. In this case beacon-based systems are not a suitable alternative since the operator would have to fix beacons along all possible routes which may require permission from the local authority and may prove to be expensive especially if routes change frequently (e.g. in reaction to competition) and beacons have to be moved. Hence a completely vehicle-based AVL system may be more appropriate. GPS and Datatrak are the obvious choices since they do not require any roadside infrastructure and provide flexible systems. GPS has an advantage over Datatrak in that there is no subscription charge (at present) and that receivers can be bought from a variety of companies thus providing desirable competition amongst suppliers. In order to benefit from a GPS-based AVL system there should be a clear line-of-sight to the GPS satellites for the majority of the route, so this type of technology may not be suited to routes which traverse ‘closed’ environments, such as tunnels, etc.

Beacon-based systems are most suited to joint ventures between bus operators and local authorities where the bus operator does not actively seek to have the company’s whole network of routes covered by the AVL system or, alternatively, only has a few routes. Beacon-based systems are very popular due to the fact that they are regarded as proven technology and hence relatively low risk.

In a comparison of the strengths and weakness of systems it was found that the Williams Industries system and GEC Tele-Tag system were the ‘best’. Peek Traffic’s Bus Tracker system has produced favourable results in implementations which have had the benefit of European Union funding. Although London Transport’s COUNTDOWN did not fair so well it should be remembered that London Transport did much pioneering research into AVL systems and many other users and manufacturers of AVL systems have benefited from the years between the installation of COUNTDOWN and their own systems which allowed initial problems to be resolved.

If a real-time passenger information system is to be installed in a deregulated environment then it would be unwise to integrate a schedule into the AVL system if the timetable changes frequently. Hence if the bus service environment is unstable, a system which is based on information which has been inputted by the driver (or controller) may be more suitable (as is the case with the Mark IV SLE system). Whatever means is chosen for the
input of trip information into the AVL system, it is vital that this information is kept up-to-date and operational decisions such as cancellations or curtailed trips are also added, as and when they occur.

In practice there has been reasonable stability of bus routes in the real-time passenger information systems implemented in the deregulated areas of Britain, so the incorporation of a timetable is generally seen as a desirable feature since it also allows information regarding non-fitted buses running on the routes to be shown. Scheduled information should only be presented in emergencies and not be accepted as the norm and care must be taken not to display scheduled information if the bus has broken down or was turned short of its destination, as the information presented may be misleading.

The cost of moving roadside infrastructure such as beacons, interrogators or displays should be considered before implementing real-time passenger information in an area which is prone to route changes. Also costs after the system has been installed such as running costs (e.g. power for displays), maintenance, upgrades of hardware and software, technology advancements which may make some components incompatible with the rest of the system and prospect of future expansion should be borne in mind. The running cost of real-time passenger information systems was found to be approximately 10% of the initial capital expenditure.

Joe McGrath, project manager of the Strathclyde PTE real-time passenger information system, notes that capital costs are usually easier to justify to sponsors than running costs, so it may be worthwhile for a group of bus operators or planning authorities to set-up their own radio navigation network which, although it will have a large initial cost, will have a small running cost. Alternatively, he suggests the use of the Datatrak network for positional information but in order to avoid paying subscription costs to the network, a separate communication channel could be employed for the transfer of data. Operators could negotiate a one-off payment for this facility and thus avoid an annual subscription fee to Securicor.

Computing costs are currently lower than communication costs (Engels & Bonara, 1995), therefore distributed real-time passenger information systems (which have minimal data transfer between components) are the most cost-effective. Modular systems which have standard interfaces and protocols are the preferred option, as these systems can be expanded according to available resources and/or the results of a trial route. As AVL and
communication technology is progressing at a rapid rate, upgrades of individual components in modular systems can be implemented as superior versions appear on the market, without replacing the whole system.

Many factors need to be considered when specifying an AVL system. Sometimes real-time passenger information schemes do not always proceed according to a well defined plan and although all eventualities cannot be accounted for, the risk involved in implementing new technology can be minimised if comprehensive maintenance agreements and penalty clauses for poor system performance are agreed upon with the supplier before any contract is awarded so that the risk involved is shared equally between the supplier and the client. Emphasis should be on the manufacturer to produce goods which operate for a reasonable amount of time before failure and payment should be deferred until the system performs according to the promises given by the manufacturer. The AVL system should function reliably and accurately before the displays at stops are switched on.

The required accuracy of the predicted arrival time information at stops will be determined by the extent passengers are able to compare the information given by the system with their own observations (e.g. clearing a bus from the display) showing that a bus is ‘due’ and a bus not appearing at all.

It is recommended that displays at locations other than at bus stops (such as supermarkets, train stations etc.) should be encouraged as they may result in patronage generation by attracting new users to the bus system, as has happened in Ipswich and Liverpool. Some respondents felt that passenger information should be given at home where the decision to travel is made. The experiences of Stoke-on-Trent and Ipswich have shown that mass distribution of timetables and route information to homes also results in an increase in patronage. Alternatively, the World Wide Web could be used for information purposes (which would probably encourage a younger/ more professional clientele) as an increasing number of homes have internet access.

Advertising the benefits of an AVL system may increase patronage by increasing passenger confidence in the bus system and increasing the perception of passenger security, since buses can be fitted with panic alarms which ensure quick police response times to incidents. Driver concerns about ‘big brother watching’ may also be overcome by highlighting the increased security aspects of the system, when introducing the idea
of AVL to staff at bus garages.

It is difficult to isolate the affect real-time passenger information has on patronage, since bus use is dependent on many factors, such as economic climate, attractiveness of route, population etc. However it is interesting to note that real-time passenger information systems have resulted in a substantial increase in patronage in schemes where the real-time passenger information formed part of a package of complementary measures to improve bus travel for passengers and provide information at non-bus stop locations, e.g. Liverpool’s SMART routes and Ipswich’s SuperRoute 66. Therefore investing in a simple and inexpensive AVL system and using the remaining funding on other measures such as new low floor buses, new shelters, good static information and timetables sent directly to homes or possibly a smartcard scheme which allows more innovate fare schemes to be implemented may yield the optimum results. It is recommended that AVL systems should be as simple as is needed to achieve their main objective. Apart from the reduction in costs, simple systems have the benefit of being easier to maintain and are likely to have greater reliability.

The AVL market is fairly lucrative and is expanding rapidly with time. AVL technology is very flexible and so there is great opportunity to specify the most appropriate system which meets the need of the user rather than just buying a system ‘off-the-shelf’. It would be in the user’s best interests to specify a system and then put out invitations to tender for the specified system rather than inviting tenders for complete systems. This obviously requires more work on the part of the organisation concerned, but will provide greater value for money and will make the most out of the competition which exists in the AVL market.
CHAPTER 6: CONCLUSIONS

Abstract

This thesis has investigated how AVL technology can be used in the bus industry. Two main areas have been considered: the use of AVL data for real-time passenger information purposes and the use of non real-time AVL data for improving bus operations. Guidelines which can be used to aid specification of AVL and real-time passenger information systems have been produced and current best practice in the UK has been identified.

Although non real-time AVL data has much potential, it is currently under-utilised. It has been shown that non real-time AVL data can be used to: identify sections of a bus route which would benefit most from bus priority measures, estimate the passenger arrival rate at stops (when used in conjunction with an on-board patronage survey), improve scheduling and compile punctuality statistics. However before non real-time AVL data can be used for such purposes, ‘spurious’ entries which are present in the data must be removed.
6 CONCLUSIONS

6.1 FINDINGS

Following the recent decline in bus patronage in the UK, transport planning authorities are striving to increase the attractiveness of buses in order to combat increasing levels of congestion and growing concerns about the damage this traffic is causing to the environment. Real-time passenger information systems are seen as the way forward by many planning authorities and have the added benefits of being high profile and at the leading edge of technology, thus bringing the bus into the 21st Century.

The introduction of AVL and real-time passenger information systems around the country has been swift and the market is still expanding. Five years ago, London Transport was the only organisation experimenting with this type of technology. Today, there are about a dozen organisations who have real-time passenger information systems which are currently ‘on-line’. However there has been a tendency for many local authorities and bus operators to follow the lead of high profile initiatives without fully assessing the relative benefits of all systems on offer. Therefore an investigation into the types of AVL technologies currently available which would highlight the positive and negative aspects of various technologies was identified as being a worthwhile endeavour. In order to aid such an investigation, project managers of real-time passenger information systems currently operational in the UK were interviewed. These interviews proved to be very informative and highlighted many aspects of implementing AVL technology which would not normally be considered when specifying a real-time passenger information system. Guidelines for system specification were drawn up so that potential users of AVL and real-time passenger information systems could benefit from the hindsight of current users.

Current best practices for real-time passenger information systems were identified as a result of these interviews and include:

- modular systems
- inexpensive on-bus equipment
- time bus passed beacons stored to file
- GPS system timing
- trip information inputted by control centre
- integration with schedule, with default to schedule if the accuracy of the information presented is in doubt
• Peek Traffic or Mark IV SLE type control room route display
• GPS-based ‘learning’ of changes to routes
• distributed processing of information
• two-way fault reporting from components with a daily log
• radio paging to send information to stops
• current real-time clock displayed at stops
• event-based count-down to arrival of buses
• minimise bus to control centre communication costs by time-slot polling or exception reporting
• predicted number of minutes to arrival of buses displayed at stops instead of information on current position of bus
• user-defined messages stored in display memory or sent to display on start-up
• comprehensive static information
• key-fob activated audio information at stops
• powering of display from street lighting and rechargeable batteries
• positioning of shelter near street light
• comprehensive maintenance policy with manufacturer with deferral of payment until specified accuracy is achieved

The communication channel employed is probably the most expensive component of any AVL system. Band III radio or RAM Mobile Data seem to be the most popular methods of communication between buses and the control centre. Even though the use of existing channels, such as trunk radio, would reduce the infrastructure cost it may be necessary to make use of a dedicated data channel if the voice radio is in constant use for communication between the driver and the control centre. The communication channel employed is also usually the limiting factor for system expansion since, for reasons of cost, most users only have sufficient communication capacity to meet their short term needs.

The polling rate of buses in AVL systems which provide real-time passenger information is much higher than is needed for bus operational control, i.e. every 15-30 seconds (as opposed to approximately every 100-200 seconds). In general, time-slot polling and exception reporting allow more buses to be logged on to the system than would be possible for sequential polling, as more efficient use is made of the available resources. Similarly, radio paging is more cost-effective (and, in fact, is used by nearly all the real-time passenger information systems in the UK) than landlines for sending information to
displays at stops (but requires good radio reception at all stops) and distributed control is more cost-effective than centralised control as communication between the control centre and stops is at a minimum (since Engels & Bonara (1995) report that computing costs are currently lower than communication costs).

The location of the ‘intelligence’ of an AVL system is dependent on the operational constraints imposed on the owner of the system. For example, local authorities may wish to have the ‘intelligence’ under their control (i.e. on the roadside) whereas bus operators may prefer to have an AVL system which is completely independent of any roadside infrastructure.

Since 1994 the number of towns and cities which have real-time passenger information systems has risen considerably, therefore the question of a superior technology emerging after a system has been implemented has not really been faced. In light of this uncertainty, it would be wise to adopt a modular AVL system which has standard interfaces and protocols, as upgrades of individual components in modular systems can be implemented as superior versions appear on the market, without replacing the whole system.

Bus operations are dynamic by nature, so routes and schedules can change frequently (especially in a deregulated environment). Therefore it is essential that routes and schedules held within the AVL system are able to be easily modified by the bus operator. If a real-time passenger information system is to be installed in a deregulated environment then it would be unwise to integrate a schedule into the AVL system if the timetable changes frequently (e.g. in reaction to competition on the route). Hence if the bus service environment is unstable, a system which is based on information which has been inputted by the driver (or controller) may be more suitable (as is the case with the Mark IV SLE system). Whatever means is chosen for the input of trip information into the AVL system, it is vital that this information is kept up-to-date and operational decisions such as cancellations or curtailed trips are also added, as and when they occur.

A comparison was made between the various AVL systems used for bus operational control in the UK. It was found that GPS-based systems and Datatrak do not have very user-friendly displays and do not allow the whole route to be seen easily on one screen, with the result that controllers still continue to use conventional methods of route control such as voice radio with drivers and roadside inspectors instead of making more use of the information given by the AVL system. Peek Traffic’s Bus Tracker and Mark IV SLE’s
COUNTDOWN systems were deemed to be the most user-friendly systems in terms of layout of information presented to the operator and clarity of route map. Although schematic maps do not provide detailed road information they have the advantage of simplicity and allow bunching to be identified quickly. However route maps which incorporate the road network aid the controller in re-routing buses in cases of emergency diversions.

In a comparison of the strengths and weakness of real-time passenger information systems it was found that the Williams Industries system and GEC Tele-Tag system were the ‘best’. Peek Traffic’s Bus Tracker system has produced favourable results in implementations which have had the benefit of European Union funding. Although London Transport’s COUNTDOWN did not fair so well it should be remembered that London Transport did much pioneering research into AVL systems and many other users and manufacturers of AVL systems have benefited from the years between the installation of COUNTDOWN and their own systems which allowed initial problems to be resolved.

There does not seem to be any correlation between the accuracy of the system and the type of technology used or even the system supplier. The accuracy of the positional information has a direct impact on cost since, in general, the greater the level of accuracy the higher the cost of the system. All participants in the interviews named accuracy as being one of their prime concerns when considering which AVL system to buy.

A postal survey of users of AVL and real-time passenger information systems, carried out in April 1994, found that most respondents felt that bus operators should be responsible for paying for the on-bus equipment and any additional equipment used in their own control centres, and that local authorities should be responsible for the provision and maintenance of roadside infrastructure (e.g. beacons) and any real-time passenger information infrastructure, such as bus stop displays.

The main barrier to investing in real-time passenger information systems for local authorities and bus companies is the price of the equipment (which, incidently, can vary considerably from manufacturer to manufacturer for similar components). The cost of each display is in the region of £4,000 and, for the system to be of any benefit, several stops along a route need to be fitted with displays so that it has maximum impact on passengers. Therefore it is necessary that such a large investment is seen to be reaping significant benefits. The expected benefits of real-time passenger information systems are:
increased reliability of service, increased patronage, more efficient use of resources and improved scheduling. The extent to which each of these expected benefits has been realised is discussed below.

Reliability of service

The only systems which have produced an increase in reliability of service were ones in which the operator had a financial stake in the AVL system or the real-time passenger information scheme, which provided an incentive for the operator to ensure that some productivity gains were obtained. Also, operators who have a financial stake in the system are more likely to ensure that buses which are fitted with location equipment are assigned to the correct route and also encourage drivers to enter the correct information into the system.

Patronage

Although, the information is well received by the travelling public, real-time passenger information on its own does not produce the patronage increases witnessed by schemes which have provided new low floor buses, a more frequent service or reduced in vehicle time via improved traffic management measures (such as the Red Routes in London). However it should be noted that bus patronage depends on many factors and so real-time passenger information cannot be viewed in isolation.

Displays at locations other than at bus stops (such as supermarkets, train stations etc.) may result in patronage generation by attracting new users to the bus system, as has happened in Ipswich and Liverpool, especially if they provide a comfortable waiting environment. The experiences of Stoke-on-Trent and Ipswich have shown that mass distribution of timetables and route information to homes also results in an increase in patronage.

Efficient use of resource

None of the bus operators interviewed were currently using non real-time AVL data to improve scheduling or to optimise fleet usage. However most operators used the AVL data to check passenger complaints of late arrival or early departure at given locations along the route.
Non real-time AVL data is available at negligible marginal cost and since it provides a continuous record of the activities of all buses throughout the whole operating day, there are many potential uses for this data. It has been shown in this thesis that non real-time AVL data can be used for the compilation of punctuality statistics, to identify areas of the route which would benefit most from bus priority measures and to improve scheduling by highlighting areas which incur the greatest deviation from schedule (although, identifying bus bunching from non real-time AVL data can be difficult because of the quantity of data involved).

However non real-time AVL data can only be of use for analytical purposes if it is an accurate representation of events taking place in reality. Analysis of non real-time AVL data from the Route 18 in London showed that the time at which a bus was at a given position along the route is not 100% accurate because of the method of polling and capacity of the communication channel employed. One of the main problems of using non real-time AVL data is that since the events recorded in the data have already happened it is very difficult to extract what happened in practice when there is conflicting information in the data, e.g. two events happen at the same time and both are equally possible.

Once the non real-time AVL has had all the ‘errors’ removed from it, it can be used to estimate the passenger arrival rate at stops along a bus route (in conjunction with on-board passenger counts). The passenger arrival rate can then be used to calculate how long buses spend at stops. If the time a bus spends at stops is removed from the total time it takes the bus to traverse a link, the remaining amount of time can be assumed to be the time the bus spends moving and hence the moving speed of the bus can be obtained. Separating the time spent moving between stops from the time spent at stops allows a stronger case to be made to the local authority for bus priority measures, such as bus lanes or priority at traffic lights etc, along links which slow down the progress of buses significantly. The local authority can then compare the moving speed of the bus along that link after the bus priority measures have been implemented with the moving speed of the bus before priority was given, in order to assess the effectiveness of the bus priority measure.

It was found that estimation of patronage and the speed of buses as they move between stops using AVL data produced results which were comparable with those obtained by other methods. However the main point to note is that, this new method of estimating
patronage has the potential to provide a larger and superior data set than is otherwise available at present, at very low cost.

The passenger arrival rate and the speed of buses as they moved between stops were used as inputs for a simulation model. However none of the 17 days of AVL data tested met the criteria for a valid model and therefore the model cannot, at present, be used as an aid to controller training, as initially envisaged. Hence it appears that while the passenger arrival rate and moving speed of buses obtained from AVL data is useful for aggregate analysis, it is not sufficiently representative for the disaggregate modelling which was attempted. It is unclear whether the problems associated with the data used in the analysis are common to all AVL systems since data from other AVL systems were not available for comparison. However it is likely that large AVL systems which utilise more than one radio aerial range and do not have systems in place to check for multiple receipts of data from a given bus and systems which do not have sufficient communication capacity to comfortably poll all vehicles in the polling cycle, will encounter similar problems.

6.2 Recommendations

AVL systems provide a valuable bus operation control tool. However care must be taken when specifying a system. It is recommended that the following attributes of AVL systems should be considered in the specification stage:

- main function of the system
- choice of suitable technology
- accuracy of positional information
- re-initialisation of bus position
- communication
  - frequency of polling required for continuous tracking of all buses
- system time
- user-friendliness
- information stored to files
- physical characteristics of the route
- capital and running costs
- maintenance
  - durability
  - fault reporting
opportunity for in-house maintenance
• external maintenance contacts
• comprehensibility and availability of computer manuals
• flexibility
• potential for expansion
• interface with other systems

Additional attributes which need to be borne in mind when specifying a real-time passenger information system include:
• accuracy of information
• driver input
• integration with schedule
• map or predicted arrival time information
• real-time count-down or event-driven count-down to arrival
• communication
  • centralised or distributed processing
• power requirements for displays at stops
• user-configurability
• clarity of information
• information content
• integration with audio unit at stop
• on-board next stop displays

It is recommended that AVL systems should be as simple as is needed to achieve their main objective. Apart from the reduction in costs, simple systems have the benefit of being easier to maintain and are likely to have greater reliability.

If a transport authority’s main aim is to increase the patronage on buses than it is advised that they spend the money which is required for a real-time passenger information scheme on more buses to increase the frequency since, although uncertainty of waiting time is a major deterrent to bus travel, frequency and reliability are seen by many passengers as also being important attributes.

AVL systems are like any other technology in that they can, and very often do, produce spurious information. Using a ‘black box’ inside an AVL system to compile management statistics is an easy way to use inaccurate data for important decision making. It is
important that AVL data is retained on file in its purest form (e.g. the time a bus passes
certain positions along the route) and to calculate management statistics from this data
after anomalies have been removed from it. Since non real-time AVL data is more
manageable than real-time data, checks for anomalies can be made far more easily.
Accuracy has been highlighted as an important attribute of an AVL system. This regard
for high accuracy should be extended to non real-time AVL data as well as to real-time
data.

All real-time passenger information systems are susceptible to the problem of an incorrect
fleet or board number being entered into the system which results in misleading
information being presented to passengers at stops. It is recommended that board numbers
should be obtained from ticket machines (as in the Williams Industries system) as ticket
machine information tends to be fairly reliable, since inputting trip information into the
machine is a necessary part of the driver’s working day and does not form an additional
task which may be forgotten. Alternatively control centres can input driver or trip
information into the system or obtain updates automatically from the operator’s garages
via landline.

6.3 FURTHER WORK

Observations of the boarding process seem to indicate that passengers take longer than
expected to board a bus if it is full or there are many passengers alighting. This research
has shown that the stop time of buses accounts for approximately half the scheduled
journey time of buses between termini. Accurately modelling the amount of time required
for the boarding process (which dominates the stop time for between 55% and 60% of
stops (see Table 4.8, Section 4.3.1.2)) may yield a more accurate representation of bus
operations in simulation models. Therefore it is recommended that further research be
done on this phenomenon in the morning and evening peak, when buses are most likely
to reach capacity. (This aspect could not be investigated in this research because of a lack
of data for buses which reached capacity).

Bus capacity was found to be 80 passengers in the Route 18 patronage survey, although
the advertised bus capacity is 91 passengers. Many factors affect the practical bus
capacity, e.g. attitude of driver, presence of luggage, willingness of passengers to take
seats upstairs. Further research should be carried out to explore the effect of representing
the capacity of a bus as a distribution function (which is expected to have a relatively small variance), as this will have implications for the modelling of bus operations during the peak periods when capacity is likely to be exceeded.

A major disadvantage with simulation models is that since bus operations are inherently complicated, assumptions and simplifications have to be made in order to carry out the model development. A factor which is difficult to model but which has an important effect on the operation of a route is the characteristics of individual drivers. If driver information was included in the AVL data a proper estimate of the effect of driver characteristics could be obtained and the model could be improved. It is also recommended that more patronage data be collected (with the associated AVL data) so that the average of the passenger arrival rate is taken over more values and smaller passenger arrival rates intervals can be used in the model and that the model be re-run when the accuracy and integrity of the available AVL data improves.

Many of the real-time passenger information systems visited as part of this research were in the early stages of development. It would be a useful exercise to update the information gathered in the structured interviews with project managers in, say, 5 years time when the systems are well established, since some reliability and maintenance problems may make some technologies, which appear feasible now, too expensive to contemplate in the future.
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APPENDIX A  SURVEY FORM (ABRIDGED)
<table>
<thead>
<tr>
<th>LT Stop No.</th>
<th>Name</th>
<th>Time</th>
<th>Nb</th>
<th>Tb</th>
<th>Na</th>
<th>Ta</th>
<th>OAP</th>
<th>Pass</th>
<th>Exact</th>
<th>Change</th>
<th>Dead</th>
</tr>
</thead>
<tbody>
<tr>
<td>1485</td>
<td>Sudbury Swan</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2805</td>
<td>Barnham Park</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2806</td>
<td>Fusilier</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>2807</td>
<td>Copland Avenue</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>3285</td>
<td>Ealing Rd</td>
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<td></td>
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<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>14946</td>
<td>Wembley Central</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1482</td>
<td>Park Lane</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>3284</td>
<td>Copland School</td>
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<td></td>
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<tr>
<td>1220</td>
<td>Wembley Triangle</td>
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<td>3282</td>
<td>Waverley Avenue</td>
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<td></td>
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<tr>
<td>3277</td>
<td>Tring Avenue</td>
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<td></td>
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</tr>
<tr>
<td>2809</td>
<td>Harrow Tavern</td>
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</tr>
<tr>
<td>3275</td>
<td>Wyld Way</td>
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</tr>
</tbody>
</table>
The nomenclature used in the survey form is as follows:

- **LT Stop No.** The code used by London Transport to uniquely identify stops
- **Name** Name of the stop
- **Time (GMT)** Time the bus reached the stop (not the time the bus left the stop)
- **Nb** Number of passengers boarding at the stop
- **Tb** Time in seconds for all the passengers at the stop to board
- **Na** Number of passengers alighting at the stop
- **Ta** Time in seconds for all the alighting passengers to alight
- **OAP** Number of passengers that were recorded as senior citizens
- **Pass** Number of passengers who used a pass (those who had a pass and bought an excess fare were classified under Exact or Change and not pass)
- **Exact** The number of passengers who tendered the exact fare
- **Change** The number of passengers requiring change
- **Dead** Dead time: can be boarding, alighting or neither boarding/alighting
- **Comments** Observations of bunching or non-scheduled behaviour, coded as follows:
  1. **Bus Passed**: refers to occasions when the bus the observer was sitting on was passed by another bus.
  2. **Passed Bus**: refers to the observer's bus passing one in front.
  3. **Bus skipped stop**
  4. **Bus waited**
  5. **Bus terminated short**
  6. **Driver changed bus (transferred passengers to new bus, same duty)**
  7. **Duty change over**
  8. **Breakdown**: A breakdown as recorded in the survey can either mean a bus breakdown (if this is the case then it will be the recorded on the last entry for that bus/trip combination), a ticket machine failure or doors jamming. The latter two breakdowns were more common than the former.
  9. **Transfer passengers from survey bus**: Passengers were transferred from buses if there was a mechanical problem or failure with the bus or the driver was instructed to do so by the controller (because of bunching along the route).
  10. **Passengers transferred from another bus onto survey bus**
  11. **Bus in front (within 50m)**
  12. **Bus Full**

-999 indicates that no data is available for that entry. It should be noted that not all of the above measurements were recorded at every stop. The time related measurements, i.e. Time, Ta, Tb and Dead, were shaded to make them distinct from the counting related measurements.
APPENDIX B  POSTAL QUESTIONNAIRE TO LOCAL AUTHORITIES
Questionnaire for Users of Automatic Vehicle Location Systems

The aim of this questionnaire is to assess what types of AVL systems are being used by bus companies and local authorities and to what extent the knowledge of the real time location of the bus is used to provide information for passengers. If a certain section is not applicable to your organisation then instructions will be provided to guide you to the next relevant question. Your assistance in completing this questionnaire is greatly appreciated.

Respondent

Name: Date:
Position in organisation:
Name of organisation:
Address:

Telephone Number:

AVL System

1. What does your organisation call the AVL system you use?

2. By what name does the manufacturer sell the AVL system?

3. What is the main basis of vehicle location? (Please circle the appropriate system)

   Radio navigation network: Datatrak, Omega, Loran-C, Other (Please specify)
   Beacon: Microwave, Infrared, Inductive Loop, (LF, HF, UHF) Radio
   GPS
   Odometer
   Other (Please specify)

4. What criteria did you use to choose which technology would be the main basis of vehicle location?

5. What criteria did you use to choose the manufacturer who won the contract?
6. How did you decide how many beacons per route to use?

7. What is the accuracy of this system? (Please explain your answer i.e. the accuracy at the
time of polling and how often the bus is polled)

8. What is the system’s greatest margin of error, e.g. not reporting a bus if 2 buses are
close together or maximum distance travelled between polls?

9. How long have you been using an AVL system?

10. Have you had the same system for all this time?
    If not, please give details, i.e. of upgrades etc.:

11. Is the AVL system linked to a bus priority at signal controlled junctions scheme?
    Yes / No

12. Do the drivers have consoles in their cabs so that they will know their progress is
    relative to the schedule and so can take appropriate action if they are behind schedule?
    Yes / No

13. Are you planning to add additional features such as these to your AVL system?
    Yes / No

14. If the whole network is not covered, then how did you decide which routes to include
    in the scheme?

15. Are you planning to extend the AVL system to the whole of your network?
    Yes / No
    If No, why not?
16. How is the AVL system being evaluated, i.e. what criteria is being used to measure its success?

17. How did you decide that the money spent on AVL would not be better spent elsewhere, e.g. newer buses, etc.?

For Real Time Passenger Information Systems

*If your AVL system is not linked to any kind of passenger information system and you do not intend to do so, please go to Question 23*

18. Please specify how many of each of the following are/ will be linked to the AVL system to provide real time information for passengers?

<table>
<thead>
<tr>
<th>Now</th>
<th>Within the next 5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>____ Bus stops</td>
<td>____ Bus stops</td>
</tr>
<tr>
<td>(Out of a total of ____ bus stops which are under the authority’s control)</td>
<td>(Out of a total of ____ bus stops which are under the authority’s control)</td>
</tr>
<tr>
<td>____ On Board buses</td>
<td>____ On Board buses</td>
</tr>
<tr>
<td>(Out of a total of ____ buses which are under the authority’s control)</td>
<td>(Out of a total of ____ buses which are under the authority’s control)</td>
</tr>
<tr>
<td>____ Telephone enquiry services</td>
<td>____ Telephone enquiry services</td>
</tr>
<tr>
<td>(Out of a total of ____ which are under the authority’s control)</td>
<td>(Out of a total of ____ which are under the authority’s control)</td>
</tr>
<tr>
<td>____ Bus stations</td>
<td>____ Bus stations</td>
</tr>
<tr>
<td>(Out of a total of ____ which are under the authority’s control)</td>
<td>(Out of a total of ____ which are under the authority’s control)</td>
</tr>
<tr>
<td>____ Travel enquiry offices</td>
<td>____ Travel enquiry offices</td>
</tr>
<tr>
<td>(Out of a total of ____ which are under the authority’s control)</td>
<td>(Out of a total of ____ which are under the authority’s control)</td>
</tr>
<tr>
<td>____ Other (Please specify)</td>
<td>____ Other (Please specify)</td>
</tr>
<tr>
<td>(Out of a total of ____)</td>
<td>(Out of a total of ____)</td>
</tr>
</tbody>
</table>
19. How would you say that the passenger information system has benefited your organisation e.g. greater patronage, better image, etc)? (Please specify what form of passenger information system you have and its benefits)

20. How is the passenger information system being evaluated, i.e. what criteria is being used to measure its success?

For Real Time Passenger Information at Bus Stops

If your AVL system is not linked to passenger information at bus stops, please go to Question 23

21. If the whole network is not covered, then how did you decide which routes to include in the scheme?

22. Are you planning to extend the passenger information system to the whole of your network?

   Yes / No  
   If No, why not?

Passenger Information

23. What passenger information do you provide, e.g. timetables, leaflets, telephone enquiry service?

24. How much does your organisation spend a year on information provision (in £ and as a percentage of your annual budget)? What fraction of this is due to the real time passenger information system?
Costs and Benefits

25. What was the total cost of the AVL system?
   AVL System only:
   Passenger Information System:
   Research and Development:

26. How much does the AVL system cost you? (Please breakdown the cost as far as possible)
   Capital cost:
   Running cost /year:

27. What have been the benefits of the AVL system to your organisation, e.g. staff reductions, increased patronage, expansion of workforce, training for staff, greater staff workload, improved image, greater reliability of service, etc.? (Please be as explicit as possible)

General Questions

28. What are the problems you have faced using this system (either the AVL or the real time passenger information system)? Have there been any adverse effects?

29. What roles do you think that operators and authorities should play in expanding AVL control and real time passenger information?

30. What research do you think needs to be done concerning AVL or real time passenger information?

Please send the completed questionnaire to: Miss Antoneta Lobo
   Centre for Transport Studies
   University College London
   Gower Street
   London WC1E 6BT

If you have any queries, please ring 0171-391-1560

Thank you for your help and cooperation.
APPENDIX C  QUESTIONNAIRE USED IN INTERVIEWS WITH LOCAL AUTHORITIES
Questionnaire for organisations which implement Real-time passenger information systems

The aim of this questionnaire is to establish guidelines for system specification which could be used by local authorities who may be considering implementing a real time passenger information system and to identify best practices amongst existing systems. Your assistance in completing this questionnaire is greatly appreciated.

Respondent

Name: 
Position in organisation: 
Name of organisation: 
Address: 

Telephone Number: 

Real-time passenger information system

1. What is your real-time passenger information system called?

2. By what name does the manufacturer sell the AVL system?

3. What is the main basis of vehicle location? (Please circle the appropriate technology)

   Radio navigation network: Datatrak, Omega, Loran-C, Other (Please specify)
   Beacon & Odometer: Microwave, Infrared, Inductive Loop, (LF, HF, UHF) Radio
   GPS
   Odometer Only
   Other (Please specify)

4. Please describe how your system works in terms of vehicle equipment, communication network and data collection facilities:
5. Please give a list of the main sub-components of your real-time passenger information system (if some sub-components, e.g. radios, were already present before the real-time passenger information system was commissioned then identify the number in use before by using [ ]):

<table>
<thead>
<tr>
<th>Environment</th>
<th>Sub-component</th>
<th>Number involved in scheme</th>
<th>Capital cost of sub-component per unit</th>
<th>Running cost of sub-component per unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garage</td>
<td>Control centre hardware</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control centre software</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buses</td>
<td>Transponder/GPS Receiver ** (** delete as appropriate)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radio</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Odometers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roadside infrastructure</td>
<td>Beacons</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Communication to sign from control centre: radio/landlines ** (** delete as appropriate)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real-time passenger information</td>
<td>at stops</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>on board buses (e.g. next stop display)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>at terminals in travel centres</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>telephone enquiry service</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>hand-held terminals</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. What was the total cost of your AVL system (excluding the cost of the real-time passenger information system)?

7. What was the additional cost of the real time passenger information system?

8. What is the maximum positional accuracy (e.g. ± 10 metres) for the location of a bus in:
   a) Urban areas:
   b) Rural Areas:

   To obtain this level of accuracy:
   a) How often are buses polled? Every _____ seconds
   b) What is the maximum number of buses that can be logged onto the system?
   c) What is the cost of the communication system (e.g. cost of airtime etc.)?
9. To what degree does your system require a secondary method of establishing location in order to obtain a location accuracy of less than ± 20 metres? (* Please ✓)

<table>
<thead>
<tr>
<th>Secondary system</th>
<th>Essential*</th>
<th>Recommend*</th>
<th>Cost of secondary system £</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odometer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beacons (state number per km)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Map matching using GIS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Differential GPS</td>
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<td></td>
</tr>
<tr>
<td>Other (please specify):</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10. What data is automatically written to the files which the system keeps as a record of the activities of buses throughout the day (e.g. bus number, link number, time taken to complete link, time reached position along link, position of bus at every poll etc.)?

11. Do you currently have the following features in your AVL system: (* Please ✓)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Currently installed*</th>
<th>Planned to be installed in next 5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic compilation of management statistics (e.g. average speed along links, average headway etc) - please specify:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bus priority at traffic lights</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Displays in driver’s cab which shows minutes ahead/behind schedule** or headway from bus in front** (** delete as appropriate)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ticketing information from Wayfarer** or smartcard** ticket machines providing automatic estimates of current load of bus** or patronage at stops** (** delete as appropriate)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (please specify):</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

12. What attributes of an AVL system should a bus company/local authority take into account before specifying a system for use on an urban bus route?
13. What additional attributes need to be considered when specifying a real-time passenger information system?

Displays

14. What type of displays do you use at bus stops to display real-time passenger information?

<table>
<thead>
<tr>
<th>Display Type (Please circle)</th>
<th>Specification</th>
<th>No. of these displays currently used</th>
<th>Company which manufacture display</th>
<th>Capital cost of display per unit</th>
<th>Running cost per year per unit (e.g. power, maintenance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED/ LCD/ CRT/ EM Flip/ Other (please specify):</td>
<td>No. Lines:</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Number of characters:</td>
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<td></td>
<td>Size of characters (in terms of either pixels or mm)</td>
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<td></td>
<td>Total dimensions of display (height x width x depth)</td>
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<td></td>
</tr>
<tr>
<td>LED/ LCD/ CRT/ EM Flip/ Other (please specify):</td>
<td>No. Lines:</td>
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<td>Number of characters:</td>
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<td>Total dimensions of display (height x width x depth)</td>
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<tr>
<td>LED/ LCD/ CRT/ EM Flip/ Other (please specify):</td>
<td>No. Lines:</td>
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<td>Size of characters (in terms of either pixels or mm)</td>
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<td>Total dimensions of display (height x width x depth)</td>
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</tr>
</tbody>
</table>

15. What attributes need to be considered when specifying a display which is to be used for real-time passenger information at bus stops?
Evaluation of the system

16. How long have you been using an AVL system?

17. What are the problems you have faced using this system (either the AVL or the real time passenger information system)? Have there been any adverse effects?

18. Has reliability/regularity of buses increased since the introduction of the AVL system? (** Please delete as appropriate)

   Yes/ No/ Inconclusive/ Have not investigated**

19. How much has patronage increased by since the introduction of the real-time passenger information system? (** Please delete as appropriate)

   / Have not investigated**

20. Do passengers say they will travel more because of the real-time passenger information system? (** Please delete as appropriate)

   Yes/ No/ Inconclusive/ Have not investigated**

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

Please send the completed questionnaire to: Miss Antoneta Lobo
Centre for Transport Studies
University College London
Gower Street
London WC1E 6BT

If you have any queries, please ring 0171-391-1563

Thank you for your help and cooperation