Route Choice Responses to Variable Road User Charges and Traffic Information

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The candidate confirms that the work submitted is her own and that appropriate credit has been given where reference has been made to the work of others

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Abstract

This study investigates the drivers' route choice in response to variable road user charges and traffic information. Firstly, this study investigates the effects of information concerning traffic conditions on drivers' route choice behaviour and the way in which drivers evaluate the value of information concerning delay time. Secondly, drivers' response to different types of variable road user charges and their sensitivity to these road user charges are explored. Thirdly, the way that the uncertain information influence drivers' behaviours are also analysed. Finally, this study investigates the extent to which socio-economic characteristics influence drivers' responses to road user charge and to the information concerning traffic conditions and charges.

The traffic information is provided via VMS and related to the expected delay time. Three types of the variable road user charges are applied: fixed charges; time-based charges; and delay time-based charges. Three SP surveys are conducted to collect data. The main survey is conducted in Leeds and Seoul, and the additional survey is conducted in Leeds. Logit models are used for analysing the main SP survey data. The repeated measurement problem in the main survey data is corrected using the jackknife method and Kocur's method. A regression method is used in the analysis of the additional survey data. Some results reveal that Utility Theory was not enough to explain the results. Therefore, Prospect Theory is applied to the results and is found to give a satisfactory explanation.

The results indicate that drivers are less likely to choose a route characterised by recurrent delays and as the length of delay reported on their usual route increases. drivers value delay time information more highly than free travel time and become increasingly sensitive to delay time as it increases. The delay thresholds in this study are 10 minute for the normal delay time and 15 minutes for the extra delay time on VMS.

Among three different types of road user charges them, the fixed charges have a stronger effect on drivers' route choice than do the others. The values of time are 3.9 pence per minute in terms of the fixed charges, 4.5 pence per minute in terms of the total time-based charges and 4.3 pence per minute in terms of the delay time-based charges.

Drivers prefer the routes for which information is provided to those for which it is not provided. This indicates that drivers prefer avoiding uncertain charges and that providing charge information encourage them to choose the route for which charge information is given. When the charge information is given with a range, drivers' route choices are influenced more by the median value of range of charge information than by the size of the range of charges. Female drivers are more likely to choose the certain charge route than are male drivers. Low income drivers are more sensitive to the increases of the range of the charge on their route choices.

Application of Prospect Theory explained the way drivers interpret the choice situation and make a route choice in response to uncertain information about charges. The way people edit and simplify the choice context cause inconsistent preference which Utility Theory can not explain.

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Chapter 1
Introduction

1.1 Background

Although road user charging has long been suggested by economists (e.g. Pigou 1929) as a means of influencing behaviour, it has in practice been used mainly to raise revenue. However, as congestion becomes a pressing problem, it has again attracted the world's attention as a means of restraining traffic demand. Road user charging contributes to expand transportation capacity by reducing demand rather than by increasing the supply of transport facilities. Recent technical developments related to road user charges have made it more advanced and sophisticated, and make it possible to vary the levels of charges depending on the traffic conditions (e.g. as a function of travel time or time spent at low speeds) and so achieve a charging regime which is closer to the theoretical optimum whereby the charges are proportional to the delays caused by the motorist.

Even though use of road user charges is a theoretically attractive means of reducing congestion and even though related technologies already have been developed, it has not been easy to implement such charges in real-world applications due to various very practical obstacles including its perceived political unpopularity, a fear of invasion of privacy and particularly its apparent unacceptability to the public (Gomez-Ibanez and Small 1994).

Another potential solution to the growing problem of congestion is to influence traffic demand via advanced traveler information system (ATIS). Such systems offer the prospect of fast and reliable traffic information to drivers. These aim to improve the drivers' decision making processes and to achieve efficient use of the existing road network (Bonsall and Parry 1991; Emmerink *et al.* 1995a).

1.2 Combination of Road User Charges and ATIS

Road user charges and ATIS have been researched separately in different fields. However, since the late 1980's, several researchers (for example, Brett and Estlea 1989; Emmerink *et al.* 1995a) have suggested combining road user charges and ATIS in various ways.

Brett and Estlea (1989) suggested that it is desirable to combine these systems for two reasons. First, because these systems are able to share the technology. Secondly, because providing information releases additional trips from suppressed demand, but this latent demand would remain suppressed by road user charges.

Van Vuren and Smart (1991) also suggested that providing traffic information may achieve more efficient use of the road system but that the release of suppressed demand would cause the overall improvement to be negligible. Therefore, they concluded that route-guidance systems should be combined with road user charges in order to manage demand.

Emmerink *et al.* (1995a) proposed that the combination of these systems would be economic and efficient. Firstly, road user charges could provide a strong incentive to follow system optimal routes. Secondly, road user charges would suppress the latent demand generated by providing information. Thirdly, ATIS would increase the public acceptance of road user charges scheme. They also suggested that ATIS could not only provides the data which is used for the correct levels of charges and variable charges, but could also provide the charge information to drivers. Finally, combining these systems could yield synergy effects on the cost side by sharing the equipment and technologies.

I will suggest that this combination may improve drivers' decision making by providing information concerning traffic conditions and charges and may also lead to redistributional effects, depending on the value of time. I will also suggest that providing information is necessary for implementing certain types of road user charges (when the charge depends on the traffic conditions and is thus difficult to predict). It is unfair and inefficient to implement the variable charges without letting drivers know what the charge will be.

1.3 Objectives

An important issue in the implementation of these systems is to develop an understanding of the way these systems affect drivers' behaviour. This understanding is a necessary prerequisite to the estimation of the expected benefits of these systems and would help to improve their design and operation. This study investigates drivers' responses to the combination of ATIS and the variable road user charges.

Firstly, this study investigates the effects of information concerning traffic conditions on drivers' route choice behaviour and the way in which drivers evaluate the value of information concerning delay time.

Secondly, drivers' response to different types of variable road user charges and their sensitivity to these road user charges are explored. Variable road user charges include several types of charging regime whereby the charges depend on the time taken, the distance traveled or the time spent in congested conditions. Previous studies concerning road user charges mainly considered cordon charges, or tolls, and many of them focused on the public acceptability, elasticity and influence on travel pattern (for example, Holland and Watson 1978; Larsen 1988; HRC 1991; Meland and Polak 1993). Several studies have investigated the effects of variable road user charges on network conditions but most of them have done this without any consideration of the possibility that the behavioural response might depend on the nature of the charging regime (Milne and Van Vliet 1993; Milne *et al.* 1993; Smith *et al.* 1994).

Thirdly, implementation of variable road user charges should be accompanied by relevant charge information. Therefore, this study considers the practical application of the charge information, and the design of charge information such as the way charge information is given, and the presentation of different charging schemes. The necessary degree of accuracy of charge information may be decided depending on the way the charges are calculated, and on the traffic conditions. The way that the uncertain information about charges influences drivers' behaviour is also analysed.

Finally, this study investigates the extent to which socio-economic characteristics influence drivers' responses to road user charge and to the information concerning traffic conditions and charges.

1.4 Data Collection and Analysis

In this study, three surveys are conducted to collect data. The main survey investigates the effect of traffic information and variable road user charges on drivers' route choice. The main survey is conducted in Leeds. This survey is also repeated in Seoul, Korea. An additional survey aims to investigate the extent to which the degree of uncertainty of charge information influences route choice.

Stated preference (SP) method is used in the surveys. The approach is applicable to investigate responses under a hypothetical situation which does not currently exist in the real world. Even though traffic information systems have been studied they are still a new and advanced concept to drivers. In the particular case of variable road user charges there is little evidence from real-world implementations (Gomez-Ibanez 1994). Therefore, the survey of this study had to be based on a hypothetical situation and the SP survey method is applicable for this situation.

A number of authors (Wardman 1987; Jones 1989; Pearmain and Kroes 1990) recommended the testing and development of the SP experimental designs before the actual survey, through the pre-tests including of a pilot survey and simulation. Three pilot surveys and simulation tests were used in order to improve the design for the main survey.

Logit models are used for analysing the main SP data and in the analysis of the additional survey data.

One of the advantages of SP methods is the possibility of getting a number of responses from each respondent. However, when the repeated observations from each respondent are analysed by applying the simple modeling method, a potential problem is created because of upbiased significance due to the repeated observation from each respondent. This study uses a variety of approaches to explore this issue and to test the robustness of the simple model estimates.

Most of the analyses are based on Utility Theory. However, the theory is not enough to interpret some of the results related to the uncertainty of charge information. Prospect Theory, which is applicable to decision making under uncertainty, was therefore applied to interpret the results and to give a deeper explanation of the results.

1.5 Overview of the Thesis

Following this introductory chapter, Chapter 2 briefly introduces the concept of traffic information systems and their expected effects. It also gives a thorough review of the literature on drivers' responses to traffic information systems. Drivers' responses to traffic information are found to vary depending on drivers' characteristics, systematic factors which are related to the traffic information systems and road systems, and to the characteristics of the traffic information.

Chapter 3 sets out the background to research about the road user charges by providing a definition and discussing objectives and charging methods. It also summarises the examples which have been implemented or studied, for example, Singapore' Area Licensing Scheme, and Hong Kong's ERP (Electronic Road user charges). It reviews the literature on drivers' response to road user charges. The responses are classified into three categories: influence on travel pattern such as route shift, time shift, mode shift; willingness to pay; and the acceptability of road user charges.

Chapter 4 briefly describes the general view of this study including the objectives, the survey method, and the analysis of the results. It also describes the way of presenting traffic information and charging systems, as well as presentation of charge information in the main survey.

Chapter 5 briefly discusses the SP survey method including the concept, key features, errors related to the SP responses and the principles of SP design. The chapter also details the experimental design adopted and describes the survey structures. The various different types of network presentation for the current study are also discussed. It also describes the role of simulation and pilot studies during the pre-test for SP design. Chapter 6 reports the three pilot surveys and simulation tests conducted in order to improve the experimental design of the main survey. It also reports the data collection process of the main survey in Leeds.

Chapter 7 provides a descriptive analysis of the results. It summarises the respondents' characteristics and experiences of different types of traffic information. Finally, it discusses respondents' attitudes toward introducing road user charges in Leeds city centre.

Chapter 8 presents the model development process and details the analysis undertaken. It consists of four parts: The first part presents the process of model development in order to find the best fitting model, the second part discusses the final model results; the third part presents the results of models segmented by the respondents' socio-economic characteristics; and the final part present the results and analysis of the Seoul survey.

Chapter 9 raises the issue of the "repeated measurement problem" caused by allowing several observations from each respondent (Cirillo *et al.* 1993). The jackknife method and Kocur's method are applied to estimate models using the main SP results. The results are compared with those of the simple method in order to test the robustness of the estimates presented in Chapter 8.

Chapter 10 reports on the additional SP survey which investigates the way in which the uncertain charge information influences drivers' behaviour. It details the experimental design adopted and the data collection. It analyses the effect of providing charge information on drivers' route choice using tabulations. It also reports on the results about the main factors which had influenced drivers' route choice under uncertain charges.

Chapter 11 gives a review of Prospect theory. It also applies this theory to the additional survey results and explains the drivers' route choice decision making process in response to the uncertain charges.

Chapter 12 summarises the findings from the experiments and draws appropriate conclusions.

Appendices include questionnaires of three pilot surveys, the main survey, the additional survey, brief descriptioin of Prospect Theory and the example of the simulation test presented in chapter 6.

Chapter 2

Review of Traffic Information Systems

2.1 Introduction

This study aims to investigate drivers' responses to the traffic information and road user charges. One of its purposes is to investigate the effects of information concerning traffic conditions on drivers' route choice behaviour and the way in which drivers evaluate the value of information concerning delay time. Before concerning this work, it is necessary to review relevant previous studies and put their findings in context to. Therefore, this chapter briefly introduces traffic information systems and what effects are expected from them, and also reviews the literature on drivers' response to traffic information systems.

In the next section the concept of advanced traffic information systems is explained and the expected effect or purposes of them are discussed. Section 2.3 discusses the importance of understanding drivers' responses to traffic information and reviews the modeling approaches which have been used to analyse route choice behaviour. The influence of drivers' the socio-economic characteristics and travel patterns on their responses to traffic information is addressed in section 2.3.4. The influence systematic factors such as road types, credibility of information, the relationship between drivers' own observation about the traffic conditions ahead, are reviewed in section 2.3.5. Finally, section 2.3.6 reviews the way in which the characteristics of traffic information influences drivers' responses to that information.

2.2 Advanced Traveller Information Systems

2.2.1 Intelligent Transport Systems

Recent developments in telecommunications and information technology have made it possible to apply traffic information systems to the road network and to have great impact on the transport field. Such systems were briefly termed, Intelligent Vehicle Highway Systems(IVHS) was used but "Intelligent Transport Systems(ITS)" is now a more generally accepted term. ITS is defined as

> *"a collection of technologies, systems and transportation management concepts that collectively aim to make surface transportation more efficient and safer" (U.S. Department of Transport (DOT) document 1994)*

The expected effects of ITS are well summarised in the document:

> *"ITS represents the evolution of the nations physical transportation infrastructure by bringing it into the information age. This is critically important because as travel demand continues to increase, ITS will help provide increased capacity and efficiency without relying on new construction. ITS applications will also improve safety eliminating 1.2million crashes per year, saving thousands of lives and $26 billion in lost productivity" (U.S. DOT document 1994).*

Many other specialised systems have been developed under the general heading of ITS, for example Advanced Traveller Information System (ATIS), Advanced Transport Telematics (ATT) and Road Transport Informatics (RTI). They are designed to provide traffic information to drivers in order to solve congestion problems (Khattak *et al.* 1993b). However, while they have different names, they ultimately have the same meanings and shared common purposes. These are described in the sections below.

2.2.2 Purpose of ATIS

In this section, the common purposes and the expected effect of ATIS as a result of providing traffic information will be summarised into 5 major points.

First, providing traffic information may be expected to reduce traffic congestion in urban networks (Schofer *et al.* 1993). It may also be expected to achieve the efficient use of the existing road network by providing drivers with fast and reliable traffic information (Bonsall and Parry, 1991) and by encouraging them to divert from congested routes to ones where traffic is flowing more freely. This would then also increase the overall efficiency of the entire road network. Therefore, providing traffic information can extend potential network capacity by using the existing network more efficiently and thus provide a cheap alternative form to capacity expansion via road building (Emmerink *et al.* 1995a). The United States Department of Transport (DOT, 1998) reported that a combination of ITS and new construction will achieve future traffic growth at a 35% saving compared with construction alone.

Secondly, providing traffic information aims to help and improve the drivers' decision making process by providing real-time traffic conditions or route-guidance information about current network conditions. It also decreases uncertainty of driving, and the driver anxieties which result from congestion and route-findings stress. These results in more efficient travel behaviour (Schofer *et al.* 1993; Adler and McNally 1994). Emmerink *et al.* (1995b) reported that considering uncertainty costs is important in assessing the benefits of providing information, because as the uncertainty cost becomes more important, provision of information becomes more effective.

Thirdly, it is suggested that the provision of traffic information may make it possible to achieve optimum system equilibrium. Without route guidance or information, it is difficult to establish system equilibrium because of a lack of network knowledge by drivers, so only a sub-optimum will be reached. By providing high quality information, not only can the drivers' own costs be reduced but also the cost of the whole network. As overall congestion levels are reduced, so the system as a whole should benefit too, including informed and uninformed drivers (Emmerink *et al.* 1994).

Finally, providing information can reduce unnecessary mileage, traffic volumes and congestion which are currently wasted as a result from a lack of information by assisting them to find efficient routes (Bonsall 1992a). Jeffery (1981) reported in a study of the inter-urban route choice that about £540 million was effectively wasted in Great Britain in 1979 by drivers who failed to find minimum time or distance routes on unfamiliar journeys. He suggested that this loss represented the potential benefits available to a perfect system of route guidance. He also suggested that the consequent saving in vehicle-kilometres might also produce a saving in road accidents, bringing the total benefit to around £575 million per year (1979 values).

2.2.3 Functional Classification

Lee *et al.* (1994) summarised the function of ATIS under four categories; in-vehicle routing and navigation systems (IRANS), in-vehicle motorist services information systems (IMSIS), in-vehicle signing information systems (ISIS), and in-vehicle safety advisory and warning systems (IVSAWS).

In-vehicle routing and navigation systems (IRANS) provide drivers with information about potential destinations, travel, modes, and how to get from one place to another. They include trip planning, multi-mode travel co-ordination, pre-drive route and destination selection, dynamic route selection, route guidance, route navigation, automated toll collection and route scheduling. In-vehicle motorist services information systems (IMSIS) provide drivers with advertising information and signing for motels, eating facilities, service stations and other signing displayed inside the vehicle also directing motorists to recreational areas and historical sites. In-vehicle signing information systems (ISIS) provide non-commercial routing, warning, regulatory, and advisory information that is currently depicted on external roadway signs. In-vehicle safety advisory and warning systems (IVSAWS) provide warnings of unsafe conditions and situations affecting the drivers on the roadway ahead, for example, hazard warnings, road condition information, automatic or manual aid requests and vehicle condition monitoring.

2.3 Findings on Responses to Traffic Information

2.3.1 Importance of Responses to Traffic Information

The currently expected effects of ATIS are based on the assumption that drivers' behaviour will be influenced by the information provided and that they will change their behavior to produce the optimum equilibrium. However, as Bonsall (1992a) pointed out, the existing assumption is not realistic because, as can be demonstrated, drivers are very selective in their acceptance of information and often want to make their own decision.

Therefore, understanding drivers' responses to ATIS is an important issue in determining the benefits of traffic information, as well as the impact on system design and control strategy (Khattak *et al.* 1991; Koutsopoulos *et al.* 1995). If the number of people complying with advice is low then the provision of that advice will have minimal effect on the overall transport system (Bonsall and Hounsell, 1994). Factors influencing drivers' responses to traffic information are also important to investigate. Bonsall (1992a) and Barfield and Mannering (1993) emphasized that the way in which drivers' route choice is influenced by ATIS is important in terms of evaluating the ATIS' impact on network performance and environmental conditions.

2.3.2 Models of Responses

Route choice models have been developed in order to investigate the potential impact of the introduction of traffic information on network performance. This section is heavily based on the review of the existing models of route choice in the context of in-vehicle guidance system by Bonsall (1992a). The approaches to modelling route choice can be categorised depending on the way informed drivers and uninformed drivers are assigned to the network.

The first and most popular approach is to assign both groups of drivers using stochastic user equilibrium (SUE) methods. This assumes that informed drivers have perfect knowledge (zero-variance), while uninformed drivers have higher link travel time (variance) (see for example Tsuiji *et al.* 1985, Koutsopoulos and Lotan 1989; Van Vuren and Watling 1991). This approach is attractive but has limitations, for example the results are dependent on the way the value of variance is decided and it is difficult to examine the benefits of providing driver information.

The second approach is to model the network performance on a particular day, assuming that uninformed drivers are assigned according to uncongested costs while informed drivers are assigned according to congested costs (see Van Aerde *et al.* 1989; Rakla *et al.* 1989). This approach tends to overestimate the benefits of providing information.

The third approach is to assign the uninformed drivers according to a medium term user equilibrium solution and to assign the informed drivers based on a disturbed demand matrix which represents actual conditions on a particular day. This approach was used in the version of SATURN by Watling in order to examine the effect of a disturbance of a particular day in the network and demand matrix (Smith and Russam 1989; Watling 1990).

All the above conventional models are based on the assumption that drivers will accept and comply with guidance or information and will try to minimise travel time or distance. However, Bonsall (1992a) pointed out that it is not a realistic assumption because drivers are very selective in their acceptance of advice. Minimizing travel time is not always the main criteria of route choice.

A number of researches have investigated route choice rules in response to real-time information on drivers' current routes. Mahmassani and Chang (1985) used a model of boundedly-rational decision makers to study the day-to-day dynamics of departure-time decision of urban commuters. They concluded that commuter behaviour was boundedly-rational for an acceptable departure time, but also contained an indifference band of tolerable schedule delay which determined the acceptability of a particular decision on any given day. Mahmassani and Jayskrishnan (1987) assumed the route selection rules in their study as that drivers would try to keep their original routes until the traffic conditions on an alternative recommended route is perceived better than those on the original route. This behaviour reflects drivers' attitudes to the uncertainty in using an unknown route. Mahmassani and Chen (1991) reported that through repeated experience, drivers reached their own conclusions about appropriate switching rules.

Adler *et al.* (1992) applied another approach to understand route choice behaviour, called the conflict model. This model works by analysing how and under what conditions drivers perceive that their objectives will not be met, and the way in which these drivers react and respond to the situation. They concluded that there are three primary factors in the conflict model, the threshold of conflict tolerance, the motivation improvement index, and the value of information and that these directly influence route choice behaviour and real-time information search and acquisition.

Lotan (1994) applied a default behaviour model to understand route choice. This assumes that drivers follow their usual behaviour pattern and modify it only if the information received differs substantially from their existing perceptions and their knowledge. She applied the default principle to the approximate reasoning model and reported that there is compatibility between knowledge and information; whenever information differs from knowledge, knowledge rules are adjusted while information rules are adjusted when information was not significantly different from existing perceptions.

2.3.3 Responses to Traffic Information

The influence of traffic information on route choice depends on the kind of information given, the reliability of the information, the types of information, the way in which information is presented, and whether this is user-optimum or system optimum. The influence also depends on the drivers' characteristics, such as experience or familiarity with the network. Therefore this section briefly reviews the literature on drivers' responses to traffic information focusing on the factors which affect the driver's behaviour and responses to traffic information.

The factors have been or can be roughly categorised into three main groups. The first group contains individual factors such as socio-economic factors, travel patterns and preferences. The second group contains systematic factors which involve the road types, quality of traffic information, market penetration and reliability of traffic information. The final group contains the characteristics of the traffic information including types of information, the timing of information, content of information and information format.

2.3.4 Relevant Individual Factors

A number of researchers have found that the drivers' responses to traffic information depend on socio-economic factors such as sex, age and income levels and on the drivers' travel pattern such as travel time, trip purpose and knowledge of the network (for example, Khattak *et al.* 1993; Allen *et al.* 1995; Benson 1996). This section will briefly review the way in which individual factors influence drivers' route choice in response to the traffic information.

2.3.4.1 Socio-Economic Factors

2.3.4.1.1 Gender

Previous research has indicated that female drivers are more reluctant to change their route as a result of traffic information than male (Bonsall 1992a; 1993; 1995; Conquest *et al.* 1993; Khattak *et al.* 1993a; Mannering *et al.* 1994; Emmerink *et al.* 1996). However, Caplice and Mahmassani (1992) reported the reverse effect.

Khattak *et al.* (1993a) explained this tendency using the concept of "risk attitude", that is, women are more risk-averse in their route choice than men, and that drivers who are more inclined toward "adventure and discovery" are more likely to divert. Emmerink *et al.* (1996) also explained this tendency as a result of females' risk-averse attitude and as a result of the different positions of female drivers in labour market such as female's lower wages, more part-time jobs and so on. However, Caplice and Mahmassani (1992) reported that female drivers were more likely to listen to radio reports and that female commuters tended to switch departure time more often than males as a result of reports.

2.3.4.1.2 Age & Income

Allen *et al.* (1991) reported that old drivers were more hesitant to divert than younger drivers as a result of traffic information, and that they were more than three times as likely to refuse ultimately to divert.

Bonsall (1992a) and Bonsall and Joint (1992) reported that young drivers were less likely to accept prescriptive information. Wardman *et al.* (1997) also found that younger people tend to comply less with advice from VMS signs. They suggested this was because younger drivers were less sensitive to delays and therefore less likely to change their behaviors because of expected congestion.

Khattak *et al.* (1993b) observed that drivers who had higher income were more willing to divert in responses to traffic information in order to save travel time. Perhaps this may be because of their perceived higher value of time.

2.3.4.2 Travel Pattern

2.3.4.2.1 Knowledge of the Network

Drivers' response to traffic information varies according to their knowledge of the network (Bonsall 1992a). Many researchers have found that drivers are less likely to comply with advice or change route as a result of traffic information as their knowledge of current network increases. In other words, drivers who are familiar with their current route are less likely to comply with advice (Dudek and Huchingson 1982; Khattak *et al.* 1991; Mahmassani and Chen 1991; Bonsall and Joint 1991; Bonsall 1992a). When drivers face congestion and no information is available, familiar drivers are likely to divert, while unfamiliar drivers are likely to stay (Khattak *et al.* 1993a; Bonsall and Hounsell 1994).

When drivers are familiar with alternative routes, they are more likely to change their route or comply with advice as a result of traffic information (Khattak *et al.* 1993a; Bonsall and Hounsell 1994). When drivers are unfamiliar with an alternative route or never use it, they are less likely to choose the alternative routes as a result of information (Wardman *et al.* 1997).

Drivers who have better knowledge of networks tend to make better use of information to make their own decision rather than to follow the advice of traffic information (Bonsall and Joint 1991; Mahmassani and Chen 1991; Hato *et al.* 1995). Kawashima (1991, quoted in Bonsall 1995) found that those who were familiar with a network were less likely to comply with the information because they wanted to make their own judgment about the quality of the advice. Hato *et al.* (1995) reported that the value of information on commuting trips increased as drivers' experience on the routes increases. This is because those who were more experienced and familiar with routes are able to make better use of the traffic information to change their route than others.

2.3.4.2.2 Travel Time

Many researchers have found that drivers with longer travel time on the current route were more likely to divert as a result of traffic information (Caplice and Mahmassani 1992; Khattak *et al.* 1993a; Khattak *et al.* 1993b; Emmerink *et al.* 1996). Khattak (1993b) suggested that this tendency was probably the result of their increased number of greater opportunities to change routes. Emmerink *et al.* (1996) also suggested that this tendency was probably the result of their increased number of opportunity to take alternative routes and they have more chance to listen to traffic information, which would lead them to switch routes.

2.3.4.2.3 Trip Purposes

Researchers have found that drivers' responses to traffic information varied depending on the trip purposes which in turn have different time constraint: Hato *et al.* (1995) reported that as a result of traffic information, commuters were more likely to stay on the expressway than drivers on shopping trips. Also drivers on shopping trips are more likely to change their route to avoid congestion than commuters. Emmerink *et al.* (1996) reported that when drivers were on a business trip, they were more likely to listen to traffic information than drivers with other journey purposes and that commuters were significantly less likely to be influenced by traffic information than business travellers.

2.3.4.2.4 *Listening Propensity*

Previous research (Bonsall and Joint 1991; Caplice and Mahmassani 1992; Bonsall *et al.* 1994; Emmerink *et al.* 1996) has indicated that drivers who have more experience of traffic information are more willing to change their route as a result of it. For example, Mahmassani *et al.* (1990) found that drivers who usually listen to radio traffic information are more likely to change their route as a result of traffic information. Emmerink *et al.* (1996) also reported that drivers who more frequently passed variable message signs are more willing to change their route as a result of traffic information. They also reported that the more drivers listen to radio traffic information, the more likely they are to change their route as a result of it.

2.3.5 Relevant Systematic Factors

2.3.5.1 Road Types

Bonsall (1992a) reported that road type or hierarchy of road was an important influences on drivers' route choice. Adler and McNally (1994) and Zhao *et al.* (1995) found that drivers generally preferred motorways to the other classes of roads even when traffic information stated that expected travel times were similar on both and even when the non-motorway road was uncongested.

Hato *et al.* (1995) found that drivers' route choice after receiving information was strongly dependent on their intended route choice before receiving information even if the same information was given in both routes. They reported that drivers who had intended to take the motorway before receiving information were more likely to choose the motorway after receiving information than the drivers who had intended to take the non-motorway road.

Emmerink *et al.* (1996) investigated the satisfaction levels of route choice adjustment as a result of traffic information and reported that drivers whose alternative route was still on motorway were more satisfied than those who were sent off the motorway. They recommended that a route guidance system should preferably not send drivers off the motorways.

2.3.5.2 Habit and Experience

In general, drivers are unlikely to change from their original routes, but two opposing sets of results have been produced by previous research. Adler and McNally (1994) reported that once drivers changed their route as a result of traffic information, they were more willing to divert again and reluctant to return or change back to the original route. However, Khattak *et al.* (1993a) reported that drivers with longer travel time were more likely to return to their usual route after diverting as a result of traffic information.

A number of researchers (Mahmassani and Chang 1991; Mahmassani and Jayakrishnan 1991; Lotan 1994; Adler and McNally 1994) have found that after drivers changed their routes from that initially intended, as a result of traffic information, they were inclined to be less sensitive to absolute speed and more concerned with relative speed.

2.3.5.3 Drivers' Observation vs Traffic Information

A number of researchers (Bonsall and Joint 1991; Hato *et al.* 1995; Wardman *et al.* 1997) have found that the drivers' response to traffic information was influenced by the degree of congestion encountered and by the visible traffic conditions ahead. Khattak *et al.* (1993b) reported that when drivers observe congestion, they generally estimate the length of delay from the queue in front of them and this estimate may support their route choice as more information becomes available.

Many researchers (Khattak *et al.* 1991; Bonsall and Whelan 1992; Khattak *et al.* 1993a; Khattak *et al.* 1993b; Bonsall *et al.* 1994; Wardman *et al.* 1997) have found that drivers are more likely to divert after receiving traffic information from VMS, radio or In-vehicle guidance than as a result of their own observations. This indicates that drivers are more influenced in route choice by traffic information than by their own estimates about traffic condition.

Khattak *et al.* (1993a; 1993b) suggested this behaviour is a reflection of the drivers' uncertainty about their own ability to estimate delay, they therefore place more confidence in the reported information. Bonsall *et al.*(1994) suggested this tendency is likely to depend on whether drivers had found the information system reliable in the past. While Wardman *et al.* (1997) reported that respondents' route choices were influenced by visible delays, they also reported that drivers who were more familiar with the network and those who had found VMS unreliable, tend to trust their own observation of visible queues more than VMS information.

2.3.5.4 Reliability of Information

The reliability of information is an important influence on the responses to traffic information. Bonsall (1992a) reported that the effect of traffic information or guidance on route choice depended on whether it was credible, relevant and clear, i.e. the frequency of updating, the detail degree of about the network and evidence it is based on and how appropriate information. He also pointed out that acceptance of the advice depends crucially on its credibility.

Shirazi *et al.* (1988) reported that the majority of commuters (94%) in their study said that they would consider diverting as a result of receiving traffic information if more accurate information was available, of these commuters, nearly 70 % said they would definitely divert. It was also reported that respondents considered the credibility of information crucial (Shirazi *et al.* 1988; Bonsall 1992a). Dingus and Hulse (1993) pointed out that appropriate and timely information is an important factor leading drivers to change their routes.

Shirazi *et al.* (1988) also asked commuters how they would like to see the quality of traffic information improved. They found that commuters suggested the first more timely and accurate information, secondly more frequent reporting and thirdly better uses of electronic freeway message signs (VMS).

Zhao *et al.* (1995) suggested that providing high quality traffic information would attract more drivers to use and accept traffic information. A number of researchers (Bonsall and Joint 1991; and Bonsall *et al.* 1994; Zhao *et al.* 1995) have found that when drivers perceived traffic information to be more reliable, they were more likely to respond to it. Hato *et al.* (1995) also reported that when the accuracy of information received is low, it tended to have a negative effect on the perceived value of the information, in order to influence drivers' route choice, he found that respondents required highly accurate and reliable information. Wardman *et al.* (1997) reported that drivers who experienced unreliable traffic information from VMS were less sentisitive to information and were more likely to believe their own observations of visible traffic conditions ahead rather than VMS information.

2.3.5.5 Market Penetration of Traffic Information

Schofer *et al.* (1993) reported that the market penetration of traffic information would influence the effect it had on travel conditions. Mahmassani and Chen (1993) reported that the reliability of traffic information depends on the proportion of informed drivers and tends to decrease when market penetration of the information increases. Arnott *et al.* (1991) and Mahmassani and Chen (1993) explaind this effect as when many drivers respond to the information, it makes rapid changes in traffic conditions and thus makes it difficult to predict the conditions and generates greater discrepancies between traffic information provided and actual traffic conditions. Bonsall *et al.* (1991) suggested that if all travellers had equal information, the benefits from information might be sub- optimal. Therefore, when the penetration levels are low, benefits to individual drivers can be expected to be at their greatest. Mahmassani and Chen (1991) suggested the adequate levels for market penetration of traffic information be as low as 10 or 20 percent, depending on initial conditions.

Emmerink *et al.* (1994) also reported that by providing information only to a limited number of drivers who might change their travel behaviour, the expected road usage will increase while the expected link travel costs will decrease.

2.3.5.6 Experience of Traffic Information and Expectation

The credibility of information is also dependent on drivers' accumulated experience with the quality of traffic information they received on previous journeys (Bonsall 1992a) and this affects their responses to the information. Mahmassani and Chen (1991) reported that previous good experience with traffic information increased the compliance rate. Bonsall *et al.* (1991) reported that respondents preferred to test the reliability of traffic information on a trial basis before they would consider using it.

The influence of information on route choice was also dependent on whether the provided information coincided with the drivers' expectation based on their experience. Bonsall and Joint (1991) reported that most drivers did not change their route as a result of advice from traffic information and one of the common reasons for this was that they believed the advised route was likely to be congested despite information to the contrary. Hato *et al.* (1995) reported when the information received coincides with drivers' expectations, the effects of traffic information could have a large effect on their route choice, and when they receive the information they want (such as less travel time on preferred route), they are more likely to change their route. Benson (1996) also reported that those who had experienced inaccuracies on VMS are less likely to use alternative routes recommended on VMS.

2.3.6 Factors Related to Characteristics of the Traffic Information

The characteristics of the information system can also have a significant effect on drivers' route choice. Allen *et al.* (1991) reported that when the system was more sophisticated and gave more information (e.g. displaying congestion levels and alternative routes), drivers were more willing to accept it and divert to the recommended routes.

2.3.6.1 Prescriptive vs Descriptive (Advice vs Information)

Research has indicated that drivers respond differently to traffic information depending on whether it is prescriptive or descriptive, i.e., information about traffic conditions only or guidance (e.g. advice on the best alternate route). Several authors found that responses to prescriptive and descriptive information varied with the context and drivers' characteristics such as age and gender.

Bonsall and Parry (1990) and Bonsall and Hounsell (1994) reported that regular drivers preferred descriptive information to prescriptive information because they did not want to allow their route choice decision to be controlled by a machine and they believed they themselves could make better decisions than those provided by real-time information.

Bonsall *et al.* (1991) and Schofer *et al.* (1993) reported that when drivers were unfamiliar with the networks, they might be more willing to use prescriptive information, i.e. guidance, while drivers in familiar areas preferred to use descriptive information about traffic conditions in order to make their own route choices.

Khattak *et al.*(1993b) and Bonsall (1995) reported that descriptive information i.e. information without advice was likely to have more impact on route choice than prescriptive information, i.e., only guidance. However, Bonsall (1995) suggested that if prescriptive information was given with the reasons for that advice, it might be more effective than either of them.

Researchers have found that drivers were more willing to divert in response to a combination of prescriptive and descriptive traffic information than either of them separately (Mannering 1989; Mahmassani *et al.* 1990; Bonsall 1991; Khattak *et al.* 1993b).

2.3.6.2 Qualitative vs Quantitative Information

Schofer *et al.* (1993) reported that qualitative descriptions of congestion information, such as " jammed" or "operation at posted speed limits", were less likely to influence route choice than quantitative information, giving estimates of travel times in minutes. Khattak *et al.* (1993a and 1993b) also suggested that quantitative and specified length of delay information was useful to drivers and that drivers might be more likely to accept and respond to more detailed and accurate traffic information. Wardman *et al.* (1997) also reported that when information about the length of delay is specified, i.e., quantitative, it has more impact on route choice than unquantified and qualitative delay information. Mast and Ballas (1976, quoted in Bonsall 1995) discovered that when the extent of expected delay was quantified and delay was severe, drivers were more likely to change their route as a result of receiving information.

Wardman *et al.* (1997) reported that when drivers received qualitative and unquantified delay information such as "long delays" or "delays likely", they valued "long delays" at between 35 and 47 minutes and "delay likely" at between 10 and 31 minutes depending on the cause of delay. This is consistent with Bonsall and Merrall (1995) and Bonsall and Palmer (1995).

Wardman *et al.* (1997) reported that the effect of "all clear" VMS messages on route choice were different from that of a "blank" sign indicating nothing about road conditions. Firmin *et al.* (1997) reported that 27% of respondents prefer a blank sign compared to 17% respondents wanting a message saying "no information" when no information is available. But 56% want some other type of information, such as displays showing the speed limit, time of day, or general traffic conditions (Light or Heavy).

2.3.6.3 Pre-Trip vs En-Route Information

Adler and McNally (1994) categorised the travel decision making process into three stages; pre-trip planning, enroute decision, and post-trip evaluation. The first stage involves selection of journey purpose, destination, departure and desired arrival times and initial route choice. The second stage involves enroute decision making as travel conditions are evaluated and the initial decisions are modified. This may include route change, changes to activity patterns and revision of travel objectives. The final stage, post-trip evaluation is where drivers update their knowledge based on experience from the trip and update their perception for future trips.

The timing of providing information, i.e. the stage at which information is given, is important and has different impacts on drivers' behaviour because each stage has different objectives which it attempts to achieve.

Polak and Jones (1993b) suggested that when information was given a higher position in the decision making process, it was more likely to influence various dimensions of behaviour, most influence being achieved when it is provided.

Bonsall *et al.* (1991) reported that many respondents were not interested in pre-trip information for every day trips, particularly if they had to get up earlier to get it, while they were very willing to receive updated information during their journeys.

2.3.6.4 Static and Dynamic Information

Schofer *et al.* (1993) reported that responses to traffic information varied depending on whether information was static or dynamic. Static information e.g. the location of shops or tourist sites, does not account for the current traffic situation but may help destination decision, while dynamic information such as details about accident information, involves real time information on traffic conditions which may have an influence on route diversion. Bonsall *et al.* (1991) reported that dynamic information was more likely to influence drivers' behaviour than static information and that most respondents said they preferred either dynamic pre-trip information or dynamic en-route information.

2.3.6.5 Length of Delay and Value of Delay Information

Several researchers have found that drivers are more likely to divert when the length of delay is reported on their usual route increase (Huchingson and Dudek 1979; Mannering 1989; Mahmassani *et al.* 1990; Khattak *et al.* 1991, 1993a and 1993b).

Huchingson and Dudek (1979) found that the relation between length of delay and diversion could be plotted as a S-shaped curve, in which few drivers were willing to divert in response to minor delays and most drivers were willing to divert as a result of long delay, i.e. between 30 and 60 minutes. Khattak *et al.* (1993b) found that drivers were significantly more likely to divert if the expected delay was at least 20 minutes, which means delay threshold is 20 minutes. They therefore recommended that diversion information should only be given if the threshold is approached or reached rather than for every minor delay. Wardman *et al.* (1997) found that respondents become increasingly sensitive to delay time as it increases, that is, the value of expected delay time increases as the amount of delay time increases, at least within the range of delay times between 5 and 30 minutes. Bonsall and Merrall (1995) also found that as the length of delay increased, the effect of information tended to be greater.

Previous studies, reviewed by Wardman *et al.* (1997), have found that delay time was valued more highly than free flow time and a number of ratios have been calculated, e.g. 1.43 from Wardman (1991), 1.39 from Oscar Faber TPA (1992), 1.7 for commuters and 1.0 for other journey purposes from Hensher *et al.* (1990). Wardman *et al.* (1997) also found that additional delays on the VMS were valued more highly than normally expected travel time. They suggested that this was probably the result of the uncertainty, stress, frustration and the worse driving conditions involved.

2.3.6.6 Cause of Delay

A number of researchers (e.g. Khattak *et al.* 1993b; Bonsall 1995) have found that when the delay information is given with the cause of delay, it tends to be more influential on drivers' route choice than without it.

Khattak *et al.* (1993b) suggested this may be result of car commuters' initial route choice being based usually on recurring congestion, when delay is caused by other reasons, such as an accident rather than recurring congestion, it makes them react to information differently. Bonsall (1995) also reported that when the information includes details about the length of the delay and advice about what the driver should do, it has more impact on route choice than information about the length of delay and the cause of the event.

Many researchers (Khattak *et al.* 1993a; Bonsall 1995; Bonsall and Merrall 1995; Bonsall and Palmer 1995; Wardman *et al.* 1997) have investigated the ways in which different information about causes of delay has different effects on route choice. Usually four specified causes of delays were included such as road works, congestion, accidents and no reason given. The common findings were that responses to delay information caused by an accident was expected to be greater than those to congestion caused by traffic or road works, while delay information with no cause of delay information has the least influence on route choice.

2.3.6.7 Information Format: How to Present

Previous research has shown that the way in which information is presented may have a significant influence on the respondent's route choice. Schofer *et al.* (1993) and Dudek *et al.* (1983) reported that drivers preferred concise messages rather than a conversational style. He also reported that some drivers are likely to find map-based information more useful than others.

2.4 Summary and Implications for This Study

This chapter has reviewed the concept and purposes of ATIS. ATIS provides drivers with fast and reliable traffic information and aims to improve drivers' decision making process and to increase the overall efficiency of the entire network. Understanding drivers' response to traffic information is important for assessing the benefit of ATIS and for designing and controlling the systems.

Drivers' responses to traffic information were found to vary depending on drivers' individual factors, systematic factors which related to the traffic information systems and road systems, as well as the characteristics of the traffic information.

Female and older drivers were less likely to be influenced by traffic information on their route choice. When drivers are familiar with the current network, they are less likely to change their route choice as a result of traffic information and prefer to make their own decision based on the information provided and their experience. As the overall journey time increases, drivers are more willing to divert routes as a result of traffic information. Shoppers are more sensitive to traffic information, while commuters are less likely to be influenced by it. Those who listen to radio traffic information more are more willing to change their route as a result of the information.

The responses to traffic information vary, depending on the preferred and intended route choice (usually motorway is more preferred than surface route). Drivers generally are more likely to change their route as a result of traffic information rather than by their own observation of traffic condition ahead. Reliability of information is also very important to the responses to traffic information. The more reliable traffic information, the more willing are drivers to accept and follow the information. When drivers have good experience with traffic information from previous journeys, they are more likely to accept and be influenced by it. The amount of detail provided also influence drivers' responses to traffic information.

This study will investigate the effects of drivers' individual factors on their response to information, particularly that responses segmented by their sex, age and income levels and explores drivers' response to the combination of traffic information and road user charge. Drivers' experience with traffic information and their perceived usefulness of it will also be considered in analysing results. According to the literature, drivers' responses to traffic information also varied depending on the purposes of journeys. One of the main purposes of a road user charge is to tackle the congestion problem usually during the morning peak time and commuters will be the most affected by the charges. Therefore, in this study, mainly commuting trips will be considered.

The extent to which responses to traffic information vary depends on the characteristics of the traffic information. Quantitative information has more influence on route choice than qualitative information. Pre-trip information is more likely to have an influence in various dimensions of behaviour, while drivers are more willing to receive updated information during their journeys. As the expected length of delay increases, drivers are more likely to divert as a result of information. When the cause of delay or the reasons for the advice is given with the delay information or advice, information is more effective than without it. Information about the delays caused by an accident has been found to be most influential on route choice. Those who are familiar with the network prefer descriptive information, while unfamiliar drivers are more willing to receive prescriptive information. Drivers also preferred concise traffic information rather than in a conversational style.

The timing of providing information i.e. pre-trip information or information during the journey was seriously considered in this study. However, it was decided to examine only information provided during the journey. This is because including two types of information makes the experiment design too complicated, considering it is already very much complicated by combining traffic information and road user charges in a study. Also providing the information during journeys make it easy and simple to observe drivers' response to traffic information directly while pre-trip information gives an effect in various dimensions.

This study will investigate the extent to which the amount of delay information affect drivers' route choice and the way in which drivers evaluate the value of information concerning delay time. The effect of providing information about the cause of the delay on route choice will also be explored in this study. The details of the design of the experiment will be described in chapters 4 and chapter 5.

Chapter 3

Review of Road User Charges

3.1 Introduction

The idea of pricing the use of the road has a long history. For example, many of the early turnpikes of the late 17th and early 18th centuries were built as private toll roads. United States, in the 1940s and 1950s, numerous toll roads were built to finance expensive bridges or tunnels. Road pricing has traditionally been used to raise revenue for the construction or upgrading roads.

Recently, since traffic congestion has become serious, and public have become increasingly concerned about the environmental problems caused by traffic, road pricing has increasingly been seen as a means of managing traffic congestion and air pollution. Therefore, it was suggested that any charge should be related to the use of the road and the contribution of driver to traffic congestion. In this way, the basic objectives of road pricing and the number of charging methods have been extended. This has lead to the development of more advanced forms of road user charges such as time-based charge, distance based charge and congestion based charge and to the development of relevant technologies such as electronic road pricing and smart cards.

One of the purposes of this study is to investigate drivers' response to variable road user charging. It is necessary to have a basic and general understanding about the concept of road user charging, objectives, and charging methods. Examples have therefore been given of road user charges which were either implemented or researched. This chapter aims to give a background understanding about road user charging, and so provide the basis for designing a methodology to investigate responses to road user charging.

Section 3.2 describes the definition of road user charges used in this research, as well as the theoretical background and objectives of road user charges. It also summarizes the various charging methods. This section justifies the choice of the kind of charge to be used in the study. Section 3.3 and 3.4 briefly summarizes the main examples of cities where road user charges have been implemented or where their implementation is planned. These give an idea about the current stage of road user charge in practice and the current stage of development in related technology. Section 3.5 reviews findings from previous studies about the responses to the various road user charges systems. The responses to road user charges can be categorized into three common issues; the influence on travel pattern, willingness to pay and acceptability. This section will give an indication of which responses to investigate in order to investigate the effect of road user charges in this study.

3.2 Road user charges

3.2.1 Definition of Road User Charges

Various terms for road user charges are used in the literature, for example, road user charges, road pricing, and congestion pricing.

Milne (1992) defined the general concept of **road user charges** as any fiscal form of traffic restraint which affects the mode, time, route, destination of frequency of journeys.

Lewis (1993) and Ison (1996) defined a **road user charge** as a generic term to cover indirect charges and direct charges. Indirect charges include purchase tax, annual license, taxes on tyres, fuel and so on, while direct charges involves monitoring the actual time or distance of vehicle travel and charging appropriately such as cordon pricing.

May (1992) defined **road pricing** as charges which are levied on drivers in order to correct the difference between the marginal social cost and the marginal private cost of the journey.

Gomez-ibanez and Small (1994) defined **congestion pricing** as a particular form of road user charges which imposes higher charges on drivers who cause congestion directly based on the amount of road use.

'**Road user charges**' is the broad term referring to any methods of charge, while '**road pricing**' is specific to the charge which is relevant to road use and '**congestion pricing**' is more specific because it focuses on reducing congestion.

3.2.2 Objectives of Road User Charges

The initial objective of road user charges was to raise revenue to fund transport project such as the construction of roads. The practical objectives of road user charges have been developed and extended. The objectives of road user charges can be categorized as follows (May 1992; Milne 1993).

- to raise revenue for funding other transport policies
- to reduce congestion and to improve efficiency of the road network
- to reduce environmental impacts such as all impacts of noise and vibration, primary pollutants (e.g. carbon monoxide), visual intrusion, severance and danger of accidents.
- to improve accessibility and to help to revitalize urban areas.
- to redistribute road network space more equitably between private cars and road-based public transport.

These various objectives lead to different designs of road user charge systems and consequently different performance. The Norwegian toll rings in Bergen, Oslo and Trondheim have been designed to raise revenue for new road projects and public transport investment. Examples including the Singapore Area Licensing Scheme, the proposed Hong Kong Electronic Road user charges system and early studies in London were designed to reduce congestion. The case of proposals for the Randstad and for Stockholm have been focused primarily on environmental improvements, as well as congestion relief and revenue raising for transport project (May 1992; Milne 1993).

3.2.3 Types of Road User Charging Methods

The Smeed Report (Ministry of Transport 1964) and Milne (1992), indicated the inadequacies of the current indirect system of user charges and identified nine criteria for the design of road pricing systems. The report suggested that in contrast to the current indirect system, charges should be closely related to the amount of use of the roads and levels of congestion. It also suggested that charges should vary depending on the different roads, different times of day, week or year and on different classes of vehicle involved.

However, in the past, the availability of suitable technology has imposed constraints on the way the charges are levied. Although ideally, drivers should be charged continuously, based on the amount of road use and levels of congestion, such as by the distance they travel in a charged area or by the time they spend traveling in it. In practice, the lack of suitable technology has meant that this has not been implemented. Instead simple charge methods such as point pricing or cordon pricing have been used.

However, recently technical development related to road-pricing may make an ideal road user charge possible, whereby charge levels are decided depending on the current road conditions. For these charging system, various methods have been studied to determine the charging levels. These have included time spent driving, distance driven or time spent driving under congested conditions.

The development of road user charges in terms of technology is beyond the scope of this study but has been considered by Milne (1992). The following sub-sections introduce several kinds of road user charging based on the way the charge is levyed or of measuring the amount of use of the road system. They are based on categories in Milne (1992).

3.2.3.1 Extension of Existing Charging

In 1982 Hong Kong increased the existing car ownership taxation in an attempt to reduce congestion. In Singapore, vehicle purchase tax and vehicle licensing were used in order to reduce vehicle use by constraining ownership. These methods were criticized because these were not related to the amount of road use and did not vary the charge rate by time and location (May 1992; Milne 1993).

Another approach is to increase the amount of tax on fuel and thus reduce the amount of vehicle use, to reduce carbon dioxide emissions. However, this approach is criticized because it does not vary by time and location and it would affect the unnecessary trips such as off-peak and leisure journeys (Lewis 1993; Milne 1993).

3.2.3.2 Supplementary Licensing

Supplementary licensing is an extension of conventional vehicle licenses, but allows the charge to vary by the time of day and by location. In this scheme, drivers must buy an additional license to travel within a charged area defined by a cordon. Charge rates can vary by time of day, by direction and vehicle types. This systems was proposed for London in 1974 and applied in Singapore, and will be discussed later in section 3.3. Because it is also defined by cordons, May (1992) categorized supplementary licensing as a form of cordon charging.

3.2.3.3 Cordon Tolls

This is the most common charging type. It has been implemented in several cities e.g. Bergen, Oslo, Trondheim, and will be discussed later in detail in section 3.3. This type of charge is directly related to the number of boundary crossings or specified points passed (cordons) by the driver. In this system, the charge may vary by the time, direction of travel and vehicle type. This charging system has been criticized as being inflexible and inequitable, however, because it imposes the same charge on long or short journeys regardless of the amount of road uses and because it applies not to the journey within cordon, while it is applied to even a short journey just across boundary (Milne 1993; Smith *et al.* 1994; MVA 1995).

3.2.3.4 Distance-based Charges

Distance-based charging relates to road use but not to congestion levels. In this system, a charge is directly proportions to the distance traveled within the charged area (May 1992; May *et al.* 1994). The advantage of this system is that charges would be predictable based on route choice and there would be no incentives for aggressive driving, such as driving faster. There would be no question of unfair charging due to unavoidable congestion such as an accident or road works on the network (MVA 1995). However, this type of charging is not strictly related to congestion levels. This system was proposed for Cambridge in 1993 (Milne 1993) and in the London Congestion Pricing Scheme in 1995 (MVA 1995).

3.2.3.5 Time-based Charges

In a time-based charge system, the charge is directly proportional to the time spent traveling within a charged area (MVA 1995). Time-based charging can be categorized as road pricing and congestion pricing, because it is directly related to the road use and to the congestion levels.

A time-based scheme was proposed for a pilot experiment in the London Borough of Richmond. This system employed TIMEZONE microwave beacons, an in-vehicle unit and smart card technology. The in-vehicle meter is switched on and switched off as the vehicle crosses a cordon. The price per unit time can be varied depending upon time of day, day of week, location, vehicle type and vehicle activity (May 1992; Milne 1993; Smith *et al.* 1994a).

This system has been criticized by several authors (MVA 1995; Collins and Inwood 1996) for a number of reasons. First, it would encourage drivers to speed. Bonsall and Palmer (1997) studied this issue using a driving simulator and concluded that drivers were indeed likely to take more risks when they were subject to time-based charges. Secondly, it would be difficult for drivers to predict charges, which may result in perception of unfairness. Finally, it would be unfair if a charge was levied due to unavoidable incidents such as accidents or road work (MVA 1995).

3.2.3.6 Congestion-based Charge

Congestion-based charging, also called 'time-in congestion charging' or 'delay-based charging' (Smith *et al.* 1994), is similar to the theoretical concept of congestion pricing. In this system, the charge is related to the congestion caused by each driver and is levied depending on time spent driving in congested conditions. The charge would vary according to traffic conditions, both across the charged area and by time (May 1992; Milne 1993; Smith *et al.* 1994). This system was proposed in the Congestion metering in Cambridge in 1993 (Gomez-Ibanez and Small 1994; Ison 1996). However, the concept has attracted similar criticisms to those outlined above for time based charges.

3.2.3.7 Implication for the Study

In this study for the sake of simplicity, the term 'road user charges' will be used throughout, unless a more specific type of charging is being described. The road user charges being studied will be related to the amount of road use and to congestion levels.

Smith *et al.* (1994) compared the network effects of four road-user charging systems in the Cambridge network and suggested congestion-based charging would have the best effects in terms of relief of congestion. They ranked the four charging systems in the order: congestion-based charge (best), time-based charge, distance-based charge and tolls (worst). They concluded that congestion-based charging reduces congestion substantially at comparatively low levels of charging, that time-based charging is much more effective when demand is elastic and that distance-based charging discourages through traffic and encourages traffic originating within the charge area to make use of the longer unpriced orbital route.

The charges that become under time-based charging and congestion-based charging depend on the amount traffic condition. These methods have been criticized because it would be difficult for drivers to predict the charge accurately. This could be compensated for by providing charge information. There is no need to provide charge information under Supplementary Licensing or Cordon charging because the charges under these methods are extremely predictable. Distance based charging would produce fairly predictable charges and might or might not need information to be given.

3.3 Implementations of Road User Charging

The previous section described the concept of road user charging, its objectives and the charging methods. This section will introduce examples of road user charges. Even though a considerable amount of research about road user charges has been undertaken, actual implementation has been very limited and there is no application of congestion pricing. The objectives of road user charging in Norway is to raise revenues. The objective in France is to raise revenues and to reduce congestion and the objective in Singapore is to reduce congestion. Oslo introduced electronic pricing, and Trondheim has a completely automated toll collection system with variable charging rate.

3.3.1 Singapore : ALS (Area License Scheme) and ERP (Electronic Road Pricing)

Singapore was, in 1975, the first city to introduce road user charges on a large scale. The objectives of this scheme were to reduce congestion and improve public transport by restraining traffic flows at peak periods into or through the central business district (Lewis 1993).

The scheme was an Area Licensing Scheme (ALS) in which vehicles were required to purchase and display a special paper license on their windscreens whenever entering the city's central area (restricted zone) during charged hours. The boundary of the restricted zone was drawn up to include areas with congestion problems and a major arterial which was a bypass route. The charges applied only to vehicles carrying fewer than four persons and taxis. Charges were levied only during the morning from Monday to Saturday. To provide alternatives for motorists, bus service to the central area was increased. Parking charges were also raised in the central area (Holland and Watson 1978). ALS has proved to be flexible, simple, and a successful and economical method of traffic restraint (Gomez-Ibanez and Small 1994).

As indicated above, ALS was started in 1975. In 1989, the restriction period was extended to include an afternoon rush hour and the exemption for car pools was abolished. There were further extension of the restricted hours in 1994. In 1995, a Road Pricing Scheme (RPS) was started on the East Coast Parkway (ECP), one of the busiest expressways in the city and was extended to two more expressways, the Pan Island Expressway (PIE) and the Central Expressway (CTE) in 1997 (Clark 1998). A further 35 charge points are being set up on the CTE, PIE and all around the CBD on 1 September, 1998.

The first trial for Electronic Road Pricing (ERP) in Singapore tool place in 1990 and, since 1st April 1998, vehicles have been charged using ERP. Singapore's ERP scheme is the most sophisticated in the world. Vehicle simply pass under gantries at up to 120 km per hour and the system automatically identifies the vehicle and deducts an appropriate amount of charge from the user. At present electronic road pricing fees are only charged on the East Coast Parkway (ECP) into the city between 7:30-9:30 a.m. on week days. Tolls are varied according to the time of days to the ECP (Clark 1998).

Since the introduction of ERP at the start of April, traffic volumes have dropped by about 15% at the first two gantry points on the East Coast Parkway (ECP). The average traffic speed has raised to around 50-60 km per hour whereas before it was often as low as 30 km per hour (Clark 1998).

3.3.2 France : Motorway Tolls

In France, a point road user charge was introduced on the motorway between Paris and Lille in 1992. This part of motorways was seriously congested by the traffic returning from the countryside on Sunday afternoon and evenings. The objective of this scheme was to reduce congestion rather than to raise revenues. Tolls are collected through a closed ticket system in which motorists receive a ticket on entering and pay their toll when returning the ticket at the exit. Toll rates were higher during the peak hours (from 4:30 to 8:30 p.m.) on Sunday than before and after the peak hours[1]. Toll rate were also approximately 25 % higher than the normal toll rate for longer trips and as much as 25 to 56 % higher for shorter trips. Before and after the peak hours, the toll rate were reduced by 25 to 56 % (Gomez-Ibanez and Small 1994).

[1]There are two charging periods: red period with high charging is from 2:30 to 4:30 and 8:30 to 11:30 p.m. and green period at all other times, when the charging level is 25 to 56 % lower than those of the red period.

After implementing this scheme in 1992, the variable toll scheme has distributed traffic flows more uniformly over the Sunday afternoon and evening hours. Traffic declined during the peak period, while it increased before and after the peak period. This case could be seen as a good example of efficient reallocation of peak traffic in favor of those for whose value of time is high, and it proved that the theoretical benefit of road user charging could be achieved in reality (Gomez-Ibanez and Small 1994).

Motorway toll scheme was also tested in other section of motorway into Paris (A5, A6 and A10). However, the scheme had to be canceled because drivers found the variable charges confusing (Fournier and Monsigny 1998).

3.3.3 Bergen: Toll Ring

Bergen was the first Norwegian city to introduce road user charges. A new tunnel bypass, the Flowfjells Tunnel, was constructed around Bergen and opened in 1986 in order to improve access and traffic flows. To finance this and other main roads to and from the city, tolls were introduced on routes leading into the city (Larsen 1988; Lewis 1993).

The toll system operates from Monday to Friday between 6 am to 10 p.m. for all traffic entering the city. The toll rate is fixed per vehicle and there is a reduction if tickets are pre-purchased. There are six toll collection points located on the boundary of the city. Toll collection was entirely manual via cash payment or prepaid ticket or monthly pass through the toll booths (Larsen 1988). Bergen's tolls reduced weekday traffic growth slightly despite the low level of the charge (Gomez-Ibanez and Small 1994).

3.3.4 Oslo: Toll Ring

Oslo was, in 1990, the second Norwegian city to implement a toll ring. It was the first to introduce electronic pricing on a massive scale for a large metropolitan area

(Gomez-Ibanez and Small 1994). The main objectives of the Oslo toll ring were to raise revenue to finance main road projects in Oslo and to improve traffic condition for public transport and pedestrians (Lewis 1993).

There is a single cordon at the boundary of the city. Toll collection points are installed at each road crossing and a low and fixed charge is levied on for all vehicles entering the city for 24 hours per day (Gomez-Ibanez and Small 1994). There are three options for payment: manual collection by an attendant, payment to a coin machine and electronic payment. In the case of electronic payment, the toll was charged to a driver's account via a transponder and an AVI (Automatic Vehicle Identification) system (Thorpe and Hills 1992).

The impact of the Oslo toll ring on traffic has appeared to have been quite small. The analysis of effects of the Oslo toll ring suggested that the toll might have reduced crossings by 5 to 10 %. However most of this reduction was during off-peak periods, which implied that mainly non-work trips were eliminated or diverted (Gomez-Ibanez and Small 1994).

3.3.5 Trondheim: Toll Ring

Trondheim was the third largest city in Norway and the third city to introduce a toll ring system around its central area in 1991. The objective of the toll ring system was to raise the funds for a package of road and public transport improvements (Gomez-Ibanez and Small 1994).

Trondheim's system was a cordon toll ring. Small traffic volumes made it possible for most of toll collection systems to be completely automated. Drivers could either pay at a coin machine or enroll in one of several electronic payment schemes that allow subscribers to pass through the toll plaza without stopping (Lewis 1993).

Tolls rates are highest during the peak from 6 am to 10 a.m., slightly lower from 10 am to 5 p.m. and there is no charge after 5 p.m. or at the weekends. Frequent users can get a discount up to 40 % in peak periods (Thorpe and Hills 1992, Gomez-Ibanez and Small 1994).

In order to investigate the effects of the toll ring panel surveys were conducted before and after its introduction in 1990 and 1992 (Meland and Polak 1993). This research indicated that the overall impact of the toll ring on travel behavior seemed to be quite small, and the majority of drivers perceived their travel behavior to have been unaffected by the toll ring. Some significant changes in travel behavior, however, were observed across different trip purposes. A large number of respondents living outside of toll the ring changed their behavior as a result of the toll ring: 20 % in the case of work trips, 45 % for shopping trips, and 35 % for other trips.

3.4 Preimplementation / Planning Studies

Several cities have considered implementing road user charges serious and have developed or piloted detailed charging schemes and/or relevant charging technology. Examples include Hong Kong, Stockholm, Randstad, London, Cambridge, Bristol and Leicester. The charging schemes developed for these cities were generally more complex and sophisticated than those which have so far been implemented. The effects of the road user charging schemes were studied by modeling, surveys and/or field trials. Some of the schemes were subsequently rejected particularly for reasons such as public unacceptability or invasion of privacy.

3.4.1 Hong Kong: ERP (Electronic Road Pricing)

In Hong Kong, an Electronic Road Pricing (ERP) Pilot Scheme was evaluated between 1983 and 1985. The objectives of this pilot scheme were to assess the viability of introducing a comprehensive electronic road pricing scheme on a large scale (Hau 1990).

The technology of toll collection for the Hong Kong system was based on automatic vehicle identification with an electronic number plate (ENP) (Milne 1993). All vehicles were fitted with electronic number plates, by which they could be identified as they passed a set of loops buried in the carriageway. There were a series of cordons for the charge area (the commercial districts on the tip of the Kowloon Peninsula and the north shore of Hong Kong Island). Three alternative cordon schemes were tested and different charge levels were evaluated while charge rates varied by the vehicle type, location and time of day. A charge was then added to the vehicle's account and the owner would receive a bill at the end of each month which specified his use of the road network (Catling and Harbord 1985; Gomez-Ibanez and Small 1994).

The predicted effects of these schemes by travel simulation models were that the three ERP schemes would reduce car trips by between 9 % and 13 % all day, and by between 20 % and 24 % in the peak period. In addition to simulation studies, several months of field trials were also undertaken. ENPs were installed on 2,500 vehicles owned by government agencies, by private individuals and by firms who volunteered to participate. It was proved that the ERP schemes were technologically feasible (Harrison 1986; Gomez-Ibanez and Small 1994).

The proposal was ultimately rejected principally for political reasons - that Hong Kong was to be "returned" to China in 1997. The second concern was about the confidentiality of electronic records on toll road use and the question of the perceived invasion of privacy due to monitoring vehicle movement which were also photographed for enforcement purposes. The third was the decline of economic growth in Hong Kong at that time (Hau 1990).

A new study about feasibility of Electronic Road Pricing (ERP) started in March 1997 and will be completed in June, 1999. The objectives of this study are to assess the need for ERP in Hong Kong and to examine the practicability of implementing ERP in Hong Kong. There are two preferred technology options: vehicle positioning systems (VPS) and dedicated short range communications (DSRC) (Catling 1998).

The vehicle positioning systems technology uses a combination of vehicle positioning and cellular communications to charge tolls. The DSRC will test microwave DSRC at 5.8 GHz. To test the performance of the system in real traffic conditions, a number of hired vehicles will be mixed into the local traffic and test the performance of four DSRC sites in real traffic. The field trials started in June 1998 and are being carried out to test whether the technologies will work in the urban environment of Hong Kong. Testing should be completed by early 1999 (Smith W. 1998).

3.4.2 Stockholm: Toll Ring

It was planned to implement a toll ring in Stockholm in 1997. The purpose of this system was primarily to reduce environmental problems. This includes reduction of pollution, reduction of congestion and improvement for buses and for pedestrians rather than on raising revenue (May *et al.* 1991).

The system proposed that every vehicle entering the city would be required to purchase a tagged license to travel within the central area of Stockholm. The charge rates would vary by time of day and by type of emission control on the vehicle (Lewis 1993).

Stockholm Streets and Traffic Administration conducted a simulation study which investigated the effects of a toll on mode, route choice and degree of congestion. The results reported that tolls would increase speeds, but reduce car use and the toll ring would reduce the number of cars in inner Stockholm by inducing them to travel on the bypass routes (Gomez-Ibanez and Small 1994).

Implementation of the scheme was canceled in 1997 for political reasons. However, Stockholm is considering the feasibility of a wide area charging systems using GPS or GSM technologies (Blythe 1998).

3.4.3 Netherlands : Randstad

The Netherlands also considered various forms of road user charges to reduce congestion in a growing metropolitan area of Randstad, which includes the nation's four largest cities - Rotterdam, Amsterdam, Hague, and Utrecht (Lewis 1993).

The objective of this proposal was to cover the cost of operating the system and to raise revenue for privately funded tunnels. The toll rates would vary by time of day and would make use of recent developments in smart card technology (Gomez-Ibanez and Small 1994).

This proposal was rejected as a result of doubts about the reliability of the new technology and concern about the question of invasion of privacy. Instead of it, a new plan was proposed which introduced some toll stations on interurban roads (May *et al.* 1991). There were several options in addition to the basic toll scheme, these have a supplementary license scheme, new highway lanes for freight and high-occupancy vehicles, and private funding of new road tunnels. Even though there were several plans and studies, these were all rejected for the political reason.

3.4.4 London

London has been considered for road user charges since 1960s, but no scheme have been adopted in practice yet. This section will outlines the key research into road user charging in London in chronological order.

The Greater London Council considered introducing supplementary licensing to London for restraining traffic in 1970s. Each driver would have had to buy a daily license to travel within a charged area during the working day. Simulation studies were conducted using the network model CRISTAL. The results showed that such a scheme would generate economic and environmental benefits and produce much revenue as a result of a change of travel behavior which would reduce congestion levels. The proposal was rejected as the result of perceived unfairness to lower income groups, the effects of diverted traffic, ability to enforce the display of a license and the potential impact on the central London economy (Gomez-Ibanez and Small 1994).

The Greater London Council was succeeded by the London Planning Advisory Committee (LPAC) in 1985. Under LPAC, road user charges studies were carried out by MVA using a regional model, called as the London Area Model (LAM) (Gomez-Ibanez and Small 1994). Several scenarios were assessed for analyzing the effects of road user charges, road investment and transport policy.

LPAC also carried out Scenario Testing Exercise (TASTE III) based on the model, called the London Transport Studies (LTS) model. This study, called "Strategic Advice Scenario", was conducted to compare the effects of the Government policy with those of LPAC. Three cordon rings and the charge for crossing a cordon or screen line were assessed. The results of this comparison indicated that the road user charges would reduce traffic levels by 40 % in Central London and by 30 % in Inner London (May *et al.* 1990).

The additional analysis of the Strategic Advice Scenario was undertaken with a strategic model known as START developed by the consultants MVA (Fowkes *et al.* 1993). The effects of road user charges were analysed with cordon fees and the results were that road user charges would reduce daytime traffic flow in the Central Area by 22 % and increase peak speeds by nearly 25%.

The survey about the attitudes towards road user charging in London was carried out in 1991 by the Harris Research Centre on behalf of the National Economic Development Office, the London Planning Advisory Committee and the Automobile Association (Harris Research Centre 1992). The questionnaire was asked to 500 Londoners. The results indicated that road user charging on its own would not be acceptable to the majority of people in London. However, as part of a package of policy measures, and as a source of funding for them, it would be acceptable to the majority.

The most elaborate and large scale study about road user charges in London was undertaken for 3 years (completed in 1995) in order to assess the practical feasibility of implementing road user charges within the M25. The program covered the transport, environmental, social, economic and financial impacts of road user charging, as well as the related technology. Transport model, APRIL (Assessment of Pricing of Roads in London) was designed to estimate the demand impacts of congestion charging. To evaluate the potential interaction between congestion charging and other transport strategies, tests were also undertaken with congestion charging and possible transport strategies (MVA 1995).

3.4.5 Cambridge: Congestion Metering

The city of Cambridge is the first place to carry congestion pricing close to its theory. Congestion Metering was proposed for Cambridge in 1990 to solve congestion problems. In 1993, the field trial was undertaken. This was the first time that any form of road user charges had been demonstrated practically in the UK. The main objective of Congestion Metering was to reduce congestion and improve efficiency of the network by charging an amount directly related to the congestion on the route taken (Gomez-Ibanez and Small 1994; Ison 1996).

In this scheme, all vehicles within Cambridge city should be fitted with an electronic metering device. The meter would be connected to the odometer of the vehicle and would thus be able to monitor the level of congestion. The owner of the vehicle would be provided with a unique smartcard. Once inserted in the on-vehicle metering equipment, the smartcard would allow the vehicle to move. Outside the city cordon the meter does not work, but on entering the city, fixed beacons would activate the meter thus charging the user for each unit of congestion caused (Clark *et al.* 1994)

The on-board metering device would only start charging when a combination of speed and distance traveled indicated that the vehicle was in a congested situation. The congestion threshold could be defined to travel a distance of half a kilometer in a three minute, i.e. 10 km per hour, or a vehicle stopping more than four times in that half kilometer (Gomez-Ibanez and Small 1994; Ison 1996). When congested situations were experienced, the on-board monitoring device would deduct monetary units from the user's smartcard. Charges would be deducted from the balance contained in a prepaid smart card. Under this proposal, charges on a given vehicle would vary in real time to match the amount of congestion actually experienced (Clark *et al.* 1994).

In order to investigate the behavioral responses of road users to the introduction of road use pricing in Cambridge, both revealed and stated preference surveys were conducted in 1993 by the WS Atkins Planning Consultants, in association with the Universities of Newcastle and Leeds (WS Atkins Planning Consultants 1994). The results of this survey indicated that two-thirds of all respondents said that they would be able to re-time their trip as a result of charges. Since 1993, there has been no further development or moves toward implementation principally due to a lack of political support.

3.4.6 Leicester : Environmental Road Tolling Scheme (LERTS)

The city of Leicester have carried out Environmental Road Tolling Scheme, which examines the extent to which road pricing can contribute to traffic management strategies such as encouraging use of public transport and increasing awareness of environmental conditions. A key feature of the LERTS project has been to provide an attractive public transport alternative to car travel, including 300 space park and ride site, a dedicated bus service and a public transport priority route to the city centre (Tyler 1997).

The on-street trial started in 4 August 1997. A group of participants were primarily commuters who regularly journeyed into Leicester city centre. The trial consisted of a series of four-week scenarios. Different tolling scenarios applied in which the level of charge, length of tolling period and the park and ride charge varied. The amount of charges was decided depending on the actual time of the journey (Smith M. 1998).

Electronic road tolling systems and smartcards for the payment of toll and tickets for the park and ride service were used. Electronic toll station were installed on three roads on the A47 to detect the equipped vehicles on journeys towards central Leicester (Tyler 1997).

The time, date and identification of each vehicle movement were recorded and transferred to a central management system located in the city's Area Traffic Control Centre. The central management system also connected directly to variable message signs (VMS) for the output of data. Two VMS were installed on main approaches to the park and ride site and provided real-time information on travel and environmental conditions, and current tolling charges (Smith M. 1998).

After the on-street trial, the proportion of participants using park and ride service generally increases. The mean journey time for park and ride bus has been improved which is quicker than the mean car journey time and the journey time for a service bus on the route has also decreased. The LERTS trial has been successful in operating a demonstration of road tolling on a day-to-day basis in a congested urban area (Smith M. 1998).

3.5 Findings on Responses to Road User Charges

Section 3.3 and 3.4 have described the various cases of road user charges. Each case was different depending on the circumstance, objectives, technology and effects of road user charges. This section reviews the responses to road user charges. They were classified to three categories; influence on travel pattern, willingness to pay and the acceptability of road user charges.

3.5.1 Influence of Travel Patterns

In order to achieve the various objectives of road user charges, described in section 3.2.2, the success of road user charges is dependent on the extent to which road user charges influence on drivers' behavior. Although this is not the case if the only objective is to raise revenue. Therefore, most relevant studies investigated the way of which road user charges affected drivers' travel pattern.

A number of research (for example, Holland and Watson 1978; Harris Research Centre 1991; Meland and Polak 1993) were carried out by network modeling, SP survey, interview survey or field trials. The overall result of them was that introducing charges would have a significant impact on travel patterns and on levels of traffic congestion.

This section summarizes the influence of road user charges on travel patterns. These influences have been categorized into route shift, time shift and mode shift. These influence may be expected to be different depending on locations, and on whether it is based on real implementation or planned (hypothetical studies). Therefore, these effects will be described case by case.

3.5.1.1 Route Shift

In Singapore after the road charging was introduced, it was found that the route shifts were twice as important as mode shifts in accounting for the reduction in vehicle trips entering the zone by commuters. Commuters beyond the restricted zone are more likely to change routes to avoid passing through the zone than to shift modes (Wilson 1988). The percentage of car drivers commuting to jobs beyond the zone who passed through the zone declined from 88 % to 66% (Gomez-Ibanez and Small 1994). According to the study by Polak *et al.* (1994), after introducing evening charges in 1989, cross-town traffic was reduced, and traffic diverted increased significantly on the bypass road.

In the case of the French road user charge, the route shift was quite small and temporal effects. At first, there was a slight shift of traffic from the charged route A-1 to the main parallel route, national route N17. Such a shift was not observed after the variable toll scheme had been operating for a few months. This result is probably because the alternative routes are not expressway and because the toll increased with the distance, so to take the parallel route did not offer much benefit to the driver (Gomez-Ibanez and Small 1994).

Larsen (1988) reported that in the before and after study of Bergen toll ring the number of trips by cars to and through the CBD area decreased in 6 to 7 % during the period of charging. Detours to avoid the tollgates appeared to be quite small.

Lewis (1993) reported that as a result of introducing the toll in Oslo there was a decrease in the amount of traffic, and that most of these were the result of drivers who gave up trips or diverted to destinations that did not require crossing the ring

Meland and Polak (1993) reported in their before and after survey study of the Trondheim toll ring that many of commuters, who lived outside of toll ring mainly changed their route in response road user charges. Gomez-Ibanez and Small (1994) suggested that this scheme made it possible to use the other route to avoid charge because several toll stations were placed just outside a by-pass road.

Bonsall *et al.* (1998) found followings in their study about drivers' response to road user charges using route choice simulator. First, drivers are likely change their route, when charges can be avoided by diversion. Secondly charges based on journey time or time spent in congestion are likely to influence route choices. Finally, when a £1 charge was introduced, 84% of respondents chose the option to experiment with alternative routes to reduce the charge.

3.5.1.2 Time Shift

Previous research indicated that charging over a limit time period, or at different rates according to the time of day, results in a journey time shift as drivers attempt to avoid a charge or a high charge.

Holland and Watson (1978) found that the introduction of ALS in Singapore in 1975 reduced traffic dramatically in the morning peak and drivers tended to reschedule their trips to just before or after the charging period to avoid a charge. For example, when a charge was imposed between 9:30 a.m. and 10:15 a.m., the percentage of drivers who started their trip before 7:30 a.m. increased from 28 % to 42 % for those who worked in the restricted zone, and from 50 % to 60 % for those who worked beyond.

According to the Gomez-Ibanez and Small (1994), the time shift was also found to occur as a result of road user charges in the French toll schemes. A survey was conducted in 1992 at the Chamant toll barrier. The result of it revealed that about 20 % of drivers who traveled in before and after high charge period, said they had changed their time because of the lower charging rate. Even though so many people said they started their trip earlier, the traffic during this period did not grow much. The reason was that while some people traveled earlier to avoid congestion, others were willing to pay a higher charges because of reduced congestion levels.

Larsen (1988) and Lewis (1993) reported that there was a small shift in the timing of trips after introducing charges in Bergen. Traffic crossing the cordon during the charging period changed little over a 1 year period, while traffic during the uncharged hours increased about 10 %.

Meland and Polak (1993) showed in their before and after study of Tronhiem toll ring that the car commute trips during the charged period decreased, while car trips increased outside the charged periods. According to the Gomez-Ibanez and Small (1994), the time shifting in response to road user charge also results from the fact that many work and non-work drivers of Tronheim had flexibility over the time in which they chose to travel. Drivers were encouraged to change the time of day because the charging period ended at 5 p.m., which is just 1 hour after the end of the normal work day[2]. About 3 % of inbound home-to-work trips, 13 % of inbound work-to home trips, and 19 % of inbound shopping trips shifted in time to cross the cordon after 5 p.m.

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2 In Norway, ordinary working hours are 8:00 to 16:00 and flexible working hours are quite common

According to the simulation study for Hong Kong's ERP scheme (Gomez-Ibanez and Small 1994), about 6 % of drivers would change their travel times to avoid charge, while between 40 and 45 % of drivers would pay charges rather than change their behavior.

Polak *et al.* (1993) found in their survey of London charging that commuters were flexible, that is, they were able to shift arrival time 50 minutes earlier or 40 minutes later, and to decrease time at work by 1 hour or spend 2-2/3 hours more. Drivers on shopping trips or leisure trips are generally more flexible than commuters. The survey also revealed that London commuters had already shifted their arrival times at work by an average of 16 minutes in order to avoid congestion.

Polak and Jones (1993a) investigated the way in which drivers re-schedule their journeys in response to road user charges in London. The results revealed that in response to road user charges, drivers on commuting or business trips have more tight constrains on the timing of the destination activity than those on shopping or leisure trips. Drivers on work trip or business trip were more concerned about the start of the journey such as departure from home or arrival at the destination, while others on shopping and leisure are concerned about the end of the journey.

Results of the attitude surveys in response to road user charges in Cambridge (WS Atkins Planning Consultants 1994) indicated that about 31 % of respondents would reschedule their trip in response to congestion charging with 24 % still using their cars at the same time of day.

Bonsall *et al.* (1998) reported from the field trial that drivers are less likely to change time or route for the journey to work than for the journey back home. They also found that female were less willing to divert or change their time of travel than were males due to charges.

3.5.1.3 Mode Shift

After introducing ALS in Singapore, cars and taxis with fewer than four persons, which was the charging criteria declined by 75% and 83%, respectively, while carpool and trucks, which were exempt, increased somewhat (Holland and Watson 1978). The reductions in cars and taxi traffic were due primarily to travelers shifting to carpools and buses, and secondarily to travelers changing their routes and hours of travel. Among vehicle-owning households, the percentage of commuters traveling to work beyond the zone in cars declined from 47.5 % to 36 % (Gomez-Ibanez and Small 1994).

Polak *et al.* (1994) reported that as a results of ALS, the proportion of car trips decreased rapidly during the charged period, while the share of bus trips increased significantly between 1975 and 1983. It was suggested that this might be the result of an increase of employment in low paid service and tourism industries within the charged area. The proportion of motorcycles and car passengers also declined significantly between 1983 and 1991.

Larsen (1988) reported in the before-and-after survey of the Bergen toll ring that the number of cars which paid the toll per trip decreased by 41 % between 6 a.m. and 9 a.m. and by 35 % between 5 p.m. and 10 p.m. This was because regular car users for work trips switched to public transport to avoid the toll ring.

According to the Gomez-Ibanez and Small (1994), analysis of the panel surveys of Oslo observed the decline in cordon crossings was due to car drivers switching to carpooling, public transport, walking and bicycling.

Meland and Polak (1993) found that in the case of Trondheim about half of the commuters who changed their behavior in response to road user charges, changed their mode and said that it was only an occasional rather than consistent change.

In the case of London attitudinal study (Harris Research Centre 1991), it was indicated that most respondents would switch to public transport among off-peak travelers, a higher proportion of off-peak travel, compared with peak travel, would not have been made. The results of the stated preference survey in Cambridge in 1993 indicated that only about 17 % would switch their mode to public transport (WS Atkins Planning Consultants 1994).

Bonsall *et al.* (1998) found in their questionnaire survey results that the proportion of respondents who would use public transport was very low, but it increased from 6% to 12% when it was suggested that the revenue from charges might fund a reduction in public transport fares.

3.5.2 Willingness to Pay

One of popular issues in studies about road user charges is willingness to pay this charge. This section summarizes findings about the willingness to pay for road user charges based on experiences of several city.

A dramatic impact was caused by the introduction of ALS in Singapore during the morning peak on traffic flows which decreased the number of cars and taxis by 72%. Watson and Holland (Polak *et al.* 1994), estimated that this change implied that the (point) price elasticity of peak period car traffic is approximately -1.5 in Singapore. Drivers in Singapore indicated that further increases in the toll would induce dramatic changes in behavior. Meland and Polak (1993) suggested in their study that doubling the toll would increase revenue by only 28 % and cause traffic to decrease by 36 % during toll hours. Polak *et al.* (1994) reported in their stated preference survey that drivers had some flexibility in time of travel and they were willing to reschedule their trip about 11 minutes earlier or later in order to save \$ 1.00 in toll charge.

Research undertaken by the Harris Research Centre (1991) into the attitudes to road user charges in London reported the results of willingness to pay a charge in detail.

Three levels of charges were introduced in the study; 50 pence, £2 and £5 per hour. If a £5 per hour charge was introduced in Central London in the peak, about 50 % of people said they would switch to public transport to avoid it. At a £ 2 per hour charge, 45% of people would remain in their cars, 34% would switch to public transport and 11 % would go by car at another time of day. At 50 pence per hour, 73% would remain in their cars, with 14% switching to public transport. These findings indicated that a relatively small amount of charge for road use could influence behavior and the response would vary as the charge increases. It also indicated that varying charge rate might be successful in switching drivers from the car to other modes.

According to Gomez-Ibanez and Small (1994), the willingness to pay a charge in London is different depending on the charge period i.e. peak time or off-peak time. As with the Central London journey, people seemed slightly more willing to pay for off-peak rather than peak travel at the low charges. This might reflect the reduced availability of public transport alternatives at off-peak rather than peak times. Response to charges in the off-peak in Central London was more remarkable because demand for travel at these times is more price sensitive. Not making the journey becomes an important response to road user charges.

The response to road user charge is also expected to be different depending on social-economic characteristics. According to research about effects of sex and income on drivers' willingness to pay (for example, Harris Research Centre 1991; Gomez-Ibanez and Small 1994; MVA 1995), male drivers seemed slightly more likely than other drivers to pay a charge to travel by car, particularly at the highest prices. Similarly those own more than two cars and those who used their car for commuting were less likely to change their journey patterns. According to the Harris Research Centre report (1991), those who found the idea of road user charging unacceptable were more likely to pay and still travel by car at the higher prices than those who found the idea acceptable.

The results of the stated preference survey carried in Cambridge in 1993 (WS Atkins Planning Consultants 1994) indicated that 72 % of respondents would switch to public transport at a road charge of £3 or less; 48 % would switch at a charge of £ 1 or less. It was further found that drivers' journey time also influence the willingness to pay a charge. Among drivers who had less than 10 minutes journey time, 45 % of them would switch to public transport at a charge of less than a pound, while among those who had between 30 and 60 minutes of travel time, only 12 % of them would switch for less than a pound.

Bonsall *et al.* (1998) reported the results from the questionnaires that one of frequent response to the charges was simply to pay it (25%) and it increased to 32% when it was suggested that paying a charge might improve traffic conditions.

3.5.3 Acceptability

Another important topic of studies related to road user charge is acceptability of road user charges. Most studies of responses to road user charges assessed road user charges in terms of policy, and for identifying some of the objections to which inhibit its political approval.

According to the Gomez-Ibanez and Small (1994), French scheme has been accepted by both the general public and government officials, as the result of careful planning and efforts to explain the scheme to motorists and journalists by emphasizing the objective of charges which were to reduce congestion rather than to raise revenue.

In the case of Bergen, there was strong opposition to the toll ring, However, this decreased and eventually turned to slight support (Larsen 1988; Gomez-Ibanez and Small 1994). A month before the opening of the toll ring, a newspaper poll was carried out. The results showed only 13 % supported and 54 % opposed. However, within a year of implementation, 50 % of respondents were in favor while 36.5 % opposed.

It was also found in Oslo that public support for their toll ring had increased since operating from 29 % in 1989 to 39 % in 1992. However, there were still over 50 % of respondents who were opposed to it (Gomez-Ibanez and Small 1994).

According to Lewis (1993), public attitudes about the toll ring in Trondheim before opening toll ring were more negative than for the other two cities in Norway. Those who accepted it have increased from only 7 % before opening to 20 % after implementing it.

Thorpe and Hills (1992) conducted a SP survey in three Norwegian case-study areas to investigate public attitudes to road-use pricing. The main findings were that Trondheim (60%) and Oslo (58%) disagree with the need for toll rings, while approximately half of responses in Bergen agree that it was necessary. They suggested that the public acceptability of a toll-ring policy increases over time once the policy has been implemented, as a result of respondents becoming more familiar with its use and as the perceived benefits become more widespread.

The above studies indicated that once road user charging schemes implemented, the acceptability of it tends to increases. The studies about the unimplemented cases reported that the public general were against the road user charging scheme.

A survey was carried out in 1990 in order to assess public attitudes to road user charges systems in Randstad and revealed that people were opposed to restrict car usage and suggested the adverse effects on some travelers (May *et al.* 1991).

The results of the attitudes to road user charges in London (Harris Research Centre 1991) showed that less than half (43 %) of respondents regarded road user charging as acceptable to some degree, while over half(53 %) regarded it as unacceptable. The results indicated that road user charging was not considered acceptable due to concerns about privacy, social equity problems and the use of the toll revenue. However, 62 % of respondents thought road user charging was acceptable and 33% still considered it unacceptable even if the revenue raised by road user charging was spent on policies to reduce congestion, for example by improving roads and public transport, as well as on other measures. Another interesting finding in the study was that there was not much difference of response to these charges between those who did find road user charging acceptable and those who did not.

Sheldon and Jones (1993) reported in their study about road user charges in London that respondents mentioned that the more complex schemes could be costly to implement and that they would find a system more acceptable if they could easily predict the costs associated with any particular journey.

The survey about London road user charges was completed in 1995 by MVA on behalf of Department of Transport (MVA 1995). Results suggested that road user charges alone would not be a popular policy among London residents. However, it was suggested that congestion charging might be less unpopular if it contributes to improve the quality of transport and the environment. The results concerning public attitudes suggested that there is much concern about congestion and the effects of traffic on the environment, among both residents and the business community. They were concerned about its impacts on both personal travel costs and convenience as well as on the community, and expressed doubts about the performance of new high technology systems, which would be required for road user charges.

Gomez-Ibanez and Small (1994) also found that the road user charging was generally unacceptable to the public and explained the reasons; people do not understand its rationale; they do not trust the new collection technologies; they fear unexpected side effects such as traffic spillovers; and they suspect that they will pay more than others while the benefits they will get will be less than those of others.

The case of Leicester Environmental Road Tolling Scheme show that there was enormous public interest but also opposition to the road pricing. Strong local media support, local political support and support from volunteers increases the public's understanding of the reasons for LERTS. It has become generally accepted that road pricing is a viable proposition. However, there is still concern about the influence of LERTS on business sector (Smith 1998).

Bonsall *et al.* (1998) asked drivers the most acceptable option of charges among fixed charges, distance-based charges, time-based charges and delay time-based charges. The result was that 72% of them chose for fixed charges, 11% for distance-based charges, 4% for time-based charges and 3% for delay time-based charges. This indicates that people are hostile to unpredictable charges.

3.6 Summary and Implication for This Study

This chapter briefly summarized the definition, objectives and types of charging methods of road user charges. Among variable road user charges, this study will adopt the time-based charge and congestion-based charges. This is because these types of charging methods are close to the "ideal" road user charges, i.e. congestion pricing, which economists suggested and therefore may be anticipated to achieve most of objectives of them. It is also necessary to provide charge information to cover the drawback of any unpredictable charges of these systems. The other systems do not need charge information to be provided to the driver because charge is extremely predictable. However, in order to prevent confusion between congestion-based charge and congestion pricing, the term 'delay time-based charge' will be used from the next chapter.

The evidence on road user charges was introduced case by case. Singapore, France and three Norwegian cities, Bergen (1986), Oslo (1990) and Trondheim (1991) implemented some kind of road user charges' schemes. These are simple in charging schemes, because of lack of technology which levy charge, and because of practical limits. Several cities such as Hong Kong, Stockholm, Randstad, London, Cambridge and Leicester considered implementing road user charges and developed detail charging schemes. The cases were generally more complex and sophisticated than those implemented. However, some of them were rejected because of several reasons such as political objection, unacceptability, invasion of privacy and so on.

The findings of previous research concerning the responses of drivers to road user charges were classified into three categories; influence on travel pattern, willingness to pay and the acceptability of road user charges. This research indicated that drivers tended to change their route to bypass route to avoid the charge if possible. A limited charging period and variable charge rate result in drivers' rescheduling their journey. It was also observed that car drivers switched to public transport or carpool to avoid charges. This study will investigate drivers' responses to road user charges considering route choice, time shift, mode change and so on. In particular, drivers' route choice behavior in response to variable road user charges is mainly explored through Stated Preference survey, which will be discussed in chapter 5.

Several studies found a willingness to pay a road user charge and also reported that this amount would be different depending on the charging period, and socio-economic characteristics of respondents. Therefore, the willingness to pay a road user charge will be a subject of the main survey in this study. This study explore the way drivers respond to different types of charges. Drivers' socio-economic characteristics will also be used in the analysis of the results.

Finally, the studies about the acceptability of road user charges were reviewed. Overall, the concept of road user charge is generally unacceptable to the public. However, support can be increased if the way of spending the revenue from road user charges is used to improve local transport systems. It was also observed that after implementing road user charges, public support increased in many cases. This study will also investigate drivers' acceptability of road user charges. It will investigate the way in which drivers' opinion may be changed to some degree, as congestion levels have become serious and the knowledge of concept and necessity of road user charges increases.

Chapter 4

Issues to be Studied

4.1 Issues Arising from the Literature Review

In the light of the review of relevant literature in Chapter 2 and Chapter 3, this chapter briefly outlines the issues to be studied.

As reviewed in Chapter 3, there are various charging methods and a considerable amount of research about road user charges has been undertaken. However, previous studies concerning road user charges mainly considered cordon charges, or tolls, and many of them focused on the public acceptability, elasticity and influence on travel pattern. Schemes which were implemented or planned to be implemented has also been very limited to simple charges such as tolls or cordon charges and there is no application of congestion pricing (for example, Holland and Watson 1978; Larsen 1988; HRC 1991; Meland and Polak 1993).

The lack of suitable technology imposed constraints on the way more advanced and ideal charges can be implemented or studied of which charges are levied continuously based on the amount of road use and levels of congestion. However, recent technical development related to road user charges may make this possible, whereby charge levels are decided depending on the current road conditions. For these variable systems, various methods have been studied to determine the charging levels including time-based charges, distance-based charges, and delay-based charges.

Several research about variable road user charges have been carried out, but most of them are focus on the acceptability. Several studies have investigated the effects of these variable road user charges on network conditions, which were based on assumption about drivers responses. They have done this without any consideration of the possibility that the behavioural response might depend on the nature of the charging regime (Milne and Van Vliet 1993; Milne *et al.* 1993; Smith *et al.* 1994).

The time-based charge and delay-time based charges have been criticized because it would be difficult for drivers to predict the charge accurately (for example, MVA 1995; Collins and Inwood 1996; Bonsall and Palmer 1997). This is one of reasons why they were excluded from the more in-dept study. There is hardly any literature about detail analysis about those charging particularly about drivers' response to them. There is also little literature about the value of time in terms of which was based on the drivers' responses rather than assumed values. Therefore, this study estimate value of time in terms of variable road user charges including the fixed charges, the time-based charge, and delay time based charges.

Recently, several authors tested the various variable road user charges to investigate which charging method are more effective or the way drivers perceived those methods. Smith *et al.* (1994) compared the network effects of four road-user charging systems in the Cambridge network (including toll, distance-based charge, time-based charge, and delay-based charge). They concluded that delay-based charging reduces congestion substantially at comparatively low levels of charging and suggested delay-based charging would have the best effects in terms of relief of congestion. Bonsall *et al.* (1998) asked drivers the most acceptable option of charges among fixed charges, distance-based charges, time-based charges and delay time-based charges. They found that the fixed charges were the most preferable and people were hostile to unpredictable charges. This study investigates whether delay-based charges is the best option to change drivers behaviour.

Certain types of road user charges, such as time-based charges and delay-based charges depend on the amount traffic condition. They have been criticized because of their difficulty in predicting accurate charges. As suggested in Chapter 1, providing information is necessary for implementing these types of road user charges and can solve the problem of the unpredictable charges for time-based charges and delay-based charges.

The research concerning ATIS and drivers' responses to them has covered a wide range of aspects. However, most previous research only focus on traffic information itself. Even though previous studies (for example, Brett and Estlea 1989; Emmerink *et al.* 1995a) have suggested combining the road user charges and traffic information systems, and Emmerink *et al.* (1995a) mentioned providing charge information, there was hardly any literature about detailed and practical information about charges and the effect of charge information on drivers' route choice. Therefore, this study investigates the practical application of the charge information, and the design of charge information. This study explores alternative ways of presenting charge information for different charging regimes and the effect of providing charge information on route choice.

For the variable road user charges, the necessary degree of accuracy of charge information may be decided depending on the way the charges are calculated, and on the traffic conditions. Sheldon and Jones (1993) reported in their study about road user charges in London that respondents mentioned that drivers would find a system more acceptable if they could easily predict the costs associated with any particular journey. This indicates the extent to which uncertain information is provided may influence drivers' responses to the information. Therefore, this study explores the way the uncertain information about charges influences drivers' behaviour in detail.

As mentioned before, previous studies concerning variable road user charges are very general and covers mainly drivers' acceptability and influence to travel pattern based on simulations. There is little literature which investigate drivers' response to them in more detail, such as whether the response are different depending on drivers' sex, income and age and so one. Previous research have shown that the drivers' responses to simple charge methods such as toll are influenced by their socio-economic characteristics. It is expected that the responses to variable road user charge will also vary depending on drivers' characteristics. Therefore, this study investigates the extent to which socio-economic characteristics influence drivers' responses to road user charge. Additionally, this study also explores the effect of cultural difference on reposes to road user charges.

As reviewed in Chapter 2, the extent to which responses to traffic information vary also depends on the characteristics of traffic information. Quantitative information has more influence on route choice than qualitative information. Several researchers have found that drivers are more likely to divert as a result of information. when the length of delay is reported on their usual route increase (Huchingson and Dudek 1979; Mannering 1989; Mahmassani *et al.* 1990; Khattak *et al.* 1991, 1993a and 1993b). Previous studies (for example, Wardman 1991; Oscar Faber TPA 1992; Hensher *et al.* 1990; Wardman *et al.* 1997), have also found that delay time was valued more highly than free flow time. The value of delay time indicates the extent to which drivers perceive delay time and in particular, the delay threshold is the point at which drivers change their behaviour. Estimating value of delay time help to understand drivers behaviour in response to delay information and to predict their response to delays stated on VMS signs. Therefore, this study investigate the extent to which the amount of delay information affect drivers' route choice and the way in which drivers evaluate the value of information concerning delay time in detail.

Drivers' responses to traffic information were found to vary depending on drivers' individual factors. This study investigates the effects of drivers' individual factors on their response to information, particularly that responses segmented by their sex, age and income levels and explores drivers' response to traffic information and charge information.

4.2 Objectives of the Study

The previous section discussed the issues which were raised from the literature and are to be investigated in this study. This section summarises the objectives of this study.

First, this study explore drivers' responses to different types of variable road user charges and their sensitivity to these road user charges.

Secondly, this study considers the practical application of the charge information, and the design of charge information: this study explores alternative ways of presenting charge information for different charging regimes such as the way charge information is given and the effect of providing charge information on route choice.

Thirdly, this study analyse the way the uncertain information about charges influences drivers' behaviour.

Fourthly, this study investigates the extent to which socio-economic characteristics influence drivers' responses to road user charge and to the information concerning traffic conditions and charges. The effect of cultural difference on reposes to road user charges and traffic information is also explored.

Finally, this study investigates the extent to which the amount of delay information affect drivers' route choice and the way in which drivers evaluate the value of information concerning delay time.

There are two surveys in this study: the main survey will explore above all objectives, while the additional survey will focus on the uncertainty survey and effect of providing charging information.

Following section will outline the main survey and additional survey including what kind of traffic information and charges systems are to be investigated, how the results are to be analysed and what new insights are sought by the research.

4.3 The Main Survey

The main survey investigates the effect of variable information about traffic and road user charges on drivers' route choice. An SP method will be used to collect data for the main survey. The issues to explore in this survey are:

- Route choice faced with traffic information
- Route choice faced with traffic information and fixed charges
- Route choice faced with traffic information and time-based charges
- Route choice faced with traffic information and delay-time based charges

4.3.1 Representation of Traffic Information Systems

In studying the effects of traffic information, it is very important to distinguish the difference between the information sources and to understand the characteristics of the information provided by each source.

There are three ways in which information can be provided to the drivers; Variable Message Signs (VMS) information, radio information, and In-Vehicle Guidance (IVG) information. The characteristics of the information provided depends on which of these information sources is used. VMS messages seem to be clear and short, and provide detailed information concerning a specific network. The radio information message is clear, descriptive and longer than those of VMS, and gives more general information to cover a wide area. IVG messages seem to be more personal and targeted to the specific journey. In this way, it is less likely to be perceived by drivers as affecting other drivers' behaviours. For this current survey it is important to choose an information source that would allow a realistic experiment, and to consider the applicability of each information source in the survey.

In this survey, VMS are used as the source of traffic information in the SP survey. VMS provides equal and easy access to information for every driver passing a specific point in the network, while the radio information and IVG are limited to those who have either the equipment and then switch it on. VMS is also able to give specific and detailed information about the specific network in which respondents are driving, while radio information covers the large area and gives general information. IVG is rejected for the current study because drivers are not so familiar to IVG, which leads to various degrees of depending on whether they believe the system to be reliable. Also because a new concept of road user charges also is introduced respondents' decisions may be confused by making them considering two new unfamiliar things at the same time.

4.3.2 Charging Systems

There are several kinds of road user charges depending on the way of measuring the levels of congestion and the amount of road use. As discussed in chapter 3, two road user charges, time-based charges and delay time-based charges are adopted in this study. With total time-based charges, the charge is directly proportion to the travel time spent in the charged area and with delay time-based charges, vehicles are charged directly in proportion to delay they experience within the charged area. Fixed charges are also used in this study. It is assumed that with the fixed charge, each vehicle is charged a fixed amount which might in practice be the same every day or might be designed to reflect traffic conditions in some previous time period, in which case, therefore the drivers might need information on the value of the charge.

4.3.3 Presentation of Charge Information

The main feature of the current study is to give charge information as well as traffic condition information. As discussed in chapter 1, providing information might be seen as necessary for implementing certain types of road user charges when the charge depends on the traffic conditions and is thus difficult for drivers to predict.

Since charge regimes based on real-time traffic information, such as total time-based charge or delay time-based charge, have never been implemented in practice, there is little information in the literature concerning how best to provide charge information.

There are two possible ways of presenting variable charge information in practice. The first is to give a charge rate formula, such as "10 pence per minute", and then make drivers calculate the price of the final charge based on the traffic conditions. This could be assisted in this task if they were given information about expected traffic conditions. When the formula is simple most drivers should find it easy to calculate the resulting charge. However, it is anticipated that some drivers would find it difficult. When this formula is more complex (e.g. " 50 pence per minute travelling at less than 10 mile per hour") it is likely that most drivers will find the calculation difficult and it may anyway be unrealistic to expect any traffic information system to supply the information required to do the calculation.

An alternative to the "formula" approach would be to provide estimates of the charges payable. In this case, it is assumed that the estimate would be based on the current traffic conditions observed by the central control centre. Such estimates would not be precise but could be quite reliable and would certainly ease the burden on the individual drivers. It may therefore be an attractive option for a real-time road user charging in the future. Of course, if the estimates are given via radio or roadside VMS, they could only relate to general destinations (e.g. "probable cost from here to city centre : 50 p"). If given via an in vehicle unit which "knows" the drivers destination and vehicle type they could be tailored appropriately.

Since total travel time on any journey is generally more predictable than the amount of delay time, it is likely that estimates of charges payable would be more accurate for travel time charges than for delay time-based charges. See section 5.3.2.2 and chapter 6.

Although drivers might want to receive precise estimates of charges, this would not be possible unless the charges were in the form of fixed tolls for passing cordons or screenlines.

4.3.4 Conduct and Replication of the Main Survey

The survey design are tested and developed through the three pilot surveys and simulation tests, which will be discussed in chapter 6. The main survey will be conducted in Leeds.

The qualitative and attitudinal results are analysed in chapter 7. The SP results from the main survey are analysed by using logit models in chapter 8. Several models are estimated to find out the best fitting model for the results and the final analysis is based on the selected model.

The main survey is repeated in Seoul. The purposes of the Seoul survey are to investigate drivers' responses to traffic information and road user charging regimes in Seoul and to investigate whether cultural difference influence drivers' responses by comparing the results between Leeds and Seoul. See section 8.6.

The analysis in chapter 8 are based on the simple logit model. The repeated measurement problem is raised in chapter 9 and the jackknife method and Kocur's method are used to correct the problem in the main survey data.

4.4 Additional SP survey

The initial plan was to conduct only a main SP survey. However, the issues which arose during the analysis of the results of that survey led to the inclusion of a second survey, which will be discussed in chapter 8 and chapter 10.

This additional survey investigates the extent to which the degree of uncertainty of charge information influences route choice.

The additional survey is conducted in Leeds and the results are analysed using a regression method. Some results from chapter 10 reveal that Utility Theory is not enough to explain the results. Therefore, Prospect Theory is applied to the results and is found to give a satisfactory explanation. See chapter 11.

Chapter 5
Design of Main Survey

5.1 Introduction

This chapter discusses the design of the main survey for this study. It consists of two parts: a brief introduction to the SP survey method, and the general survey design.

Section 5.2 briefly explains the SP method including its definition, key features and the errors related to SP. The principles of SP design are followed which should be considered at the design stage. The general SP design for the main survey are also discussed.

Section 5.3 describes the design of questionnaire for the main survey. Section 5.3.1 briefly summarises the structure of the survey. Section 5.3.2 discusses how to present local traffic conditions and charging systems. Section 5.3.3 considers the various different ways in which the network is presented in the survey and presents the network which will be applied to the current study. Section 5.3.4 describes the role of simulation and pilot studies during the pre-test for the SP design and reports briefly the applications of them to the current study. Finally 5.4 summarises the survey design which is decided as a result of this chapter and which will be applied in this study.

5.2 Stated Preference Survey

5.2.1 Stated Preference Method

A stated preference (SP) approach was used in the main survey. SP is a survey tool which obtains information about people's preferences or possible action in response to different hypothetical travel situations. Each respondent is provided with alternative hypothetical travel situations with different combinations of attributes which are relevant to the travel decision process. The SP responses were analysed to quantitative a measure of the relative importance of each of the attributes presented (Pearmain and Kroes 1990). A potential advantage of the SP method is that choice alternatives can be completely controlled by the designer which is difficult in real choice situations (Wardman 1987).

5.2.2 Key Features of SP Method.

There are four key features of SP method (Jones 1989; Pearmain and Kroes 1990), which make it a useful tool for the researcher.

Firstly, the respondents can be presented with a more interesting range of trade-offs than in real choice situations and so provide sufficient variation in the data to examine the variables of interest.

Secondly, in SP, the alternatives are presented to respondents of which attributes are combined in ways independent of one another. So the separate parameters can be estimated.

Thirdly, each respondent can be asked to make several choices in SP rather than just one per person as is the case of revealed preference (RP) method. This makes it possible to investigate how a respondent responds to different trade-offs and to carry out SP analysis with much smaller sample sizes than for RP. This is one of the key advantages of SP method in terms of cost-efficiency to the researcher. However, a potential problem is created which result from to the researcher repeated observations from each respondent. This will be discussed in detail in chapter 9.

Finally, the variables of interest and the attribute levels are defined in order to ask people to make trade-offs on the basis of these factors. Therefore, the model results can measure correctly the importance of each variable in the experiment.

5.2.3 Error Related to SP data

There are several sources of error which influence SP responses (Bonsall 1983, 1997; Wardman 1987).

1) Unconstrained response bias which is caused by respondents' failure to consider all the constraints affecting their choices.
2) Rationalisation bias: which is the opposite of unconstrained responses bias and is caused by respondents who do not consider the advantages of the rejected option over the chosen option.
3) Policy response bias: which is caused by the respondents' belief that they can influence policy decision by choosing a specific alternative.
4) Affirmation bias: which is caused by the tendency of respondents to detect the underlying philosophy and to adjust their response accordingly.
5) Misunderstanding and Uncertainty: errors are caused by the response when the respondent may not fully understand SP exercise or when it is uncertain which option is preferred. Respondent's fatigue also increases errors (Wardman 1987).
6) Good subject effect : which is caused by tendency of people knowing that they are taking part in an experiment, to rationalise the purpose of the experiment, to deduce what it is they are supposed to do, and then to act accordingly (Bonsall 1997)
7) Trade-offs : errors can arise because a SP exercise focus on the trade-offs between variables of particular interest they would, which encourages respondents to

respond to these variables more than they would in a real-life decision situations (Bonsall 1997).

5.2.4 Principles of SP Design

Previous research (Wardman 1987; Wardman and Fowkes 1988; Pearmain and Kroes 1990; Jones 1990) has indicated that there are a number of principles which must be considered in the design of SP surveys. They have been summarised below in 9 points.

1) The SP hypothetical situations should be easy to understand, appear plausible and realistic.
2) It is very important to identify the main alternatives and the levels of attributes to be considered.
3) For design of hypothetical travel situations, it should be considered that the individual effect of each attribute can be measured quantitatively.
4) The attributes and their levels should be realistic and plausible.
5) The attributes and levels should be combined realistically and present competitive trade-off decision.
6) The trade-offs should cover a sufficient range but close enough to each other to allow an accurate estimate of the boundary values.
7) Restricting the number of attributes simplifies the SP question and makes the trade-offs of interest more clear to respondents.
8) It is very important to avoid respondents' fatigue and it is also recommended that the number of SP questions per respondent be limited.
9) It is highly recommended to test and develop the SP experimental designs before the actual survey, through the pre-tests including a pilot survey and simulation.

5.2.5 General SP Experiment Design

There are three forms of responses in SP technique: choices; rankings; and ratings (Jones 1989; Bates 1989; Permain and Kroes 1990; Fowkes *et al.* 1994; Hensher 1994). Each of these is outlined briefly below.

The first choice method requires respondents to choose the most preferred alternative among the travel alternatives presented. It is straightforward to handle the result data within random utility theory. The ranking method requires respondents to rank *n* alternatives in order of preference. The rating method uses a response to be presented on a numeric or semantic scale. It provides the strength of preference as well as the order of preference. Five point scales are the most common.

In SP experimental design, an orthogonal method is usually applied, which means that there is zero correlation between the explanatory variables. The attributes presented to respondents are varied independently from one another. Therefore there will be no correlation between the coefficient estimates. The coefficient estimates will be the same, no matter how many of the explanatory variables are included in the models. This makes it possible to include as many variables as possible in models (Bates 1987; Hensher 1994).

Fractional factorial SP experimental designs involve showing respondents only a subset of the full set of options. This method is useful when a full factorial design has too many scenarios, because the full factorial design involves all the combinations. The total number of combinations is usually defined by the number of attributes and levels included in SP design (Permain and Kroes 1990). Some catalogues of design are presented in Kocur *et al.* (1982) which provide the number of hypothetical options needed to test designs

One of the advantages of SP methods is the possibility of getting a number of responses from each respondent. However, when the repeated observations from each respondent are analysed by applying the simple modeling method, a potential problem is created because of upbiased significance due to the repeated observation from each respondent (Cirillo *et al.* 1993). This repeated measurement problem will be discussed in detail in chapter 9.

5.3 Design of Questionnaire for the Main Survey

5.3.1 Structure of the Main Questionnaire

The main questionnaire in this study consist of three parts. The first part includes general questions about the characteristics of drivers and their travel patterns. This helps to determine whether the respondents are representative of the general population. It also contains questions about drivers' experience with traffic information systems such as Variable Message Signs (VMS), radio traffic information and In-Vehicle Guidance (IVG), and asks their perception about the usefulness of these systems. The second part includes SP survey questions to investigate the influence of traffic information and road-user charges on route choice. The final part includes questions about attitudes toward introducing road-user charge in Leeds city centre.

The SP exercise in the second part comprises two sections. The first section provides respondents with questions to determine the effect on route choice of traffic information without any charges. The second section introduces the concept of charges and asks questions to determine the joint effect on route choice of traffic information and charges. To avoid overloading the respondents each respondent would be asked only about one of three types of charges (fixed charges, charges proportional total time, or charges proportional to time spent in slow moving traffic). In the light of discussions in section 4.2. it was decided to use a fractional factorial design and to request subjects to make a binary choice. An example of the questionnaire is given in appendix 1.

5.3.2 Representation of Traffic Conditions and Charging Systems

5.3.2.1 Representation of Local Traffic Conditions

Information about the local traffic conditions (as they might be observed through the windscreen) are also given in this survey in order to give a more realistic decision environment to drivers and to assess whether drivers' observed traffic conditions may influence the effects of traffic conditions information on their route choice decision. Pictures of the network conditions as seen through the windscreen at the decision point will be provided in the SP questions.

This techniques has previously been used by Allen *et al.* (1991) in their experiments which showed traffic congestion levels through road environment slides in the laboratory. It has also been used in recent route choice SP experiments by Bonsall *et al.* (1994c), by Bonsall and Whelan (1995) and by Wardman *et al.* (1997) and is fundamental to the design of the VLADIMIR (**V**ariable **L**egend **A**ssessment **D**evice for **I**nteractive **M**onitoring of **I**ndividual **R**oute Choice) route choice simulator in order to represent real networks realistically (Bonsall *et al.*1994a, 1997).

5.3.2.2 Representation of Charging Systems

The aim is to investigate and compare the effects of three different charging systems (fixed charge, time-based charge and delay time based charge) on route choice. Ideally each respondent would have been offered all three types of charges. However, it is believed that this would ask too many questions to respondents and confusing to the respondents and that the quality of the data would have suffered as a result. Therefore, it becomes necessary to divide the sample into three groups, with each group being asked about a different charging system.

For those respondents receiving the "fixed charge" questionnaire, the exact value of charges can be given. For those receiving, the "time-based charge" questionnaire and the "delay time-based charge" questionnaire, the charge information must be given via a formula or an estimated range. In fact, since regular drivers would, in reality, have some prior experience of the likely level of the charge payable, it was decided to include a range estimate of the charge payable (as well as providing the formula) in each case. Using the logic outlined in section 6.3.1.2., the range estimate for time-based charges is narrower than that for delay-based charges.

5.3.2.3 Levels of Charges

The levels of charges used in this SP experiment were developed from the results and charge levels used in previous studies (Milne *et al.* 1993; Sheldon and Jones 1993; MVA 1995; Mauchan and Bonsall 1995). The relevant charge levels from other studies are summarised in **Table 5-1**

Table 5-1 The charge types and levels of existing studies

Systems	**Charge level**			
	Milne *et al.* (1993b)	**Sheldon & Jones(1993)**	**MVA (1995)**	**Mauchan & Bonsall (1995)[1]**
Applied Area	Cambridge	London	London	West Yorkshire
Types of road	urban	urban	various	motorway (M1,M62/M621)
Distance-based charge(ppk)	10 / 20 / 40	40(A) 10 / 20 (B)	40/ 70/ 160(a) 5 / 10 / 20 (b)	2.5 ~ 8
Time-based charge(ppm)	5 / 10.5 /21	12 (C) 1.5 / 3 (A)		
Delay-based charge(ppdm)	60 / 180 / 600			

ppk:pence per kilometre; ppm:pence per minute; ppdm:pence per delay minute
A: inner B: outer c: central
a: central area b: inner

[1] Note that the values in Bonsall and Mauchan's study are much less than others quoted above because they related to charges on interurban motorways rather than urban situations and so may not be relevant for the current study.

The levels of charges for the current study were based on the values of charges from these studies. The pilot surveys then tested whether such levels would be plausible and the results were used to refine the charge levels to those used in the main survey.

5.3.3 Network Representation

In order to select the best network of this survey, three designs were considered: a hypothetical network, a real network and a semi-hypothetical network. Depending on the network, the elements and characteristics of experimental design may be different.

5.3.3.1 Hypothetical Network

Route choice options

There are two routes from home to the workplace in the hypothetical network. One (route1) is short as the crow flies and goes through the city centre. There is always some delay expected in the city centre on this route. Charges are introduced only to the city centre portion of route 1. The other route (route 2) is an outer orbital road which is longer than route 1 and on which no delay is normally expected. Drivers are given information about traffic conditions and charges. They are asked to make choice between route1 and route 2 before entering city centre.

Advantages

The hypothetical network is easy to control in terms of the variables used. Those that affect the route choice decision can be included in the experiment, while it is easy to get rid of the uncontrolled variables. It also makes modelling and calibration easy. It is also easy and simple for subjects to understand the networks and routes. It does not require respondents to be familiar with any particular location.

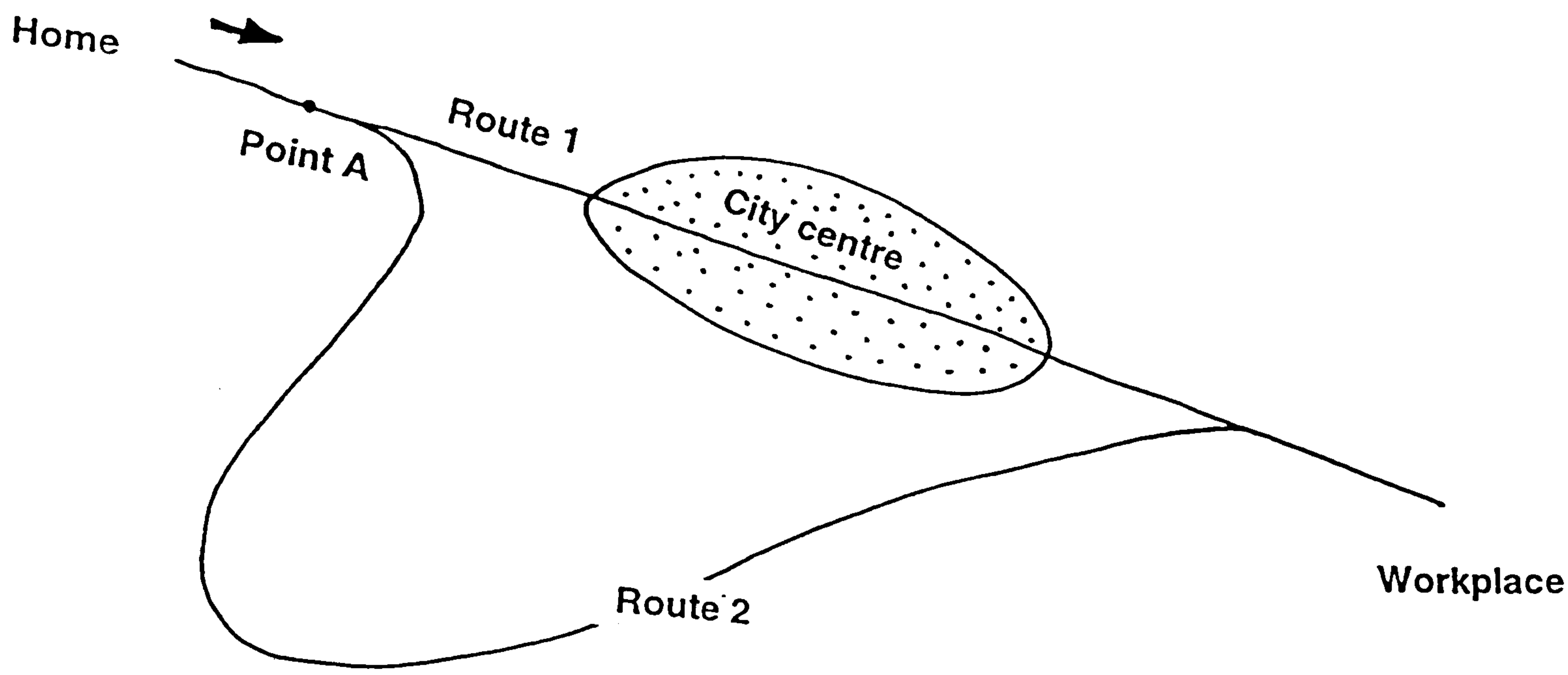

Figure 5-1 A hypothetical network

Disadvantages

The responses from subjects may be less reliable and more unrealistic when based on a hypothetical network than on a real network because subjects may think it is a kind of game. The other disadvantage is that if important factors which may affect route choice are not included in the experiment design, the results will be biased.

A number of researchers (e.g. Mahmassani and Jayakrishnan 1991; Mahmassani and Chen 1991; Adler and Mcnally 1994; Bonsall and Whelan 1995) have been used hypothetical networks in their studies.

5.3.3.2 Real Network

The real network is ideal to get reliable and realistic data based on the drivers' real route and previous experience with the network. It is not, however, an easy task to design and to control an experiment in real networks. Real networks were used in many research (e.g. Bonsall and Parry 1991; Broken and Van der Vlist 1991; Bonsall *et al.* 1995; Hato *et al.* 1995; Zhao *et al.* 1995; Emmerink *et al.* 1996; Firmin *et al.* 1997; Wardman *et al.* 1997)

Selection of Network

In the case of a real network, careful choice of the experiment's network is required in order to control the drivers' route choices. A preliminary survey is required in order to select the experiment network and sample. Among respondents of the preliminary survey, those who have appropriate residential location, work place, trip distance and travel time for commuting trip would be selected as the sample for the SP survey. The most familiar route of the selected sample would be chosen as the experimental routes.

Three locations were considered from the Leeds network, as possible sites for the study. The first option was from Moortown to the city centre along the A61, the second was from Kirkstall Abbey to City Square along the A65 and the third was from Cookridge to the city centre/university along the A660. Respondents would be asked to a preliminary questionnaire concerning which of these was most familiar to them and they would then be sent a questionnaire based on that site.

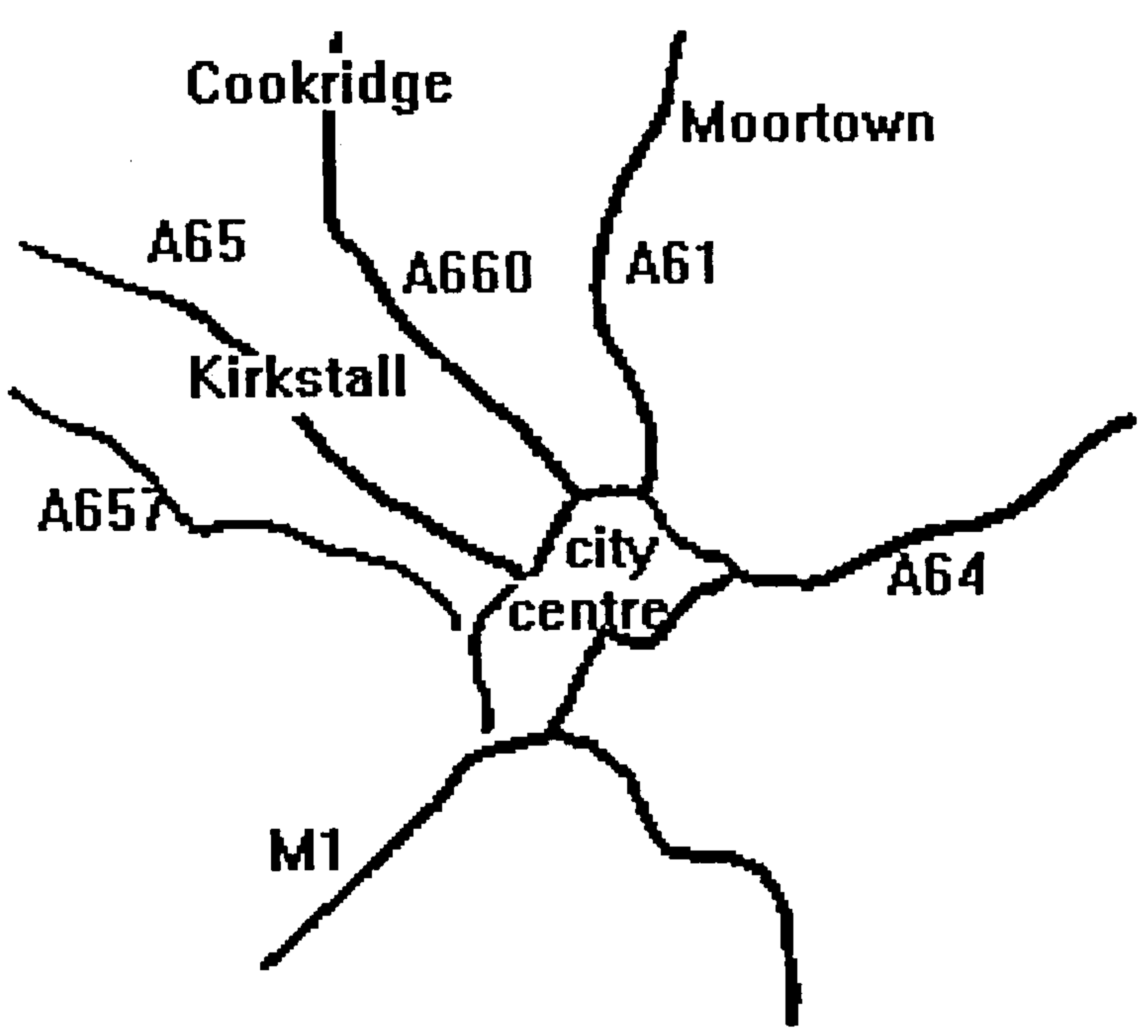

Figure 5-2 Simplified map of Leeds network

Advantages

The first advantage of using a real network is that drivers' responses can be more reliable and realistic than using a hypothetical network because their responses are based on a familiar network and actual driving experience. The second advantage is that a real network is easy for respondents to understand the choice situation exactly[2]. The third advantage is the possibility of providing a picture of the real network to the respondent to give them an idea of observed traffic conditions. This shows the location and circumstances of the network exactly and makes drivers feel more like they are driving the route.

Disadvantages

First, there may be countless routes for commuters in the real whole network which makes it difficult to choose within the network and to control the experiment. Some respondents might not be as familiar with the network as we would wish. Recruitment of sufficient respondents with good knowledge of the one or more of the locations could be difficult but is advisable. Firmin *et al.* (1997) used stop line recruitment and Wardman *et al.* (1997) used residential recruitment.

Secondly, using the real network restricts the provision of detailed information about the routes and only allows the survey to give general information, because each driver has their own network knowledge and experience with that network.

Finally, it is difficult to control the individual preference on a specific route or individual experience with the specific network. This may influence route choice more than attributes in the experiments.

5.3.3.3 Semi-hypothetical Network

The third option is a semi-hypothetical network that combines characteristics of a hypothetical network with the experience of drivers in a real network.

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2 For example, route choice situation is presented as follows. "Now you are driving along the A660(Otley Road) and you are approaching the roundabout of the outer ring road and gets the following information about the traffic conditions and charges on the A660 via VMS". It makes drivers imagine the network clearly and they might be expected to consider their route choice more realistically.

Network Design & Route Choice Options

There would be two hypothetical routes for commuting in the network. The important thing is to make respondents assume that route 1 is their own normal route and route 2 is their own alternative route. Thus even though there would be two options, they would mean different routes to each respondent[3].

In the semi-hypothetical network, charges would be levied both on the "normal route" and on all "alternative routes" in the network in order to control the alternative routes of respondents because each route from each respondent is unknown.

Before using a semi-hypothetical network in the SP survey, a filtering process would be necessary to minimise the effect of uncontrolled factors. Through a preliminary survey, questions would be asked about the location of home and work place, the normal and alternative route, travel time and normal departure time in order to select respondents who have similar travel patterns. It makes the choice situation of each driver similar and also makes their responses feasible and consistent.

Advantages

The main advantage of a semi-hypothetical network is that even though a hypothetical network is used, each respondent's specific real networks can be considered in the route choice.

Another advantages is the possibility of obtaining a big variation of travel times from respondents. The total travel time of each route is the sum of respondents' expected travel time and the extra delay. Even though the same variables of extra delay are

[3] For example, given two respondents A and B .The usual route of respondent A is A660, of which expected travel time is 40 minutes and the alternative is A61, of which expected travel time is 50 minutes. The usual route of respondent B is A65, of which expected travel time is 25 minutes and the alternative is A647 of which expected travel time is 33 minutes. With semi-hypothetical network, there are two routes: one is normal route and the other is alternative. Route 1 means A660 to respondent A and A65 to respondent B. Route 2 means A61 to respondent A and A647 to respondent B.

used for all respondents, each respondent's total travel-time can be calculated separately in the model[4].

Disadvantages

It would be very difficult to control the choice situation in the experiment using a semi-hypothetical network because drivers have their own experience and knowledge about the network and their own route has different characteristics. For example, it would be difficult to decide the location where information should be given. In the current study, it is assumed that drivers are given information at the half of way point of their journey to work. In a semi-hypothetical network, the location will be different and may have different network characteristics depending on respondents because each driver is able to imagine his own route, which will affect drivers' route choice differently.

It is tricky to provide information about observed traffic conditions during the journey. And it would not be possible to provide a picture of observed traffic conditions because each respondent will be thinking about a different route along their own real network.

5.3.3.4 Conclusion

It is difficult to implement experiments using semi-hypothetical networks and real-networks even though there are many advantages. The hypothetical network is simple and easy to design. It is also relatively easy to conduct the experiment with only small disadvantages. It also enables exclusion of the effect of respondents' experience and preference on a specific route. Therefore, I concluded that the hypothetical network should be used in this study.

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[4]If 10 extra delay minutes are given on route1, the total travel time of respondent A is 50 minutes on A660, while that of respondent B is 35 minutes on A65.

5.3.3.5 Applied Hypothetical Network

In this section, the hypothetical network used in the current study will be described. **Figure 5-3** shows a hypothetical journey from home to work. The workplace is the other side of the city centre. It is assumed that a respondent is driving from home to work on a normal working day in the morning. When he passes point **A**, he has the choice of two routes to the workplace.

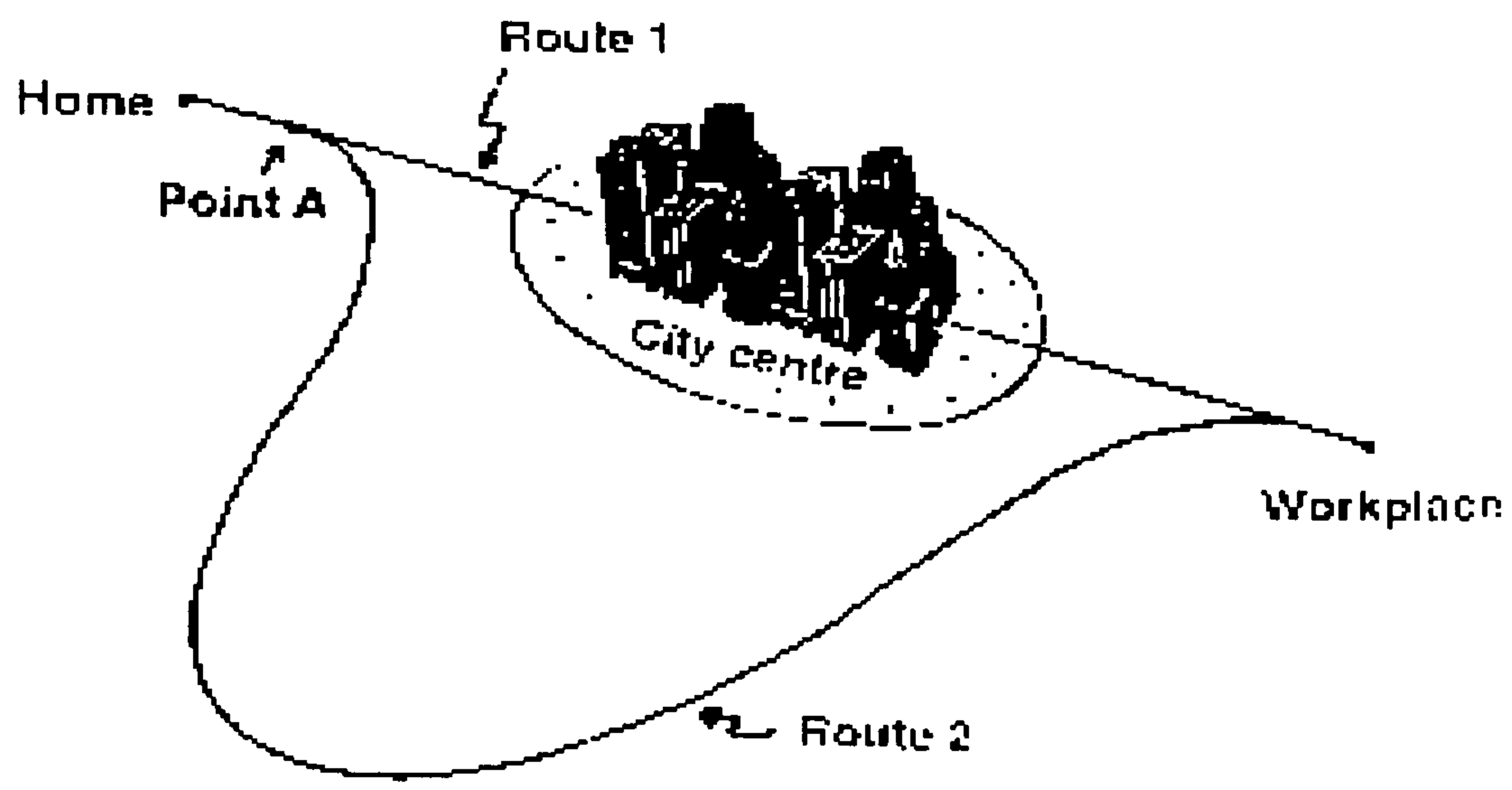

Figure 5-3 A hypothetical network

There are two routes available. Route 1 is short, 4 miles as the crow flies, and goes through the city centre. The normal travel time is about 25 minutes, of which about 10 minutes is spent in slow moving traffic during peak time. Route 2 is longer, 10 miles in total, but no delay is normally expected. The travel time is normally about 35 minutes. The travel distance and travel time in this survey were designed based on the characteristics of typical commuter journeys in Leeds, in order to make the survey design realistic to the respondents.

The pictures of the observed traffic conditions are given to respondents in SP questions. Pictures were taken from the Leeds city centre and were modified through the editing process in the computer in order to create the hypothetical network. Two observed traffic conditions are included; one for heavy traffic and the other for the free traffic. (For an example of this in the questionnaire, see appendix 1).

As discussed in section 5.3.3.1, using hypothetical network makes it possible to get respondents at any particular location. Therefore, questionnaires will be distributed to car commuters who arrive at several car parks in Leeds city centre during the morning peak between 7:00 am and 9:00 am. This is thus a choice-based sample. A self-completion interview will be used in which questionnaires will be handed out personally to the commuters and the respondent will be asked to mail back his answer.

5.3.4 Test of SP Design

As mentioned in section 5.2.4, a pre-test of the intended SP design is highly recommended in order to test the feasibility of SP design and to improve it. A simulation test using synthetic data and a pilot survey are the generally used test tool. In this section, the necessity of the test and the test methods will be discussed.

5.3.4.1 Simulation Test on SP Design

For complex SP designs, Fowkes and Wardman (1991) advised that "simulation tests using syntehtic data are conducted to ensure that the design is capable of recovering accurate estimates of a series of relative values". In order to test whether the design of SP questions is satisfactory and whether it allows accurate estimation of the values of the variables in the design, simulation tests were conducted.

Simulation within SP research consists of synthesising responses to particular designs using known values and then estimating the utility functions in the normal manner to see how efficient the designs are at extracting the specified parameters. **Figure 5-3** is a flow chart which depicts the process of the simulation test on the SP design.

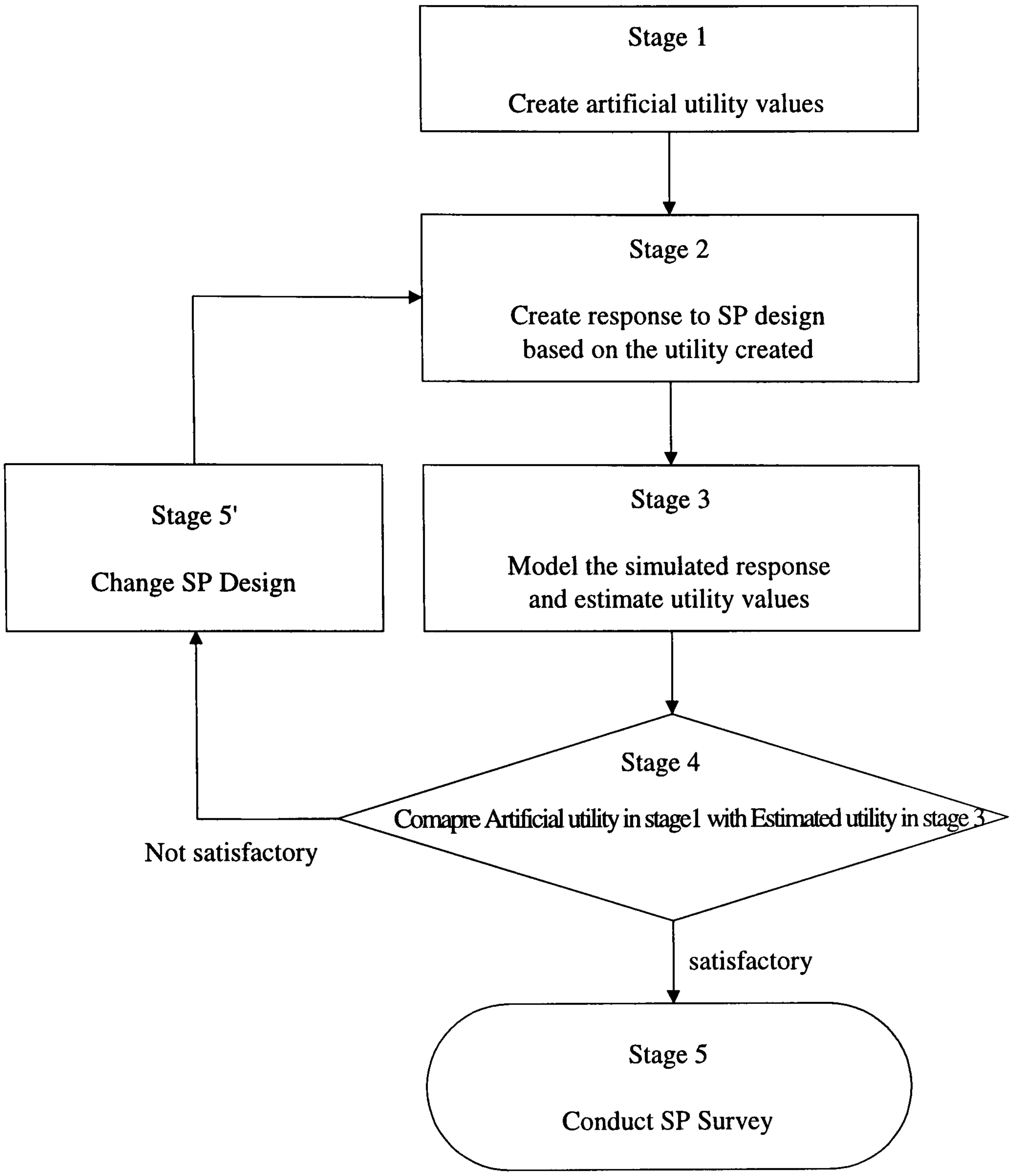

Figure 5-4 Flow chart for the process of the simulation test on the SP design
(after Pearmain and Kroes 1990)

Synthetic data was created by the artificial utility values specified by the designer. Linear logit model was chosen to simulate the response and to estimate the response as well. The simulated data was based on the random utilities of options, which are functions of the attribute values of the design, relative variation and an error component. A utility function with specified values is used to produce the deterministic component of an alternative' utility. Random numbers from a given distribution are then generated to represent the disturbance element for each alternative. Then the alternative which has highest simulated utility is selected as the response. Creating the simulated response was conducted by using MS-DOS batch program and the program source code was written in a simple FORTRAN.

The created synthetic data were used to estimate a model by using a program, "ALOGIT", which was developed by Hague Consulting Group. The estimate results were compared with those of the original artificially specified data. The comparison result indicated whether the design would be capable of estimating or whether some improvement was required (Fowkes and Wardman 1988; Pearmain and Kroes 1990).

In this study, before conducting each pilot survey and main survey, each SP design was tested using simulation. Final results of the simulations exercise showed that the designs of the SP questions were capable of supporting the intended analysis. The simulation tests for the third pilot survey will be explained in section 6.4.2. in detail as an example. Also an example of the simulation test for the third pilot survey is attatched in appendix 5. This includes the program file (appendix 5-1) to create the responses, the examples of created responses (appendix 5-2) and the model estimate results of the simulated responses (appendix 5-3).

5.3.4.2 Pilot Surveys

The previous section discussed the simulation test for the SP design. Even if it is a useful exercise, it does not provide reliable enough guidance on the way respondents would actually respond, because it is based on the artificial utility values. Pearmain and Kroes (1990) suggest that a pilot survey is required. Conducting a pilot survey helps to test the feasibility of the experimental design, and provides the value of time of respondents, which in turn helps to indicate what levels of charge and travel time should be used. The pilot survey also gives practical help in terms of identifying likely response rates, and for providing experience in handling the data with ease in the analysis of the main survey.

For this current survey, three pilot surveys were conducted in order to test and improve the SP survey design. The detailed process and the results will be discussed in chapter 6.

5.4 Conclusion

This chapter has explained the SP survey method briefly and discussed the process of development of the general survey design for the current study. This section summarises the applied survey design as a result of the previous section.

The questionnaire of the survey consists of three parts, of which the second part includes SP experiments. For the SP experiment design, the fractional factorial design is applied which show only subset of the full options. The orthogonal method is also applied which assumes that there is no correlation between the coefficient estimates.

The questionnaires will be distributed to car commuters who arrive at car parks in Leeds city centre during the morning peak. A self-completion mail-back survey will be used.

As the source of traffic information, VMS and the observed traffic conditions are used. Three types of road user charges are applied; the fixed charge, the total time-based charge and the delay time-based charge. For representing the difference of these charging regimes, with the fixed charge, the estimates of charge is given, while the total time-based charge is given with a narrow range and the delay time-based charge is given with a wide range. This reflects the uncertainty of travel time or delay time. The levels of charges used in this current SP experiment were developed from the results and charge levels used in previous studies. The pilot survey stages tested whether such levels would be plausible and the results were used to refine the charge levels to those used in the main survey.

A hypothetical network will be used for the SP experiment, and the design of the applied experimental network was described in section 5.3.3.5.

The designs of the SP for the main survey were developed using simulation tests and pilot surveys. All SP designs of the pilot surveys and the main survey were tested using simulations before conducting any surveys. In addition to simulation tests, three pilot surveys were also conducted in order to improve the SP design. The process and survey results of the pilot surveys will be discussed in the next chapter.

Chapter 6
Development of the Main Questionnaire

6.1 Introduction

In this chapter, the development of the main survey will be discussed. In order to assess the feasibility of the SP design and model estimation, and improve the survey design, pilot stated preference surveys were conducted and the survey results and feedback were analyzed.

Three pilot surveys were conducted between November 1996 and March 1997. The initial pilot survey was a simple pre-stage of real pilot surveys and was conducted in the university. In the next section, the pilot surveys are discussed one by one. The design, implementation, and the analysis of results will be discussed along with the conclusions which were drawn. Finally, the main survey design was decided and conducted in Leeds. The final section explains the data collection process such as the survey time, place, the subject and response rates.

6.2 The Initial Pilot Survey

A simple survey was conducted in university of Leeds in order to the test the feasibility of the SP design before the survey was distributed to the public.

6.2.1 Survey Design

The survey design was based on the principles outlined in chapter 5. The questionnaire consisted of three parts. The first part contained general questions, the second part included SP questions and the final part included attitudinal questions about road-user charges.

In this preliminary survey, only fixed charges and delay time-based charges were tested. In order to represent difference between two charge regimes, charge information for the fixed charge is given as an estimate of the charge, while charge information for the delay time-based charges was given as estimates of the charge with a range that reflects the uncertainty of delay time.

The SP exercise in the second part of the questionnaire consists of two sections. The first section asked questions to investigate the influence of traffic information on route choice, while the second section provides respondents with questions which aims to explore the joint effect on route choice of traffic information and road user charge.

In the first experiment, the respondents were given distance, travel time, extra delay (on VMS), cause of delay (on VMS) and observed traffic conditions information (through the windscreen view). In the second section, the respondents were given charge information as well as the same kind of information as the first section.

6.2.2 Attributes and Levels of SP Design

The attributes of the SP design were designed considering those in relevant previous studies (for example, Bonsall and Joint 1991; Khattak *et al.* 1993b; Bonsall *et al.* 1994; ;Bonsall 1995; Bonsall and Merall 1995; Bonsall and Palmer 1995; Bonsall and Whelan 1995; Wardman *et al.* 1997). The travel distance, travel time and levels of extra delay in this survey were designed based on the characteristics of typical commuter journeys in Leeds, in order to make the survey design realistic to the respondents.

The travel time is 20 minutes on route 1 based on the assumed speed 12 miles per hour and 35 minutes on route 2 based on the speed 17 miles per hour. The assumed speed was based on the normal travel speed in Leeds city center and travel distance of these routes. The route 1 should take more time because it goes through the city center and it is expected to be delayed.

Table 6-1 Attributes and Levels of SP design for initial pilot survey

	Attributes	Levels	
		Route 1	Route 2
Section 1	Travel time	20 minutes	35 minutes
	Extra delay	No delay / 5 minutes / 10 minutes delay	No delay/ 5 minutes/ 10 minutes
	Cause of delay quoted	None / Accident / Roadwork / Heavy traffic	N/A
	Observed traffic	Free flowing traffic / Heavy traffic	N/A
Section 2	Travel time	20 minutes	35 minutes
	Extra delay	No delay / 5 minutes / 10 minutes delay	No delay/ 5 minutes/ 10 minutes
	Cause of delay quoted	None / Accident / Roadwork / Heavy traffic	N/A
	Observed traffic	Free flowing traffic / Heavy traffic	N/A
	Fixed charge(£)	1.00 / 2.00 / 3.00	N/A
	Delay time charge(£	0.80-1.20/ 1.80-2.20/ 2.80-3.20	N/A

For the extra delay time via VMS, there are three levels; no delay, 5 minutes delay and 10 minutes delay. For the cause of delay variables, four levels are considered: No cause, Accident, Roadwork and Heavy traffic. Many research (e.g. Khattack *et al.* 1993a; Bonsall 1995; Bonsall and Merall 1995; Bonsall and Palmer 1995; Wardman *et al.* 1997) have investigated the way in which different information about causes of delays make different effect on route choice. They usually used these four specified categories for the causes of delay information. For the observed local traffic conditions, pictures of the network conditions at the decision point are provided. Two levels of them are considered; one for free flowing traffic which shows no traffic on route 1 and the other for heavy traffic which shows congested traffic on route 1 (for an example of this, see appendix 1). There are three levels for the road user charges: £1.00, £2.00 and £3.00. For the fixed charge, these three levels are given, while for the delay time-based charge, these three levels are given with ranges of ± 20 pence to reflect of the uncertainty of delay time. The attributes and their levels for the SP design of the initial pilot survey are summarized in **Table 6-1**. Before conducting the survey, a simulation test was conducted to test the SP design, as explained in chapter 4.

There are two sets of SP design depending on the types of charges two sets for fixed charges (Set 1) and the other for the delay-based charges (Set 2). Each set has 32 questions for each respondent, which were too many for a respondent. Therefore, to avoid overloading respondents, each set has also divided into two subsets (Set 1a and 1b, Set 2a and 2b) which has only sixteen SP choice questions; eight in which only traffic information is given and eight in which traffic information and the charge information is given. To avoid overloading the respondents, each respondent was asked only one of the four sets. From **Table 6-2** to **Table 6-5** summarize the SP design for the initial pilot survey.

Table 6-2 SP design for the initial pilot survey : Set 1a for the fixed charges

Section 1 for the traffic information only							
Question	Ttime 1	Ttime 2	Delay 1	Delay 2	Local Traffic	Causes of delays	
1	20	35	0	0	Free	None	
2	20	35	5	10	Light	None	
3	25	35	5	5	Light	Accident	
4	20	35	0	5	Heavy	Accident	
5	20	35	10	10	Heavy	Roadwork	
6	20	35	5	0	Light	Roadwork	
7	20	35	5	5	Light	Heavy traffic	
8	20	35	10	5	Free	Heavy traffic	
Section 2 for traffic information and the fixed charge							
Question	Ttime 1	Ttime 2	Delay 1	Delay 2	Local Traffic	Causes of delays	Charge (pence)
9	20	35	10	10	Light	None	200
10	20	35	0	5	Heavy	None	200
11	20	35	10	5	Free	Accident	300
12	20	35	0	10	Light	Accident	200
13	20	35	10	0	Light	Roadwork	200
14	20	35	0	5	Free	Roadwork	200
15	20	35	10	5	Heavy	Heavy traffic	100
16	20	35	0	0	Light	Heavy traffic	300

Table 6-3 SP design for the initial pilot survey : Set 1b for the fixed charges

Section 1 for the traffic information only							
Question	Ttime 1	Ttime 2	Delay 1	Delay 2	Local Traffic	Causes of delays	
1	20	35	10	5	Light	None	
2	20	35	5	5	Heavy	None	
3	20	35	5	10	Free	Accident	
4	20	35	10	0	Light	Accident	
5	20	35	0	5	Light	Roadwork	
6	20	35	5	5	Free	Roadwork	
7	20	35	5	0	Heavy	Heavy traffic	
8	20	35	0	10	Light	Heavy traffic	
Section 2 for traffic information and the fixed charge							
Question	Ttime 1	Ttime 2	Delay 1	Delay 2	Local Traffic	Causes of delays	Charge (pence)
9	20	35	0	0	Free	None	100
10	20	35	5	5	Light	None	300
11	25	35	0	5	Light	Accident	200
12	20	35	5	0	Heavy	Accident	200
13	20	35	0	10	Heavy	Roadwork	300
14	20	35	5	5	Light	Roadwork	100
15	20	35	0	5	Light	Heavy traffic	200
16	20	35	5	10	Free	Heavy traffic	200

Table 6-4 SP design for the initial pilot survey : Set 2a for the delay-based charges

Section 1 for the traffic information only						
Question	Ttime 1	Ttime 2	Delay 1	Delay 2	Local Traffic	Causes of delays
1	20	35	0	0	Free	None
2	20	35	5	10	Light	None
3	25	35	5	5	Light	Accident
4	20	35	0	5	Heavy	Accident
5	20	35	10	10	Heavy	Roadwork
6	20	35	5	0	Light	Roadwork
7	20	35	5	5	Light	Heavy traffic
8	20	35	10	5	Free	Heavy traffic

Section 2 for traffic information and the delay-based charge							
Question	Ttime 1	Ttime 2	Delay 1	Delay 2	Local Traffic	Causes of delays	Charge (pence)
9	20	35	10	10	Light	None	1.80-2.20
10	20	35	0	5	Heavy	None	1.80-2.20
11	20	35	10	5	Free	Accident	2.80-3.20
12	20	35	0	10	Light	Accident	1.80-2.20
13	20	35	10	0	Light	Roadwork	1.80-2.20
14	20	35	0	5	Free	Roadwork	1.80-2.20
15	20	35	10	5	Heavy	Heavy traffic	0.80-1.20
16	20	35	0	0	Light	Heavy traffic	2.80-3.20

Table 6-5 SP design for the initial pilot survey : Set 2b for the delay-based charges

Section 1 for the traffic information only						
Question	Ttime 1	Ttime 2	Delay 1	Delay 2	Local Traffic	Causes of delays
1	20	35	10	5	Light	None
2	20	35	5	5	Heavy	None
3	20	35	5	10	Free	Accident
4	20	35	10	0	Light	Accident
5	20	35	0	5	Light	Roadwork
6	20	35	5	5	Free	Roadwork
7	20	35	5	0	Heavy	Heavy traffic
8	20	35	0	10	Light	Heavy traffic

Section 2b for traffic information and the delay-based charge							
Question	Ttime 1	Ttime 2	Delay 1	Delay 2	Local Traffic	Causes of delays	Charge (pence)
9	20	35	0	0	Free	None	0.80-1.20
10	20	35	5	5	Light	None	2.80-3.20
11	25	35	0	5	Light	Accident	1.80-2.20
12	20	35	5	0	Heavy	Accident	1.80-2.20
13	20	35	0	10	Heavy	Roadwork	2.80-3.20
14	20	35	5	5	Light	Roadwork	0.80-1.20
15	20	35	0	5	Light	Heavy traffic	1.80-2.20
16	20	35	5	10	Free	Heavy traffic	1.80-2.20

6.2.3 Data Collection and Descriptive Analysis

The initial pilot survey was conducted in the beginning of November 1996. The questionnaires were distributed to staff and research students in the University of Leeds. A total of 40 questionnaires was distributed and 29 questionnaires were returned, giving a response rate of 72.5%.

64% of respondents were male and most of them were between 25 and 54 years old. The income distribution shows that 44% of respondents had their annual incomes under £20,000 and 32%, between £20,000 and £40,000. This income distribution is distorted because high percentage of respondents were research students. The real income levels were expected to be higher than this when questionnaires are distributed to commuters.

Respondents were asked about experience of using different types of traffic information systems and about their perception regarding the usefulness of these systems and information. About 60% of respondents have had experience with Variable Message Signs (VMS) before and 56% of them thought that the system was useful. In the case of radio messages, about 68% of respondents had listened to them and 64% of these respondents said that it was useful. Few respondents had experience with in-vehicle guidance (IVG).

Respondents were asked about their opinions about road user charge. About 32% reported that they were willing to pay for road user charge and 48% said not. Asked about how to avoid charge, 44% said they would change their departure time for work and 16% said they would change their routes from charged routes to non-charged routes. Many respondents reported that they were willing to start their journey earlier than they used to in order to avoid charges. Respondents were also asked if they could avoid paying a charge of £ 1.00, how much earlier or later they would be prepared to start their journey. 28% of them said they would start up to 20 minutes earlier, 20% start 30 minutes earlier and 8% start up to 30 minutes later. This result be influenced by the fact that most of the respondents (90%) had a flexible start time at work.

6.2.4 Analysis of Results

Logit models were estimated in order to explain the influence on route choice of traffic information and road user charge. The utility for any alternative *j* consists of relevant variables representing individual's travel situations (X_i), traffic information characteristics (I_i) and charge system (C_i):

$$U_{ij} = f(\alpha_i X_i, \beta_j I_j, \gamma_j C_j) \quad \textbf{(6-1)}$$

In this model, the *X* variable is the normal travel time, *Ttime* and the *I* variables were: dummy variable for the extra delay time information, *Delay* (D_O), dummy variable for the cause of delay information, *Cause of delay (Dc)*, and dummy variable for the observed traffic condition, *Ftraffic* (D_F). The effects of different charging regimes were represented by special *C* variables; *fcharge* for the fixed charge and *dtcharge* for the delay time-based charge. A single model was estimated which included three charge parameters for each charging regime but the results were not satisfactory because of high correlation between variables. Instead, three separate models were estimated which included each of three charge parameters.

The results of the three models are summarized in **Table 6-6**. The rho-squared values of these models are relatively high. Not all parameters have intuitive signs but model 2 has a correct sign in every parameter. T-ratio values of the parameters are low because of small sample size.

Model 1 investigates the influence of traffic information on route choice. All parameters except *Delay (DI)*, have intuitive signs. The parameter, *Cause of delay (Dc)* indicates that drivers are significantly more likely to change their routes when information about accident or roadwork is given. Bonsall (1995) and Wardman *et al.* (1997) also found that the impact of delay information increased when the reason for a delay was given. The parameter, *Ftraffic*, indicates that when drivers find free flowing traffic at the decision point, they are more likely to choose the free flowing traffic route even though extra delay information is given.

Table 6-6 Models for the influence of traffic information and road user charge on route choice

Variables	Model 1 Coeff	Model 1 t-ratio	Model 2 Coeff	Model 2 t-ratio	Model 3 Coeff	Model 3 t-ratio
Delay (DI)	0.471	1.5	-0.306	-0.8	-0.246	-0.5
Cause of delay (Dc)	-0.617	-1.7	-0.169	-0.4	-0.287	-0.4
ftraffic (D_F)	0.395	1.1	0.275	0.6	0.074	0.1
Total travel time(mins)	**-0.105**	**-4.9**	-0.058	-1.1	-0.115	-1.8
fcharge(pence)			**-0.011**	**-2.8**		
dtcharge(pence)					**-0.017**	**-3.2**
Number of observations	184		112		78	
Log-likelihood	-87.892		-57.743		-35.233	
Rho-Squared	0.311		0.256		0.348	

DI: **Dummy variable for delay information**
If VMS mentions extra delay, D1=1, otherwise 0
Dc: **Dummy variable for cause of delay information**
If VMS gives cause of delay(accident or roadwork) $D_1 = 1$, otherwise 0
D_F : **Dummy variable for observed local traffic condition on windscreen**
If local traffic is free flowing, D_F=1, otherwise 0
Model 1 for the influence of traffic information on route choice
Model 2 for the influence of information under fixed road-user charge
Model 3 for the influence of traffic information on route choice under time-based charge
The numbers in bold mean that they are significant and have correct signs

Model 2 investigates the influence on route choice of traffic information and the fixed charge. The parameter, *Delay (DI)*, indicates that drivers' preference for the route 1 decreases when delay information is given. The parameter, *Cause of delay* indicates that drivers are significantly more likely to change their routes when information about the cause of delay such as accident or roadwork is given. The estimate for free flowing traffic condition suggests that when traffic is observed to be free flowing at the decision point, drivers are more likely to choose that route regardless of delay information. The parameter for the fixed road-user charge, *fcharge*, indicates that drivers are less likely to choose route 1 as the charge increases on it. The value of time in terms of charge under fixed road-user charge is 5.3 pence per minute.

Model 3 investigates the influence on route choice of traffic information and delay time-based charge. The charge information for delay time-based charge is given with a range and the model was estimated based on the median values of charges. The parameter *Delay (DI)* indicates that provision of delay time information increases the propensity to change route. The parameter for the observed traffic conditions, *Ftraffic* shows that the free traffic conditions at the decision point has slightly influenced drivers to choose the route. The parameter *dtcharge*, indicates that the willingness to choose route 1 decreases as the charge on route 1 increases. In this case, the value of time in terms of delay time-based charge was calculated 6.8 pence per minute.

6.2.5 Implications for Subsequent Survey

This initial pilot survey has revealed several problems in the survey design. First, the SP responses reveal that route 1 is dominated in many questions of the second section, which indicates that provided trade-offs in the SP design was not plausible. Therefore, the SP design should be changed to provide competitive trade-offs between routes.

Secondly, some respondents had difficulty in understanding the delay information and observed traffic conditions. For the next survey, more detailed explanation is therefore required about the way the information is being presented. It is also necessary to clarify delay information and observed traffic conditions; that the delay information relates to the city center, while observed traffic conditions are at the decision point.

Thirdly, there were also found to too many kinds of information included in the questions so that respondents were confused. It was also found that the variable for the delay information and the variable for cause of delay information had relatively high correlation, which made it difficult to get significant parameter estimates. In order to get a better model and reduce correlation between these variables, the cause of delay variable will be omitted in the next survey.

Finally, it is also found that the inclusion of 16 SP choice questions fatigued the respondents. The number of questions will therefore be reduced for the next survey.

6.3 The Revised Pilot Survey

After the initial pilot survey, the survey design was refined. With a new survey design, a revised pilot survey was conducted in Leeds city center in order to test feasibility of SP design. This section will explain the changed survey design, analysis of the new survey results and implications for a next survey.

6.3.1 Improved Survey Design

6.3.1.1 Attributes and Levels of Traffic Information

The SP experiment design has been changed based on the results of the initial pilot survey. First, the variable for the cause of delay information was removed. Secondly, normal travel time was changed between two sections in order to reflect the effect of road user charges on demand. In the first section, normal travel time is 25 minutes on route 1 and 35 minutes on route 2. In the second section, normal travel time on route 1 was reduced to 20 minutes in order to consider the decrease of demand due to the road user charge. Thirdly, variables the levels of extra delay time attributes are redesigned for traffic information so as to reduce levels of the attributes for a simple experiment design. The variable, *No delay* on route 1 is removed because there was always delay expected on the route 1 and it is not logical if road user charge based on delay time is levied even without delay on route. The *5 minutes delay* was removed because it is the least useful and the amount of delay is relatively small. Only two levels of extra delay *10 minutes delay* and *15 minutes delay* were included. **Table 6-7** summarizes the attributes and levels of SP design for the revised pilot survey.

Table 6-7 Attributes and Levels of SP design for the revised pilot survey

	Attributes	Levels	
		Route 1	Route 2
Section 1	Travel time	25 minutes	35 minutes
	Extra delay	10 minutes/15 minutes	No delay/ 5 minutes
	Observed traffic	Free flowing traffic/Heavy traffic	N/A
Section 2	Travel Time	20	35
	Expected extra delay	10 minutes/ 15 minutes	No delay/ minutes
	Observed traffic	Free flowing traffic/Heavy traffic	N/A
	Fixed charge	50 / 70 / 100 (pence)	N/A
	Time-based charge	1 / 2 / 3 (ppm)	N/A
	Delay time charge	2 / 3 / 5 (ppdm)	N/A

ppm: pence per minute
ppdm: pence per delay minute

6.3.1.2 Attributes and Levels of Charge Information

In this revised pilot survey, time-based charge was introduced as well as fixed charge and the delay time-based charge. The levels of charges attributes are designed in a sophisticated way which considers the mechanism of each charge regimes, while the levels of the initial pilot survey was simply chosen. First three levels of charge rates for each charge regime are designed, as shown in **Table 6-7**. For the fixed charge, the levels of charge rate are given as an estimate of the charges. For the time-based charge, a charge is calculated in a way charge rate is multiplied by the total travel time of each scenario. For the delay time-based charge, charge rate is multiplied by the delay time of each scenario.

In order to represent difference between the types of charges, the charge information for the fixed charges is given as an accurate estimate of the charge. The charge information for the time-based charges and the delay time-based charges is given as an estimate of the charge with a range reflecting the uncertainty of travel time or delay time. For the time-based charge a range covers approximately ±10 % of travel time, while for the delay time-based charge, the range is approximately ±20% of the total delay[1]. The difference between these ranges is justified by the fact that delay time is more unpredictable than total travel time. The resulting charge levels for the three charging regimes are summarized in **Table 6-8**.

Table 6-8 The charge rate and levels of charges for the revised pilot survey

	Fixed charge	Time-based Charge		Delay time-based charge	
	levels (£)	rate (ppm)	levels(£)	rate (ppdm)	levels(£)
Question 1	1.00	3	0.55 - 0.65	2	0.15 - 0.25
Question 2	0.70	2	0.35 - 0.45	3	0.25 - 0.35
Question 3	0.50	1	0.25 - 0.35	5	0.80 - 1.20
Question 4	0.50	3	0.80 - 1.00	5	0.80 - 1.20
Question 5	1.00	2	0.60 - 0.75	2	0.40 - 0.60
Question 6	0.70	1	0.30 - 0.40	3	0.60 - 0.90

ppm : pence per minute
ppdm : pence per delay minute

There are three sets of SP design depending on the types of charges. Each set has eight SP choice questions; two in which only traffic information is given and six in which traffic information and the charge information is given. To avoid overloading the respondents, each respondent was asked only one of the three sets. **Table 6-9** summarises the revised SP design.

[1] **The total delay is the sum of normal delay included in normal travel time and extra delay time quoted on VMS.**

Table 6-9 SP design for the revised pilot survey

Set 1 for SP design for the fixed charge

Question	Ttime 1	Ttime 2	Delay 1	Delay 2	Local Traffic	Charge (pence)
1	25	35	10	0	Heavy	n/a
2	25	35	10	5	Free	n/a
3	20	35	0	0	Heavy	100
4	20	35	0	5	Free	70
5	20	35	10	5	Heavy	50
6	20	35	10	0	Free	50
7	20	35	15	5	Heavy	100
8	20	35	15	5	Free	70

Set 2 for SP design for the time-based charge

Question	Ttime 1	Ttime 2	Delay 1	Delay 2	Local Traffic	Charge Rate	Charge (pence)
1	25	35	10	5	Heavy	n/a	n/a
2	25	35	15	0	Free	n/a	n/a
3	20	35	0	0	Heavy	3	55-65
4	20	35	0	5	Free	2	35-45
5	20	35	10	5	Heavy	1	25-35
6	20	35	10	0	Free	3	80-100
7	20	35	15	5	Heavy	2	60-75
8	20	35	15	5	Free	1	30-40

Set 3 for SP design for the delay-based charge

Question	Ttime 1	Ttime 2	Delay 1	Delay 2	Local Traffic	Charge Rate	Charge (pence)
1	25	35	15	5	Free	n/a	n/a
2	25	35	15	5	Heavy	n/a	n/a
3	20	35	0	0	Heavy	2	15-25
4	20	35	0	5	Free	3	25-35
5	20	35	10	5	Heavy	5	80-120
6	20	35	10	0	Free	5	80-120
7	20	35	15	5	Heavy	2	40-60
8	20	35	15	5	Free	3	60-90

6.3.1.3 Preparation of Survey

Before conducting a survey, a simulation test was conducted in order to test whether the improved SP design were satisfactory, and it allowed the accurate estimation of the values of the variables. The results of this simulation exercise showed that the designs of the SP questions were capable of supporting the analysis which was planned.

The results of the attitudinal questions in the part 3 of the questionnaire from the initial pilot survey was very interesting, but the questions were very simple. Therefore, in this survey the part 3 included more detailed questions about the responses to the different levels of road user charges. Three different levels of charges are given in order to investigate how responses will change depending on the levels of charges; 50 pence per day, £ 1.00 per day and £2.00 per day.

The following seven options were provided and respondents were asked to rank them in order of preference. See an example of the questionnaire in Appendix 2.

1. I would pay the charge
2. I would drive to the edge of the charge area park and then walk or use public transport
3. I would travel before 7:30 am
4. I would travel after 9:30 am
5. I would take a bus or train all the way
6. I would move a jobs
7. Others(please specify)

6.3.2 Data Collection and Descriptive Analysis

6.3.2.1 Data Collection

The revised pilot survey was conducted at the end of January 1997. The questionnaires were distributed individually to commuters between 7:30 and 9:00 in the morning in three parking places in the Leeds City Center; one car park in Portland Way, one multistorey car park in Calverley Street and the Leeds General Infirmary car park.

A total of 90 questionnaires were distributed, 30 questionnaires for each charge regime being tested: the fixed charges, the time-based charge and the delay time-based charge. 47 questionnaires were returned and 42 contained responses which could be used for modeling. The useful response rate was therefore 47%.

6.3.2.2 Overview of Results

Among respondents, 57% were male and about two thirds of respondents were between 35 and 54 years old. The annual income distribution shows that 47% of respondents earned between £20,000 and £ 40,000 and 38% of them earned over £40,000. The average income levels are more higher than those from the initial pilot survey because respondents of this pilot survey are commuters who can afford a car for commuting. Most of them (95.2%) were full time employed and about half of them had flexible work start time.

Respondents were asked about the journey time for their commuting in the morning. The average journey time for commuting in the morning was 42 minutes with 19 minutes standard deviation. The average work start time was 8.21 a.m. with 14.2 minutes of standard deviations.

Drivers were asked about their experience of using different types of traffic information and their perception about the usefulness of these systems and information. 64.2% of respondents have had experience with VMS before and 59.6% said it is useful. 76.2% of drivers said they had listened to radio traffic information before and 73.8% of them thought that it was useful. Few of drivers have had experience with IVG. **Table 6-10** presents the results of the questions about experience and usefulness of traffic information.

Table 6-10 Experience and usefulness with traffic information systems

	Experience with information			Usefulness of information		
	Frequent	A little	Never	Yes	Somewhat	No
VMS	10	17	15	7	18	17
(%)	*23.8*	*40.5*	*35.7*	*16.7*	*42.9*	*40.5*
RADIO	13	19	10	15	16	11
(%)	*31.0*	*45.2*	*23.8*	*35.7*	*38.1*	*26.2*
IVG	1	2	39	N/A	N/A	N/A
(%)	*2.4*	*4.8*	*92.9*	*N/A*	*N/A*	*N/A*

The respondents were also asked about their attitudes to road user charging. It was assumed that road user charging had been introduced for use on roads in Leeds city center between 7:30 am and 9:30 am. Three levels of charge were given, 50p per day, £1.00 per day and £2.00 per day to each respondent. Seven options were provided and respondents were asked to rank the options in order of preference. The first option is paying a charge, second using park and ride, third traveling before 7:30 a.m. forth traveling after 9:30 p.m., fifth using public transport, six moving a job and the final is others (appendix 2 shows these questions within the questionnaire).

The most popular choice for all charge levels was to travel before 7:30 to avoid the charged period and the percentage of selecting this increased as the level of charge increased. 36% of drivers said they would travel before the charged period at charges of 50 pence per day, while 43% said they would do so with charges at £2.00 per day. The second choice was paying a charge, 31% selected this option with 50 pence per day charge. However, this percentage decreased as the levels of charge increased. The third preference was using public transport; about 15% selected this regardless of levels of charges.

6.3.3 Analysis of Results

Logit models were estimated with the SP choices data from the revised pilot survey. Firstly a single logit model including all the relevant variables was estimated but the results were not satisfactory because of high correlation between variables. Instead, four logit models were estimated: model 1 for the influence of traffic information on route; model 2 for the influence of traffic information and the fixed charges; model 3 for the influence of traffic information and the time-based charge and model 4 for the influence of traffic information and delay time-based charge. There were six variables is (five for model 1); travel time, charge, 5 minutes delay, 10 minutes delay, 15 minutes delay and observed traffic conditions. Four models were estimated using possible combination of variables was chosen by trial and error because the sample size is too small to estimate 5 parameters. Model 3 and model 4 were based on the median value of charges.

The results are summarized in **Table 6-11**. The rho-squared values of the four models were high regardless of small sample sizes. Not all parameters for the four models had the correct signs. The t-ratio values of the four models are relatively high despite of the small sample size.

Table 6-11 Logit Model Estimates for the effects of traffic information on route choice

	Model 1		Model 2		Model 3		Model 4	
Variables	Coeff	t-ratio	Coeff	t-ratio	Coeff	t-ratio	Coeff	t-ratio
Delay (DI)			**-2.311**	**-3.6**	**-1.847**	**-2.5**	**-2.595**	**-3.2**
5m delay (D_5)	0.892	1.7						
15m delay (D_{15})	**-1.765**	**-2.8**						
Ftraffic (D_F)	**1.936**	**3.0**	-0.924	-1.4	-0.364	-0.6	-0.458	-0.7
Ttime(minutes)	-0.008	-0.2	**-0.019**	**-2.1**	0.008	0.1	0.115	2.2
Fcharge(pence)			**-0.046**	**-2.8**				
Ttcharge(pence)					-0.014	-0.7		
Dtcharge(pence)							0.015	1.4
N of Observations	78		72		72		72	
Log-likelihood	-44.122		-33.864		-37.971		-37.172	
Rho-Squared	0.184		0.321		0.239		0.253	

DI: Dummy variable for delay information
If VMS mentions extra delay, D1=1, otherwise 0
D_5: Dummy variable for 5 minutes delay information
If VMS mentions 5 minutes extra delay, D_5=1, otherwise 0
D_{15}: Dummy variable for 15 minutes delay information
If VMS mentions 15 minutes extra delay, D_{15}=1, otherwise 0
D_F : Dummy variable for local traffic condition on windscreen
If local traffic is free flowing, D_F=1, otherwise 0
Ttime : in-vehicle travel time(minutes)
Fcharge : Fixed charge(pence)
Ttcharge : Time-based charge(pence)
Dtcharge: Delay-based charge(pence)
Model 1 for the influence of traffic information on route choice
Model 2 for the influence of information under fixed road-user charge
Model 3 for the influence of information under time-based road-user charge
Model 4 for the influence of traffic information on route choice under time-based charge
The numbers in bold mean that they are significant and have correct signs

Model 1 investigate the effects of traffic information on route choice, but the results were not satisfactory. Only two parameters, *15m delay* and *Ftraffic* parameters have the correct signs and are significant. Model 2 investigated the influence on route choice of traffic information and a fixed road-user charge. The model estimates are satisfactory; the value of rho-squared is very high, all parameters have intuitive signs and most of them are significant in spite of small sample size. Model 3 was estimated for the effects of traffic information and time-based charge. Only one parameter, *Delay* has the correct sign and is significant. Model 4 was estimated for the effects on route choice of traffic information and the delay time-based charge. Only one parameter, *Delay,* has the correct sign and is significant. These unsatisfactory model estimates are caused by the fact that route 2 is dominated in many questions and by the small sample size.

6.3.4 Implications for Next Survey

After implementing the revised pilot survey, many problems remained with the survey design. The first problem was that the route 2 was found to be dominated in some questions of the second section because a high value of time in terms of charge was assumed in the design. According to the results, in fact, the value of time has proved to be below 10 pence per minute. Therefore, the SP choice questions should be redesigned to reflect this. The addition of a charge usually resulted in the uncharged route being dominant in the second section. This hampered the model estimation. This survey only considered the increase of travel time due to the reduced demand on the charged route (from 25 minutes to 20 minutes) as shown in **Table 6-7**, which leads most respondents to choose the uncharged route. To establish the plausible trades-off between two routes, it is necessary to reduce the travel time on the charged route and to increase the travel time on the uncharged route due to the shift of the demand after introducing the charge.

6.4 The Third Pilot Survey

The SP survey design was again refined, in the light of the findings from the revised pilot survey. The first and third part of the questionnaire remain unchanged. With a new SP survey design, the third pilot survey was conducted in Leeds city center. This section will explain a improved new SP design, survey results, analysis and implications for the main survey.

6.4.1 Improved Design

The SP experiment design was developed, based on the results from the previous pilot surveys. First, the travel times were changed in order to reflect the expected shift of demand after road user charge and to avoid the dominance of route 2. The travel time on route 1 decreases from 25 minutes in the first section to 20 minutes in the second section after charges. The travel time on route 2 increases from 35 minutes to 40 minutes after charges. Secondly with the same justifications, the levels of delay time information on route 1 in the second section are also reduced. So delay time on route 1 decreased from 10 or 15 minutes in the section 1 to 5 or 10 minutes in the section 2. **Table 6-12** presents the attributes and levels of SP design for this third pilot survey. Thirdly, charge rates and the amount of charges are reduced because the results of the third pilot survey showed that value of time in terms of charge might be less than 10 pence per minute. Finally, the number of SP questions were changed due to the changes of the number of attributes in the SP design. Each respondent has 9 SP questions, two for the first section and seven for the second section. An example of the questionnaire is shown in appendix 3. The redesigned levels of charge rates and levels of charges are summarized in **Table 6-13**.

Table 6-12 Attributes and Levels of information for the third pilot survey

	Attributes	Levels	
		Route 1	Route 2
Section 1	Travel time	25 minutes	35 minutes
	Extra delay	10 minutes /15 minutes	No delay /5 minutes
	Observed traffic	Free flowing traffic / Heavy traffic	N/A
Section 2	Travel time	20 minutes	40 minutes
	Extra delay	5 minutes /10 minutes	No delay / 5 minutes
	Observed traffic	Free flowing traffic / Heavy traffic	N/A
	Fixed charge	70 / 120 / 150 (pence)	N/A
	Time based charge	2 / 4 / 8 (ppm)	N/A
	Delay time charge	7 / 10 / 12 (ppdm)	N/A

ppm: pence per minute
ppdm: pence per delay minute

Table 6-13 The types and levels of charge

	Fixed charge	Time-based Charge		Delay time-based charge	
	levels(£)	rate(ppm)	levels(£)	rate(ppdm)	levels(£)
Question 1	0.70	2	0.45 - 0.55	7	0.50 - 0.90
Question 2	1.20	4	1.10 - 1.30	10	1.20 - 1.80
Question 3	1.50	8	1.85 - 2.15	12	0.85 - 1.55
Question 4	0.70	2	0.55 - 0.65	7	0.85 - 1.25
Question 5	1.20	4	0.90 - 1.10	10	0.70 - 1.30
Question 6	1.50	8	1.85 - 215	12	0.85 - 1.55
Question 7	0.70	2	0.55 - 0.65	7	0.85 - 1.25

ppm : pence per minute
ppdm : pence per delay minute

There are also three sets of SP desig depending on the types of charges. Each set has nine SP choice questions; two in which only traffic information is given and seven in which traffic information and the charge information is given. To avoid overloading the respondents, each respondent was asked only one of the three sets. **Table 6-14** summarises the revised SP design.

Table 6-14 SP design for the third pilot survey and the main survey

Set 1 for SP design for the fixed charge							
Question	Ttime 1	Ttime 2	Delay 1	Delay 2	Local Traffic	Charge (pence)	
1	25	35	10	0	Heavy	n/a	
2	25	35	15	5	Free	n/a	
3	20	40	5	0	Free	70	
4	20	40	10	5	Heavy	120	
5	20	40	5	0	Heavy	150	
6	20	40	10	5	Free	70	
7	20	40	5	5	Free	120	
8	20	40	5	5	Heavy	150	
9	20	40	10	0	Free	70	
Set 2 for SP design for the time-based charge							
Question	Ttime 1	Ttime 2	Delay 1	Delay 2	Local Traffic	Charge Rate	Charge (pence)
1	25	35	10	5	Free	n/a	n/a
2	25	35	15	0	Heavy	n/a	n/a
3	20	40	5	0	Free	2	45 - 55
4	20	40	10	5	Heavy	4	110 - 130
5	20	40	5	0	Heavy	8	185 - 215
6	20	40	10	5	Free	2	55 - 65
7	20	40	5	5	Free	4	90 - 110
8	20	40	5	5	Heavy	8	185 - 215
9	20	40	10	0	Free	2	55-65
Set 3 for SP design for the delay-based charge							
Question	Ttime 1	Ttime 2	Delay 1	Delay 2	Local Traffic	Charge Rate	Charge (pence)
1	25	35	10	5	Heavy	n/a	n/a
2	25	35	15	0	Free	n/a	n/a
3	20	40	5	0	Free	7	50 - 90
4	20	40	10	5	Heavy	10	120 - 180
5	20	40	5	0	Heavy	12	85 - 155
6	20	40	10	5	Free	7	85 - 125
7	20	40	5	5	Free	10	70 - 130
8	20	40	5	5	Heavy	12	85 - 155
9	20	40	10	0	Free	7	85 - 125

6.4.2 Simulation Test

The improved SP design was tested using simulation. As explained, there are two alternatives with three or four attributes on two or three levels. There are three sets of SP design depending on the types of charges. It contained nine SP questions.

Two different pairs of valuations were specified for each set of design to recover: (VoT, VoD5, VoD10, VoD15, VoHT); (-7.5, -50, -140, -200, -100) and (-7.5, -50,

-100, -150, -50). Two runs for each design were simulated. Each run simulated the response from 200 individuals to the nine questions making a sample size of 1800 choices.

The simulation results were summarised in **Table 6-15**. The fourth column indicates the artificial utility values specified by the designer and the fifth column shows the estimated values using the simulated responses.

Table 6-15 Simulation Test Results for the Third Pilot Survey

Design	Run	Set	Specified Values (A)	Estimated Values (B)	Difference (B-A)	Ratio (%) (B-A)/A*100
Design Set 1 for the fixed charge	Run 1	VoT	-7.5	-6.7	0.9	-11.3
		VoD5	-50	-53.0	-3	6.0
		VoD10	-140	-108.1	31.9	-22.8
		VoD15	-200	-170.8	29.2	-14.6
		VoHT	-100	-33.3	66.7	-66.7
	Run 2	VoT	-7.5	-8.0	-0.5	6.7
		VoD5	-50	-47.4	2.6	-5.2
		VoD10	-100	-110.0	-10	10.0
		VoD15	-150	-134.0	16	-10.7
		VoHT	-50	-42.0	8	-16.0
Design Set 2 for the time-based charge	Run1	VoT	-7.5	-6.3	1.2	-16.0
		VoD5	-50	-64	-14	28.0
		VoD10	-140	-146	-6	4.3
		VoD15	-200	-150	50	-25.0
		VoHT	-100	-66.7	33.3	-33.3
	Run2	VoT	-7.5	-9.3	-1.8	24.0
		VoD5	-50	-50.9	-0.9	1.8
		VoD10	-100	-170	-70	70.0
		VoD15	-150	-132.8	17.2	-11.5
		VoHT	-50	-54.6	-4.6	9.2
Design Set 3 for the delay-based charge	Run1	VoT	-7.5	-5.2	2.3	-30.7
		VoD5	-50	-87.8	-37.8	75.6
		VoD10	-140	-239.5	-99.5	71.1
		VoD15	-200	-166.6	33.4	-16.7
		VoHT	-100	-126.3	-26.3	26.3
	Run2	VoT	-7.5	-10.3	-2.8	37.3
		VoD5	-50	-56.3	-6.3	12.6
		VoD10	-100	-55	45	-45.0
		VoD15	-150	-125.8	24.2	-16.1
		VoHT	-50	-97.6	-47.6	95.2

VoT: coefficient of travel time / coefficient of charges
VoD5: coefficient of 5 minutes of delay / coefficient of charges
VoD10: coefficient of 5 minutes of delay / coefficient of charges
VoD15: coefficient of 5 minutes of delay / coefficient of charges
VoHT: coefficient of heavy traffic / coefficient of charges

To show relative deviation between specified values and estimated values, the last column summarises the calculated ratio between them. ALOGIT is unable to determine the value of the scale parameter, μ. Therefore, by taking ratios, the relative attribute valuation can be obtained which will cancel out the scale parameter μ and be compared with the design values. The ratio was calculated for each statistic given by the general expression

Ratio = (Estimated Value - Specified Values) / Specified Value

The results showed that the overall results are satisfactory, which indicate that the design can recover a reasonable range of relative valuations. Therefore, the designs of SP questions were capable of supporting the intended analysis.

6.4.3 Data Collection & Descriptive Analysis

6.4.3.1 Data Collection

The third pilot survey was conducted in March 1997. The questionnaires were distributed personally to commuters who arrived Woodhouse Lane multistory car park in Leeds between 7:00 and 9:00 in the morning. There were 30 questionnaires per each charge regime: the fixed charge, the time-based charge and delay the time-based charge. Of 90 questionnaires handed out, 52 were returned and 49 were available for modeling purposes giving a response rate of 54% and contained a total of 441 choice observations

6.4.3.2 Descriptive Analysis

Among respondents, 67% were male and most of them were between 25 and 54 years old. The income distribution shows that 51% of respondents said their annual income was between £20,000 and £40,000 and 31% more than £40,000. 90% of them were full-time employment and 61% of them had flexible start time at work.

Respondents were asked about their journey time for their commuting in the morning. The average journey time reported for commuting was 35.3 minutes with 19.9 minute standard deviation. The average work start time for commuting was 8.15 a.m. To the question about who pay the petrol cost, most of respondents answered they paid it by themselves (94%).

The respondents were asked to estimates their own petrol costs for route 1 and route 2 in the SP experiments. This question was also asked in the previous pilot surveys but it has not been discussed in previous sections because there were not enough data. As a result of this third pilot survey, the average estimates of petrol costs are 69 pence for route 1(standard deviation is 42.7) and 84 pence for route 2 (standard deviation is 51.7). It is interesting that the estimate of petrol costs on route 1 is 17 pence per mile, while that on route 2 is 8.4 pence per mile that is much lower than on route 1. It means that some drivers tend to consider their car operating costs more in congested traffic.

The respondents were also asked about their experience of using different types of traffic information system and their perception about the usefulness of these systems and information. About 73% of respondents have had experience with VMS before and 88% of them said that it was useful. This indicates that respondents' route choices in the SP questions were based on their experience with VMS and good perception about its usefulness. 67% of respondents had experience with radio message and 82% of them thought it was useful. No one have used IVG before. However most of them knew what it was and some of them said that if they could afford it, it might be very useful to them.

Table 6-16 Experience and usefulness with traffic information

	Experience with information			Usefulness of information		
	Frequent	A little	Never	Yes	Somewhat	No
VMS	11	25	13	24	19	6
(%)	*22*	*51*	*27*	*49*	*39*	*12*
RADIO	12	21	16	26	14	9
(%)	*24*	*43*	*33*	*53*	*29*	*18*
IVG	0	0	49	N/A	N/A	N/A
(%)	*0*	*0*	*100*	N/A	N/A	N/A

The respondents were also asked about their attitudes to road user charging. It was assumed that charge was introduced to Leeds city center with 3 charge levels: 50 pence per day, £1.00 per day and £2.00 per day. The first choice of all three levels of charges was changing departure time earlier (about 25%). The second choice was paying a charge (about 20%) and the proportion of respondents choosing to pay the charge decreased to 14% as charge increased. The third choice was using public transport.

6.4.4 Analysis of Results

In order to explain the influence on route choice of traffic information and road user charge, logit models were estimated. As with the previous pilot, four logit models were estimated separately depending on the charge regime, but the estimates results were not satisfactory because of small sample size and too many variables. Instead, a single model was estimated which allowed a charge parameter for each charging regime. Thus it makes it possible to analyze and compare the different effects of each charge. This model also allows separate delay variables depending on the length of delay. The model was based on the median value of the range of charges presented in the case of the time-based charge and the delay time-based charge.

Table 6-17 Model for the influence of traffic information and road user charge

	Model	
	Coefficient	T-ratio
Total Travel time	**-0.068**	**-2.9**
Extra 5 minutes delay on VMS	-0.232	-1.0
Extra 10 minutes delay on VMS	-0.634	-1.7
Extra 15 minutes delay on VMS	**-1.736**	**-3.7**
Heavy traffic	**-0.612**	**-2.5**
Fixed charge	**-0.014**	**-3.4**
Time-based charge	**-0.014**	**-3.1**
Delay time-based charge	**-0.024**	**-4.2**
Number of observation	**441**	
Likelihood	**-255.650**	
Rho-Squared	**-0.164**	

The numbers in bold mean that they are significant and have correct signs

The model estimates, shown in **Table 6-17**, are very satisfactory despite a small sample size and many parameters: the value of rho-squared is reasonably high; all parameters have intuitive signs; and most parameters are significant.

The parameter, *5 minutes delay* is not significant. It may be because 5 minutes' delay is not long enough to have significant effects on route choice. The relative size of delay parameters shows that as length of delay increases, the influence on route choice become greater. The parameter, *15 minutes delay,* indicates that drivers are more likely to change their route when 15 minutes delay is given. The parameter, *Heavy traffic* also indicates that when drivers observe heavy traffic conditions at the decision point, they are less likely to choose the route.

The charge parameters indicate that other things being equal, drivers are less likely to choose the charged route. The difference of charge parameters means that a delay time-based charge has more influence on route choice than a fixed or a time-based charge. The values of time are calculated based on the model estimates. The values of time are: 4.9 pence per minute in terms of the fixed charge and in terms of the time-based charge; and 2.8 pence per minute in terms of the delay-time based charge.

The value of extra delay time presented on VMS is also estimated based on the model estimates. The value of extra 5 minutes delay is equivalent to 3.4 minutes of normal travel time that indicates that drivers value 5 minutes of extra delay less than the equivalent amount of undelayed travel time. The value of 10 delay minutes is 9.3 minutes of normal travel time, which indicates that people value the delay time slightly less than undelayed travel time. The value of 15 minutes delay is 25.5 minutes of normal travel time, much higher than normal travel time. It appears that motorists become increasingly sensitive to delay time as it increase. The value of delay time is non-linear and the value of delay time is not always higher than the value of travel time. It seems that drivers did not value delay time differently from the travel time up to a certain level of delay, but when delay time increases over the lever, they become to value it greater than travel time. This model suggests that this level is approximately 10 minutes of extra delay time. This will be also discussed in section 7.4.6.

6.4.5 Implications for Main Survey

The results from the third pilot survey were very satisfactory. The model estimates were satisfactory: the rho-squared value is acceptable; all parameters have intuitive signs; and most of parameters are significant regardless of small sample size. The delay related parameters were estimated separately depending on the length of delay. It allowed to estimate value of delay time, which showed plausible values. Three charging parameters were separately estimated and the value of time were also acceptable. Therefore, we conclude that the design of this third pilot survey is good enough for a main survey.

6.5 Data Collection of the Main Survey

The main SP survey of which design was decided in the previous section was conducted in April and May, 1997. The questionnaires were distributed personally to drivers commuting between 7:00 am and 9:00 am at the several car parks in Leeds; in Woodhouse Lane, Calverley Street, Clay Pit Lane, and Whitehall Road.

There were 190 questionnaires per each charging regime: fixed charge, total time-based charge and delay time-based charge. For the main survey, among the 570 questionnaires handed out, **236** were returned giving a response rate of 41.4%. The data from the third pilot survey was combined with those from the main survey and produced a final data set. It included a total of 281 questions and contained a total of 2626 SP choice observations. Example of the questionnaires are given in appendix 3.

6.6 Summary and Conclusion

In this section, the survey development process was discussed in order to find out the better design for the main survey. Three pilot surveys were conducted between November 1996 and March 1997. Each pilot survey results were carefully analyzed and the next survey design was refined, based on the results. **Figure 6-1** depicts the process of the survey development.

The initial pilot survey was conducted in November 1996. It revealed several problems in the survey design. Therefore, the survey design for the revised pilot survey was refined, based on the results of the initial pilot survey. Firstly, a more detailed explanation was given to respondents about delay information. Secondly, the cause of delay variable was omitted because it caused strong correlation between the delay variables and the cause of delay variable, and it also made the experiment complicated. Thirdly, normal travel time on route 1 for the second section was reduced to 20 minutes in order to take consideration of the shift of demand due to charges. Fourthly, the levels of delay time also changed. The *no delay* and *5 minutes delay* were omitted in order to give more realistic choice options. Finally, the part 3 included asked more detailed attitude questions that include different levels of charges and several options.

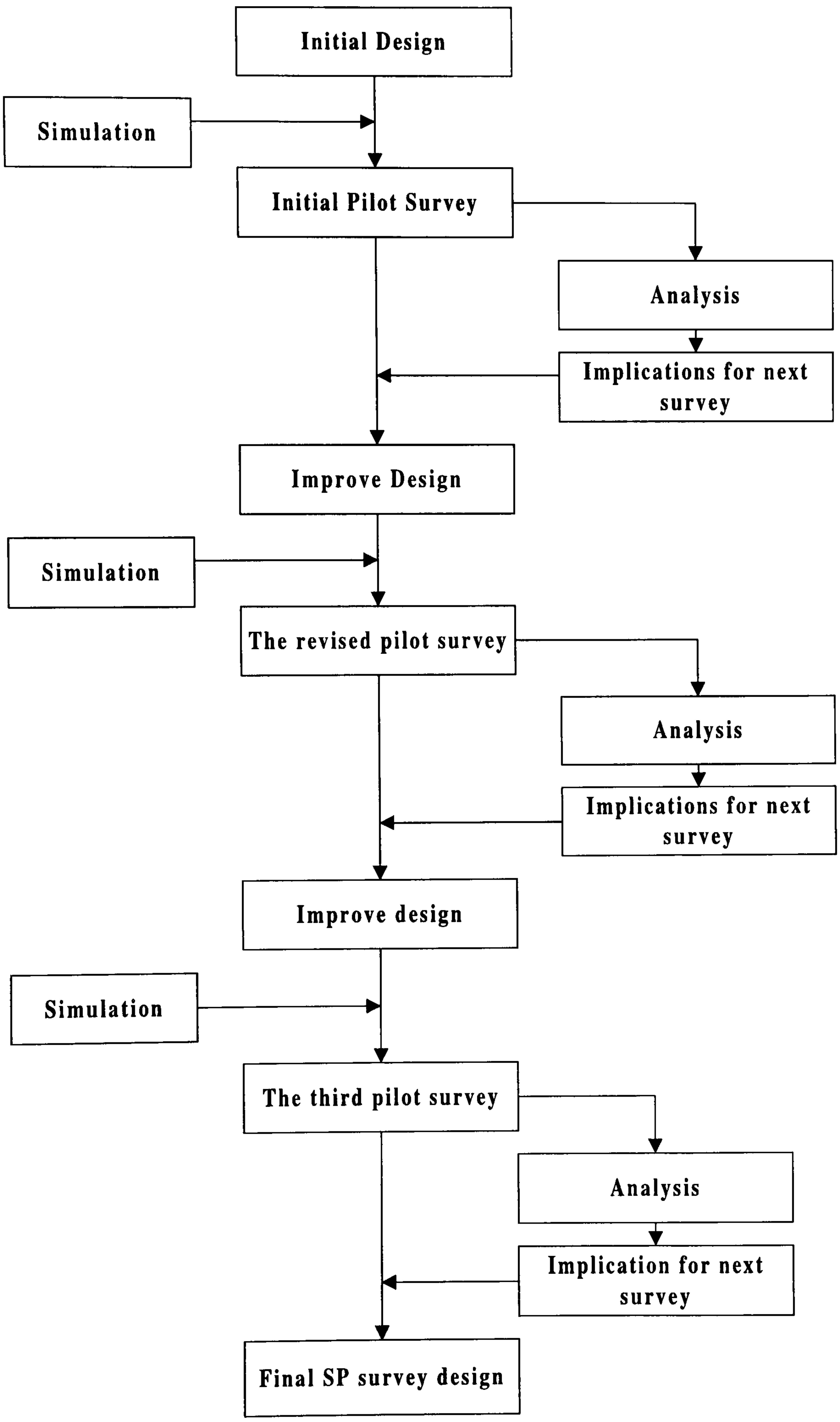

Figure 6-1 The flow chart of survey development process

The revised pilot survey was conducted in January 1997. Even though the design was developed, the survey results were also not satisfactory and showed many problems. The main problem was that after charges the uncharged route was dominated. In order to establish a plausible trade-off, charge rate and levels were redesigned based on the second pilot survey results. The normal travel time was also changed in order to reflect the shift of demand due to charges. The normal travel time on the charged route was reduced and that on the uncharged route was increased after introducing charges in the second section. Finally, the number of SP questions was changed as a result the change of the attributes and their levels.

The third pilot survey was conducted in March 1997 with the improved design. The results were very satisfactory. Therefore, the survey design of the third pilot survey will be adopted in the main survey.

This survey development process not only refined the survey design but also facilitated a number of other benefits: First it helped to develop the presentation of information about delay and charges through the feedback from the respondents. Secondly, it also helped to practice the process of dealing with data and to analyze and interpret the results. Finally, it gave the rough value of time for the respondents.

The design of the main survey was decided based on the SP design of the third pilot survey. The main survey was conducted in April and May, 1997 in the Leeds center car park to commuters during the morning peak. In total 236 questionnaires were returned, giving a response rate 41.4%. The descriptive analysis of the results will be discussed in chapter 7 and the analysis of the SP data from the main survey will be discussed in chapter 8.

Chapter 7

Main Survey : Analysis of Qualitative and Attitudinal Data from Main Survey

7.1 Introduction

This chapter discusses the descriptive analysis of the results of survey. As described in the chapter 6, there are three parts in the questionnaire. The first part included questions about the socio-economic characteristics of respondents and their travel patterns. It included questions which asked respondents to estimate their own petrol cost based on the hypothetical routes in SP experiments and questions about respondents' experience with traffic information systems and their perceived usefulness. The second part contained the SP experiments. The third part contained the attitudinal questions about the road user charging. This chapter will discuss the results from the first and third part of the questionnaire.

Section 7.2 summarizes the respondents' characteristics and travel patterns, such as sex, age, income distribution, employ status, and so on. It also includes the estimates of the petrol cost of the hypothetical routes which derive the cost caused by the congestion. Section 7.3 reports the respondents' experiences with different types of traffic information systems and their perceived usefulness.

Finally, section 7.4 discusses respondents' attitudes toward introducing road user charges in Leeds city center. Three levels of charge were given and the change in responses according to the increase of the charge will be discussed. The responses to the charges depending on the socio-economic characteristics of the respondents such as sex, age and income will also be discussed. At the end, various comments about the road user charges will be discussed.

7.2 Respondents' Characteristics and Travel Patterns

The respondents' socio-economic characteristics and travel patterns are summarized in **Table 7-1**. The sample of commuters displays an even distribution across gender, age and income categories.

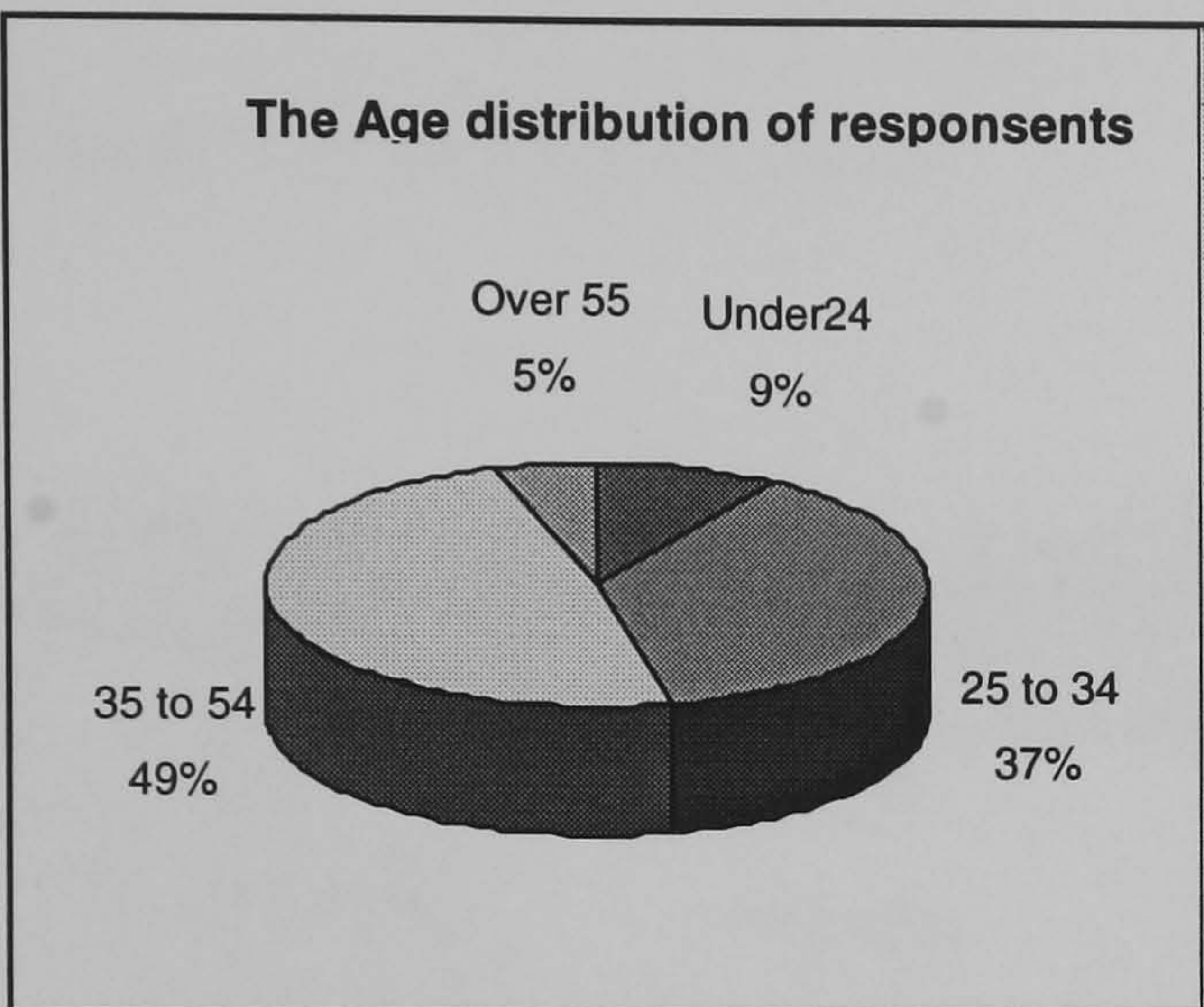

Figure 7-1 Age distribution of respondents

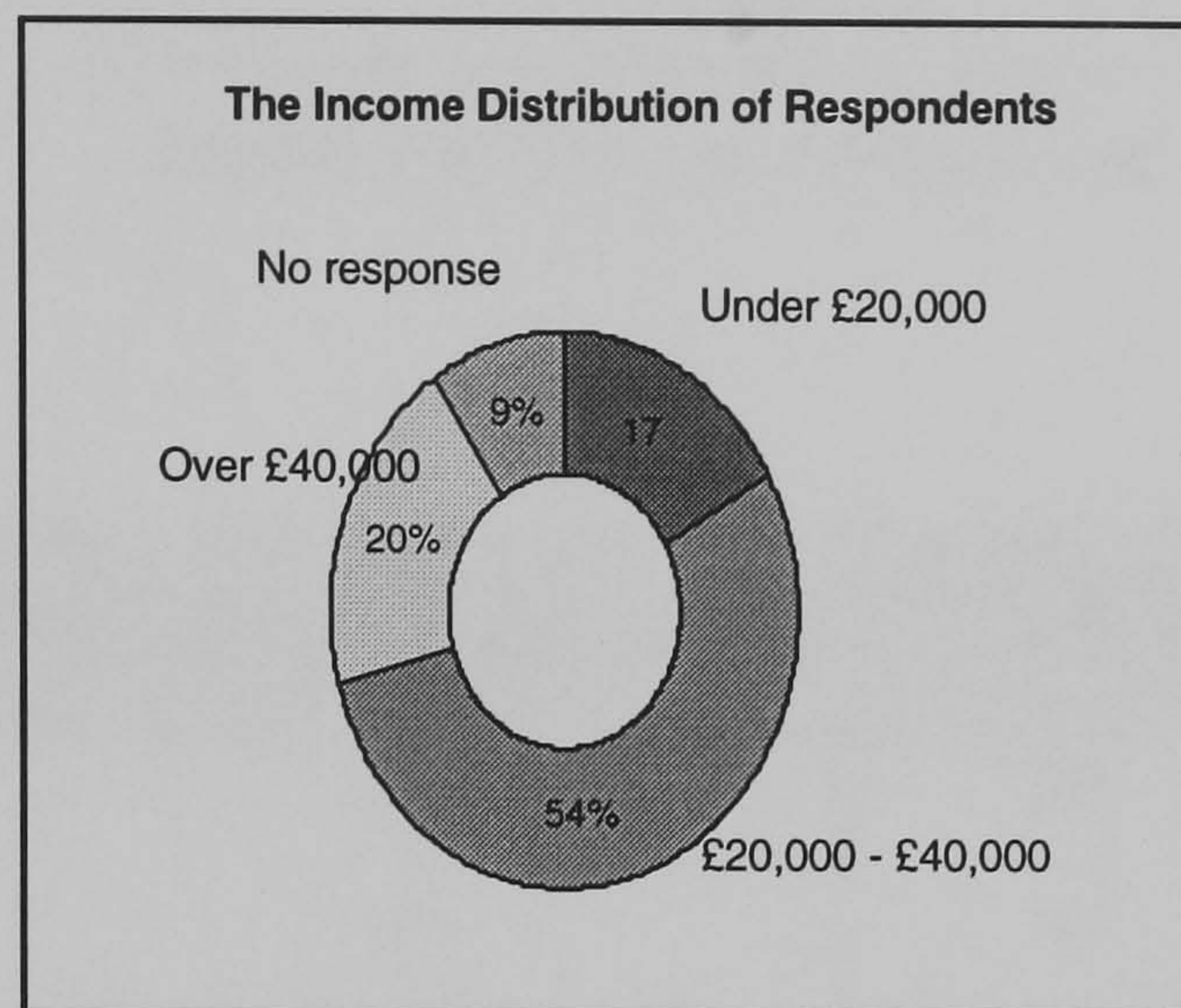

Figure 7-2 Income distribution of respondents

57.5% of respondents were male, which means the sex of sample is evenly distributed. Half of the respondents were between 35 and 54 years old and 37% were between 25 to 34 years old. This sample seems to well represent the characteristics of the population of Leeds commuters. According to 1991 Census data (HMSO 1991), total number of commuters who were employee or self-employed in Leeds was 298123 and 55% of them were male. It also reported their age distribution: 17% under 24 years old; 25% between 25 and 34 years old; 44% between 35 and 54 years old; and 13% over 55 years old.

The income distribution shows that 54% of respondents said their annual income was between £20,000 and £40,000 and 20% answered more than £40,000. 90% of them are full-time employed and 51% of respondents have flexible work start time.

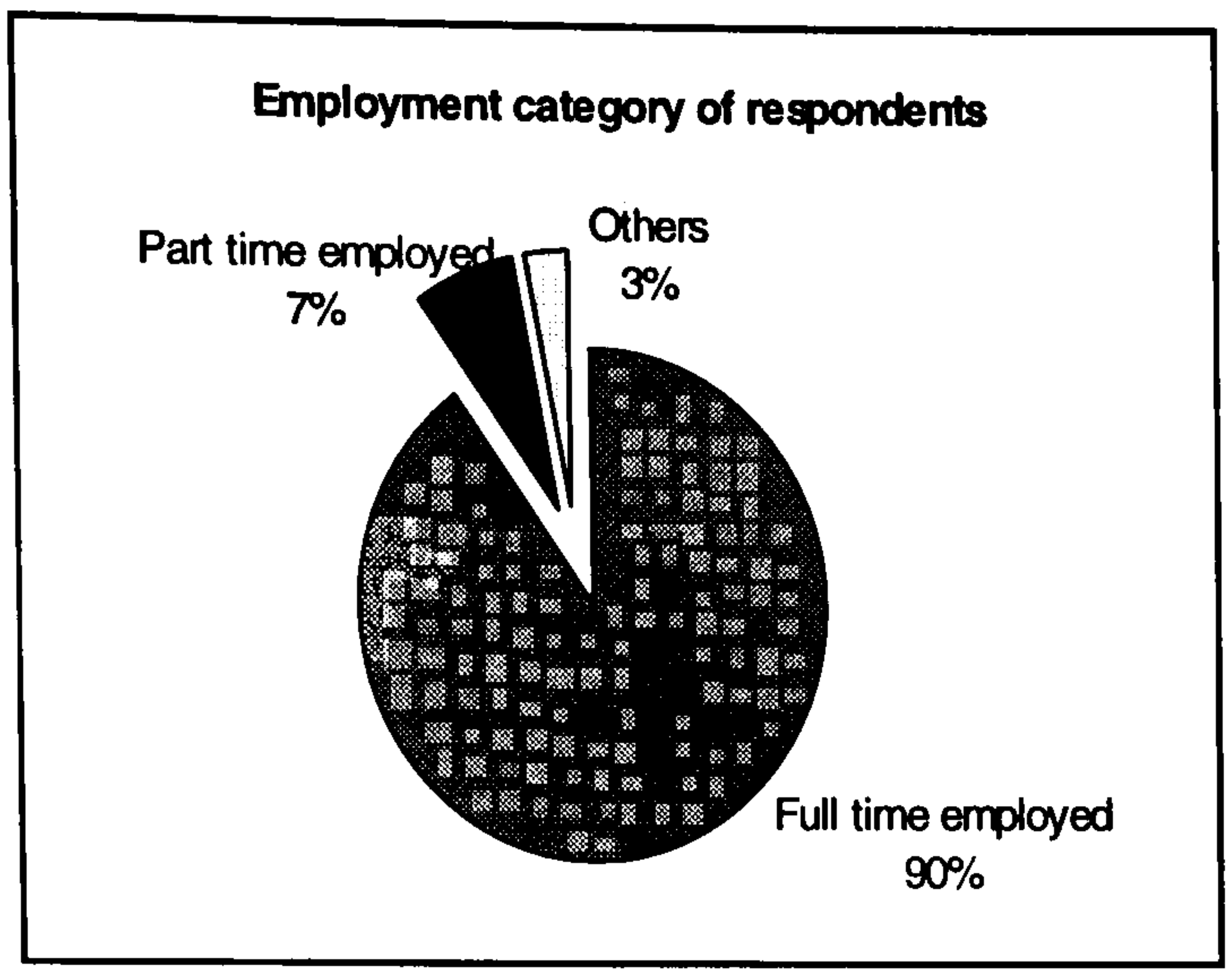

Figure 7-3 Employment status

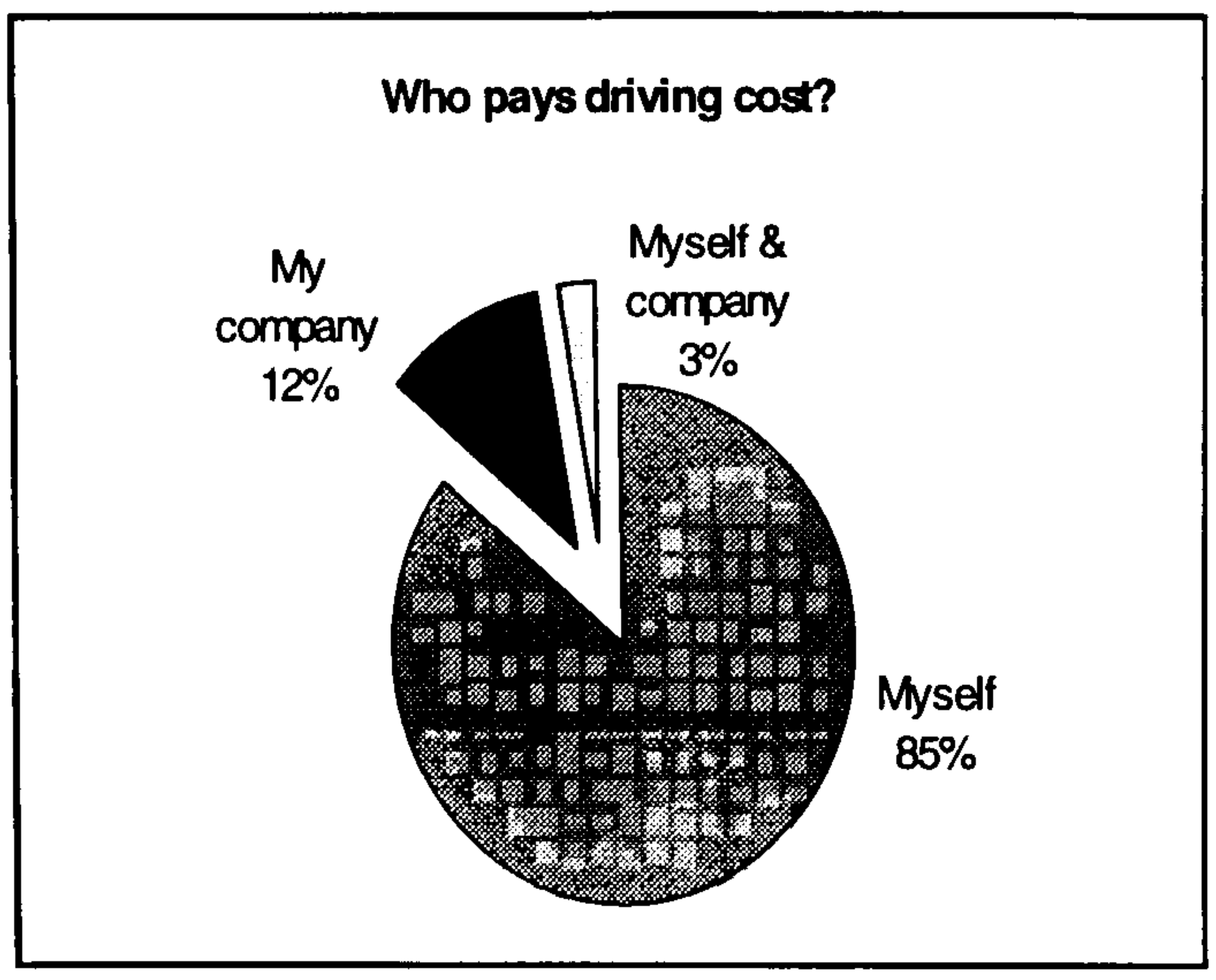

Figure 7-4 Who pay driving costs

Table 7-1 Socio-economic characteristics and travel patterns of respondents

Items	Categories	Number of respondents	(%)
Sex	Male	162	58
	Female	119	42
Age	under 24	25	9
	25-34	105	38
	35-54	137	49
	over 55	14	5
Income	under £ 20,000	47	17
	£ 20,000 - £ 40,000	151	54
	over £40,000	55	20
	No response	28	9
Who pay driving cost?	Myself	241	85
	Company	33	12
	Myself & Company	7	3
Employ status	Full time	253	90
	Part time	19	7
	Others	9	3
Work start time	Fixed	137	49
	Flexible	144	51

To the question about who pays the petrol cost, most of the respondents answered they paid it by themselves (85%) and 12% said their company paid. Only 3% reported that the cost was shared between themselves and their company.

Respondents were asked about the journey time for their commuting in the morning. The average journey time for commuting in the morning was 37 minutes with 19 minutes standard deviation. The average work start time was reported to be 8:25 a.m. with 14 minutes standard deviation.

The respondents were asked to estimate their own petrol costs for hypothetical routes 1 and 2 in the SP experiments (see the questionnaire in the appendix 4). The average estimates of petrol costs were 75.8 pence for route1 (standard deviation is 95.2) and 90.5 pence for route 2 (standard deviation is 101.9). This means that the estimate of petrol cost on route1 was 19.0 pence per mile, while that on route 2 was 9.1 pence per mile which is less than half of the cost on route 1. These results indicate that some drivers tend to consider their car operating costs much more in congested traffic. Car type and petrol type contributes to a high standard deviation. Many drivers said that it would be difficult to predict the operating costs because different types of car and different types of petrol to use. Many drivers who did not give the estimate of the costs, mentioned that it is difficult to estimate the cost but the cost of route 1 might be higher than that of route 2. The results indicate that most drivers already perceive the additional cost caused by congestion. In this study, the perceived additional cost caused by the congestion was 9.9 pence per mile, which contributes to the difference of costs between route 1 and 2.

Table 7-2 Estimates of petrol cost of hypothetical routes

	Average Petrol cost	S.D.	Petrol cost ratio(pence/mile)
Route 1	75.8	95.2	19.0
Route 2	90.5	101.9	9.1

Route 1 is 4 miles and Route 2 is 10 miles

The fact that the cost per mile of route 1 is higher than that of route 2 also means that respondents consider route 1 as congested and understand the hypothetical travel situation.

7.3 Experience with Traffic Information Systems

Respondents were asked about their experience of using different types of traffic information systems and their perception about the usefulness of these systems and information. Three systems, Variable Message Signs (VMS), radio traffic information and in-vehicle guidance systems were considered. **Table 7-3** presents the results of questions about experience and usefulness of traffic information.

Table 7-3 Experience and usefulness with traffic information

	Experience with information				Usefulness of information			
	Frequent	A little	Never	No response	Yes	Somewhat	No	No response
VMS	772	1166	587	92	1058	871	140	548
(%)	*29.4*	*44.4*	*22.4*	*3.5*	*40.3*	*33.2*	*5.3*	*20.9*
RADIO	889	1259	460	18	1230	907	128	361
(%)	*33.9*	*47.9*	*17.5*	*0.7*	*46.8*	*34.5*	*4.9*	*13.7*
IVG	18	45	2312	251	36	81	394	2104
(%)	*0.7*	*1.7*	*88.0*	*9.6*	*1.4*	*3.1*	*15.0*	*80.1*

IVG: In-vehicle guidance systems

About 73% of respondents had had experience with Variable Message Signs before of whom 29.4% had used it frequently. Of these 73.5% thought that it was useful. This indicates that respondents' route choices in SP questions are based on their experience with VMS and good perception about its usefulness. 67% of respondents had made use of radio messages about traffic conditions and 82% of them said it was useful. Most of respondent (98%) had never used in-vehicle guidance systems but they knew what it was and some of them said if they could afford it, it might be very useful.

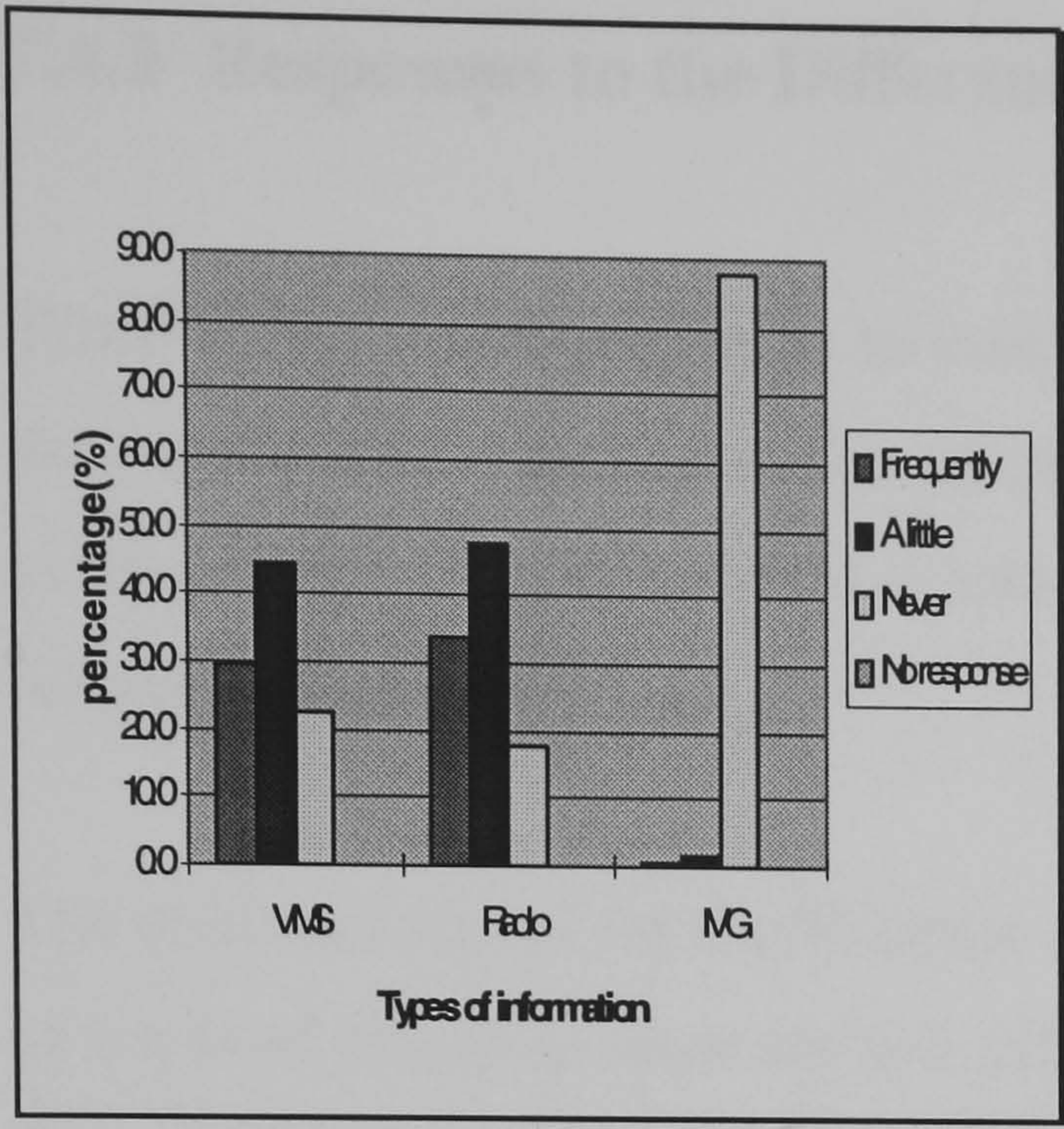

Figure 7-5 Experience with traffic information

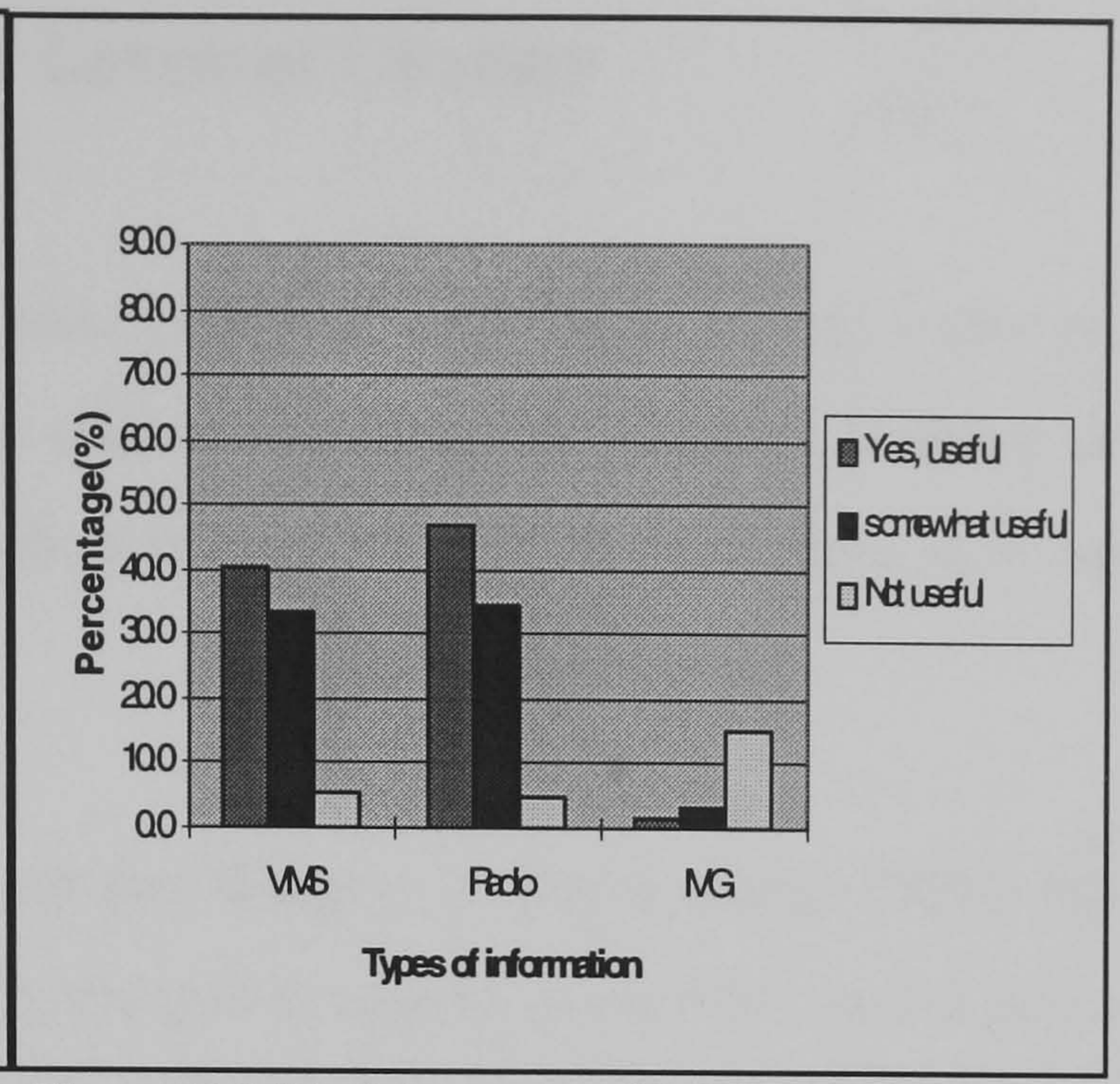

Figure 7-6 Usefulness of traffic information

7.4 Responses to Road User Charges

7.4.1 The Attitudes Questions to Road User Charges

In the third part of the questionnaire, the respondents were asked about their attitudes to road user charges. It was assumed that road user charging had been introduced for use of roads in Leeds city center between 7:30 am and 9:30 am. Three levels of charge were given, 50p per day, £1.00 per day and £2.00 per day. The following options were provided and respondents were asked to rank them in order of preference. See an example of the questionnaire in Appendix 4.

1. I would pay the charge
2. I would drive to the edge of the charge area park and then walk or use public transport
3. I would travel before 7:30 am
4. I would travel after 9:30 am
5. I would take a bus or train all the way
6. I would move a jobs
7. Others (please specify)

7.4.2 Responses to the Different Levels of Charges

There are four main responses to road user charging: the first is paying a charge, the second is driving to the edge of the charge area, parking and then walking or using public transport, the third is traveling before 7:30 am; and the final is using the public transport.

The dominant choice for the 50 pence per day charge is to pay a charge (38%) but as levels of charge increase up to £ 2.00, the percentage of those who would pay a charge decrease from 38% to 9%. These results indicate that if a road user charge was introduced, drivers would pay it until the charge level was reasonable. They are very sensitive to the increase of charges. A similar survey (Harris Research Centre 1991), conducted in London about attitudes to road user charge, found that the increases in the toll would induce dramatic changes in drivers' behavior. Meland and Polak (1993) also suggested in their study of the Trondheim toll ring that doubling the toll would decrease traffic by 36 % during toll hours.

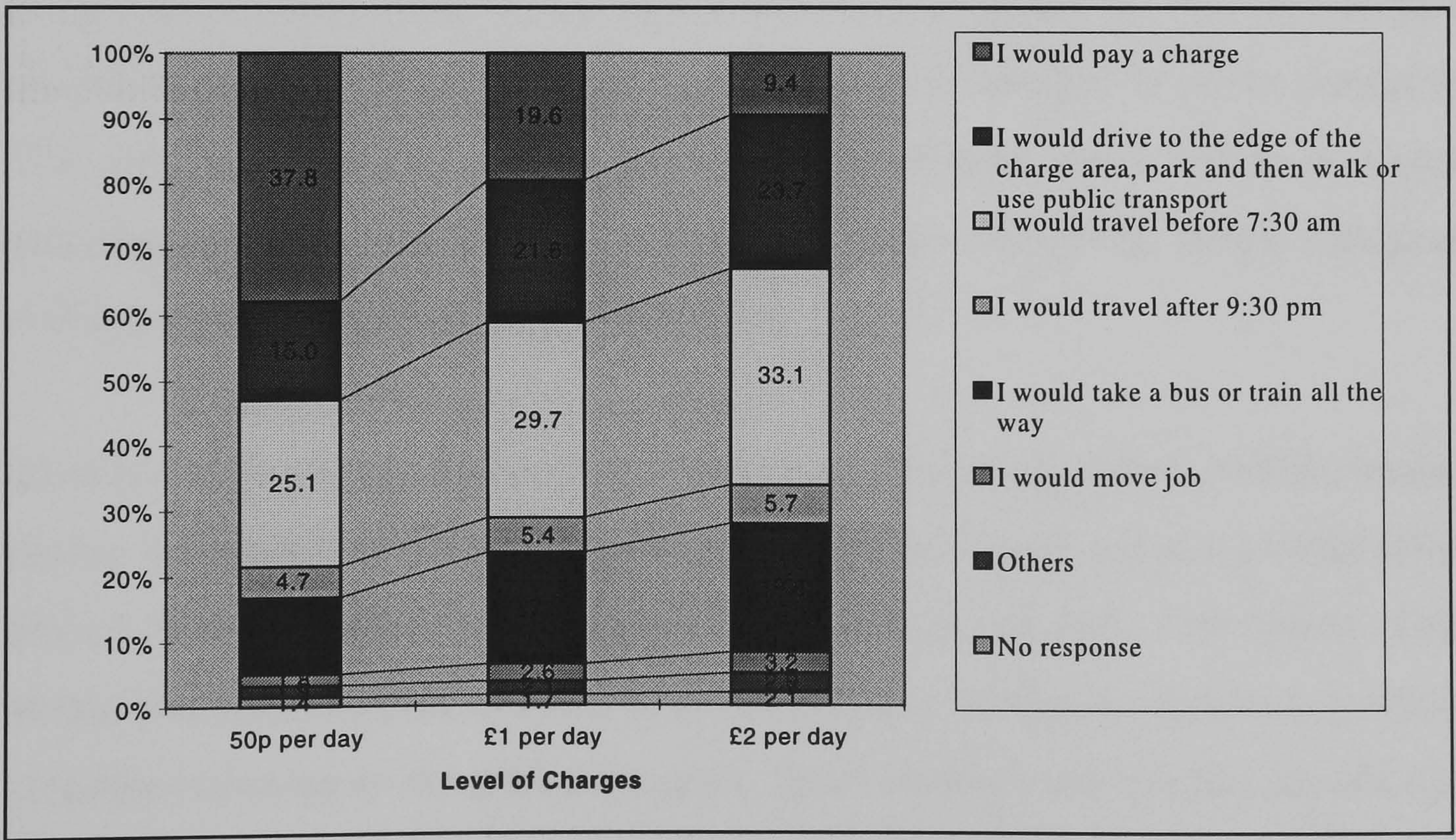

Figure 7-7 Attitudes in response to different levels of road user charges

The percentage of people who would travel before 7:30 a.m. to avoid a charge increases as charge levels increase, i.e. 25% with 50 pence per day, rises to 33%

and becomes the dominant choice for charges of £ 1.00 and £2.00. These mean that changing departure time to earlier is the most likely result outcome to avoid charge as the charge level increases. The trend of changing departure time to earlier to avoid a charge is also discovered as common responses in the other study (Holland and Watson 1978). In Singapore, after the introduction of the Area License Scheme (ALS), the percentage of car drivers who started their trip before 7:30 am increased to avoid charge between 7:30 and 9:30 am.

As the third answer, the percentages of respondents who would drive to the edge of the charge area, park and then walk or use public transport, increased from 15.3% for 50p to 21.6% for £1 and to 23.7% for £2.

Some of respondents said they would use public transport to avoid a charge and this value also increased from 11.7% to 19.8% as the charge level increased. The mode shift from car to public transport due to charges were also discovered in other studies. Holland and Watson (1978) reported there was a reduction of car and taxi use mainly due to travelers shifting to carpools and buses. In the study of the Bergen toll (Larsen 1988), it was also found that the amount of car use decreased sharply to avoid a charge because regular car users switched to public transport. The analysis of the Oslo toll ring also reported that there was a decline in cordon crossing due to a switch the mode from the car to carpooling, public transport, walking and bicycling (Gomez-Ibanez 1994).

Overall results are that if a road user charge was introduced, drivers would consider paying a charge first. But when the charge level increased above a certain level, drivers would consider changing their departure time as their first option. They would also consider park and ride to avoid a charge. As the last option they would consider switching to the public transport. These results mean that the introduction of a peak period road user charge may contribute to spread the traffic demand rather than reduce it. This is because respondents are not willing to give up their car use due to the road user charges.

7.4.3 Responses to Charges Depending on the Socio-Economic Characteristics

In section 7.4.2, the overall responses to the road user charges were discussed. The responses to road user charge is expected to be different depending on social-economic characteristics of respondents. The relevant studies (e.g. Harris Research Centre 1991; Gomez-Ibanez 1994; MVA, 1995) suggested that males were slightly more likely to pay to travel by car, and those who own more than two cars were less likely to change their journey patterns due to the charges. In this section, the responses to charges depending on the sex, age and income of respondents will be discussed.

Before the analysis of responses depending on the socio-economic characteristics, the correlation test was conducted to investigate whether there was strong correlation among sex, age, and income levels of respondents. Small negative correlations were found between sex (male = 1 and female = 2) and age (-0.15) and between age and income (-0.11), while there was small positive correlation between sex and income (-0.08). In my opinion, these correlation are small enough to be ignored.

7.4.3.1 Responses to the Charges by Sex

Figure 7-8 displays the response to the different levels of charges by sex. There seems to be no significant difference in response to charge between male and female. Males seem slightly more likely to change departure time than females to avoid a charge. Females seem to prefer using the public transport slightly more than males, as to avoid charge.

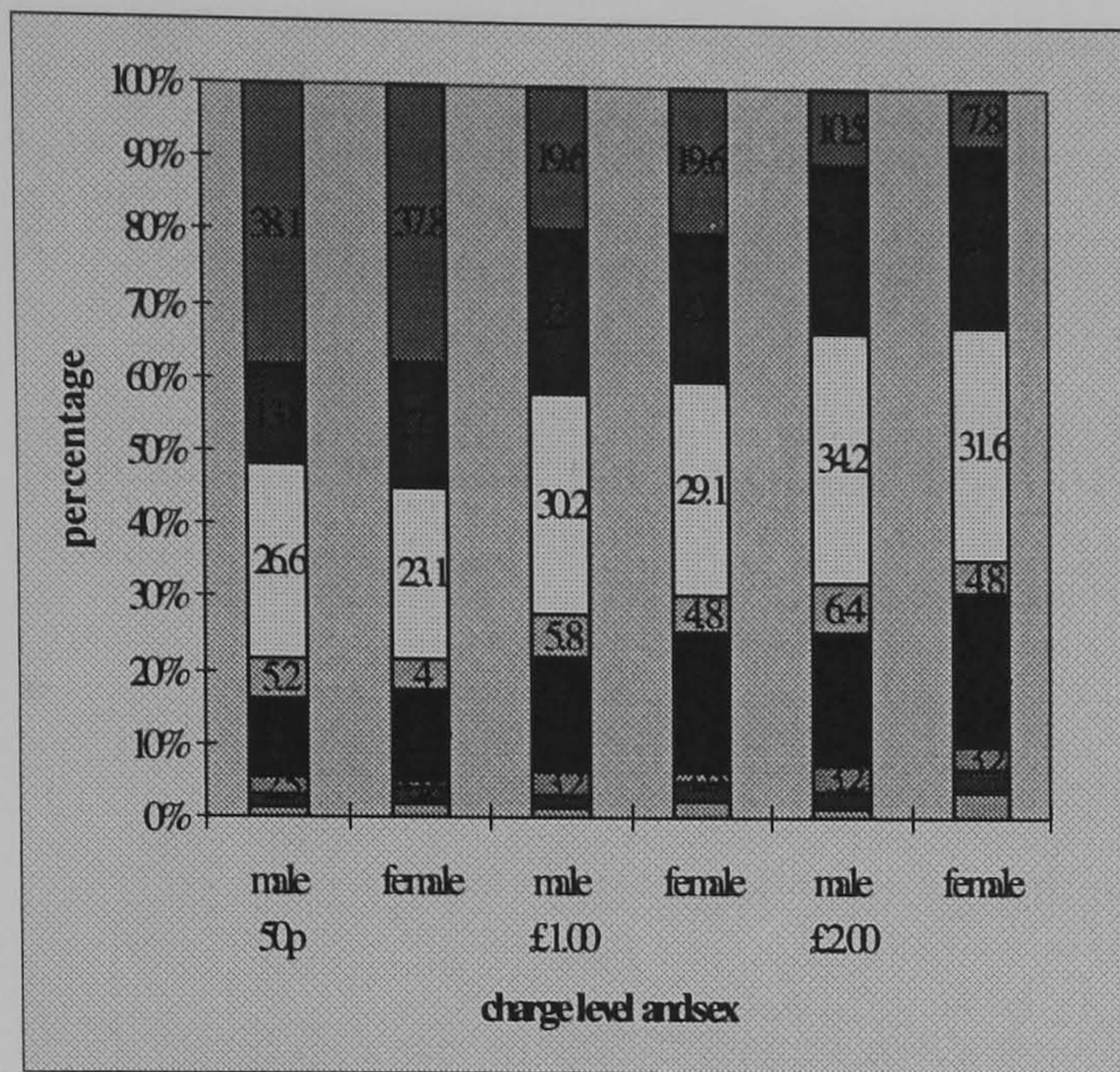

Figure 7-8 Responses to charge by sex

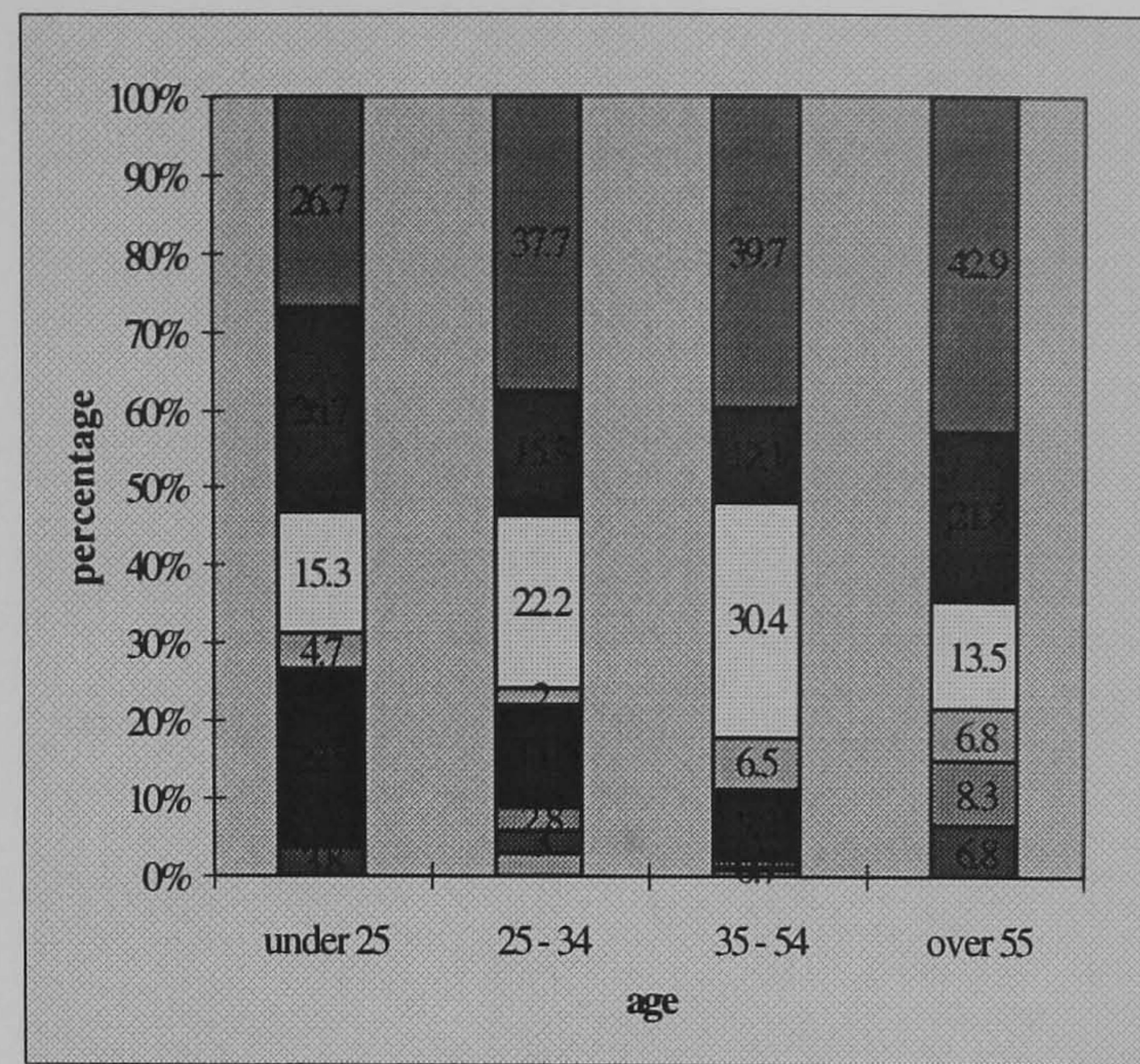

Figure 7-9 Responses to 50p per day by age[1]

7.4.3.2 Responses to the Charges by Age

In this section, the responses to the charges by age will be discussed. The age groups were divided into four: one for those who are under 24 years old, other for those who are between 25 and 34 and another for those who are between 35 and 54 and the other for those who are over 55. **Figure 7-9** to **7-11** show the responses to the different levels of charges depending on the age of the respondents. It seems that there is a different pattern in response to road user charges depending on age. The results are also summarized in **Table 7-4**.

Figure 7-9 shows the response to the charge 50 pence per day by age. If 50 pence per day charge is introduced, as the age of respondents increases, they are more willing to pay a charge. They are more likely to depart earlier except those who are over 55, as the age of drivers increases. The younger the drivers, the more they prefer to switch to public transport to avoid charges, while those who are over 55 did not even consider using public transport. Young drivers under 24 prefer to park and use public transport or walk to avoid charge, but as age increases, this option is less preferred.

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[1] **The legends of options were omitted in Figure 6-8 to 6-11 because of the limit of the space, which are the same as those in Figure 6-7.**

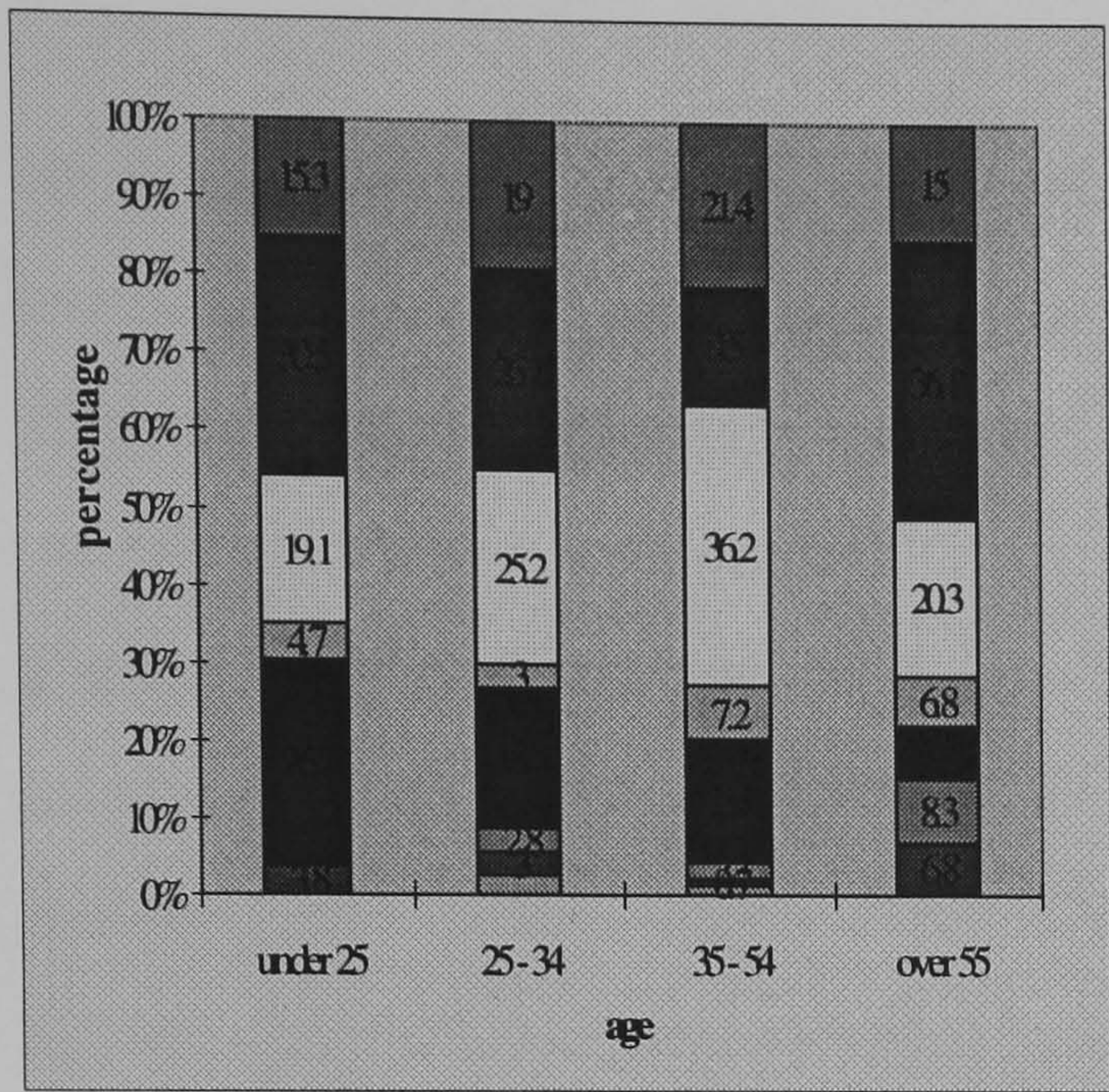

Figure 7-10 Responses to £1.00 per day by age

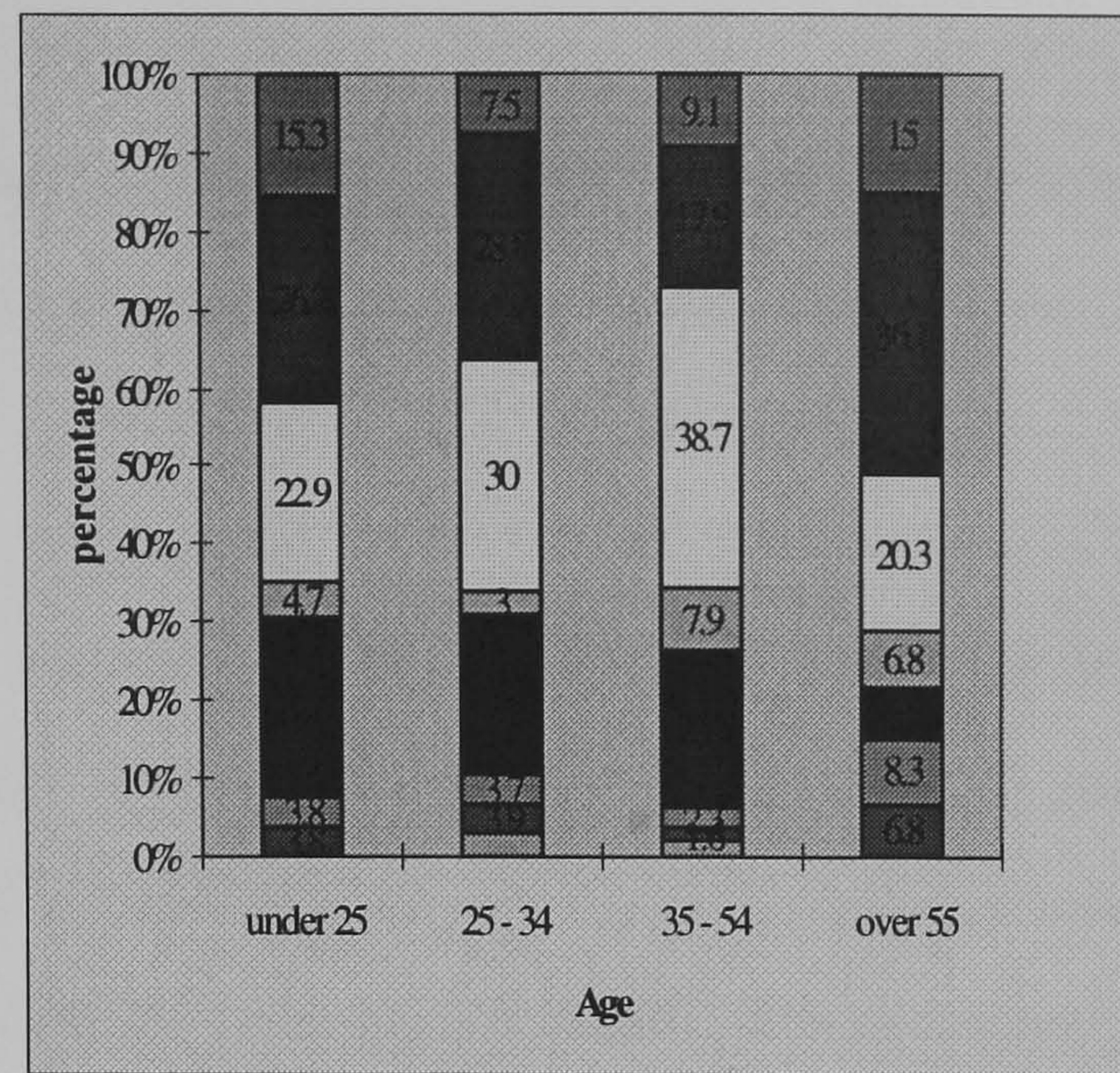

Figure 7-11 Responses to £2.00 per day by age

Figure 7-10 shows the response to the charge of £1.00 per day by age. The willingness to pay a charge slightly increase as the age increase. At the charge level of £1.00 per day, drivers would park and use public transport to avoid charges and this trend decreases as the age level increases from 30.5% to 36.2 % except for those who are over 55. The percentage of those would depart earlier increases rapidly from 19.1% to 36.2 % as the levels of charge increase to avoid a charge. The percentage of those using public transport decreases from 26.7% to 15.8% as the age of the respondents increases.

Figure 7-11 displays the responses to the charge £2.00 per day by age. The most preferred answer is to depart earlier to avoid charge and it increases as the age increases sharply except those who are over 55. The second answer is to park and use public transport or walk. This values decreases as the age of the respondents increases, except for those who are over 55. The third answer is to switch to public transport to avoid a charge, and this seems to decrease as the age of the respondents increases.

Overall, the percentage of those parking and using public transport or walking is higher for younger drivers and as age increases, it decreases. This result is the opposite of those of the previous study (Bonsall and Whelan 1995), which reported that as respondents age increases, they are more likely to use park-and-ride systems.

As above, the response to the charge by age is illustrated depending on the different levels of charge. It also appears that each age group has a certain pattern of response to the road user charges.

Those who are under 24 would pay a charge if it is reasonable. They are less sensitive to the charge levels, than the other age groups. A relatively high percentage of them is prepared to switch to public transport, compared to the other age groups. It is not much changed regardless of charging levels. Those under 24 would also be prepared to use park and use the public transport. This means they are more prepared to give up car use to avoid a charge and switch to the public transport than other age groups.

Table 7-4 Responses to different levels of road user charges by age

Charge levels	Income Categories	Options(%)[2]								
		1	2	3	4	5	6	7	9	total
50 pence per day	under 25	26.7	26.7	15.3	4.7	22.9	0	3.8	0	100
	25 - 34	37.7	15.8	22.2	2.0	13.8	2.8	3.0	2.8	100
	35 - 54	39.7	12.1	30.4	6.5	9.2	0.7	0.7	0.7	100
	over 55	42.9	21.8	13.5	6.8	0	8.3	6.8	0	100
£ 1.00 per day	under 25	15.3	30.5	19.1	4.7	26.7	0	3.8	0	100
	25 - 34	19.0	26.1	25.2	3.0	18.3	2.8	3.0	2.8	100
	35 - 54	21.4	15.0	36.2	7.2	15.8	2.3	0.7	1.4	100
	over 55	15.0	36.1	20.3	6.8	6.8	8.3	6.8		100
£ 2.00 per day	under 25	15.3	26.7	22.9	4.7	22.9	3.8	3.8	0	100
	25 - 34	7.5	28.8	30.0	3.0	20.4	3.7	3.9	2.8	100
	35 - 54	9.1	17.9	38.7	7.9	20.2	2.3	1.6	2.3	100
	over 55	15.0	36.1	20.3	6.8	6.8	8.3	6.8	0	100

[2] The legends of options were omitted in Table 6-4 because of the limit of the space, which are the same as those in Figure 6-7.

Those who are between 25 and 34 show a different response pattern to the charges. They are very sensitive to the increase of charge levels. The willingness to pay a charge decreases from 37.7% to 7.5% as the charge level increase from 50 pence to £2.00 per day. As the first alternative to avoid a charge, they would consider traveling earlier and this trend becomes greater as charge levels increase. This result indicates that they would pay a charge or change their travel pattern by traveling earlier rather than give up the car to avoid charge. They would also consider using park and ride or switching to public transport as the third options as the charge levels increase.

Those who are between 35 and 54 are also very sensitive to the increase of charge levels. Their willingness to pay a charge declines very rapidly from 39.7% to 9.1% as the charge level increases from 50 pence to £2.00 per day. As the charge increases, they prefer to change their departure time than any other option. They would also consider using public transport or park and ride options as alternatives. The results indicate that they are much less willing to give up the car use to avoid charge than other age groups.

Those who are over 55 are very sensitive to the levels of charge change and their willingness to pay decrease from 50 pence per £1.00 from 42.9 % to 15 % but a percentage of them did not change at all due to the increase of the charge from £1.00 to £2.00. They would prefer to park and use public transport and as the charge level increases, this percentage becomes greater. The percentage of them departing earlier increases less than those of the other age groups. They would not consider using public transport at all at the charge 50 pence per day but this figure increases slightly as the charge increase. The pattern of responses is quite similar to those of the under 24 year olds. This distorts the trends of responses to the charges as age increases. This might be caused by the very small sample size of those who are over 55.

7.4.3.3 Responses to the Charges by Income Levels

In this section, responses to road user charges depending on the levels of income of the respondents will be discussed. Income levels were categorized into three levels: the annual income is under £20,000, between £20,000 and £40,000 and over £40,000. The questions about income was voluntary and no response were also shown in **Figures 7-12 to 7-14**. The overall results are summarized in **Table 7-5.**

Figure 7-12 displays the responses to the charge 50 pence per day. There are clear patterns in responses depending on income levels. The higher income respondents have, they are more willing to pay a charge. As the respondents who have higher income are less likely to use park and ride (option 2) to avoid a charge. The similar proportion of drivers would travel before 7:30 am to avoid charge, regardless of income levels. Those who earned more than £40,000 are much less willing to switch to public transport to avoid 50 pence per day charge.

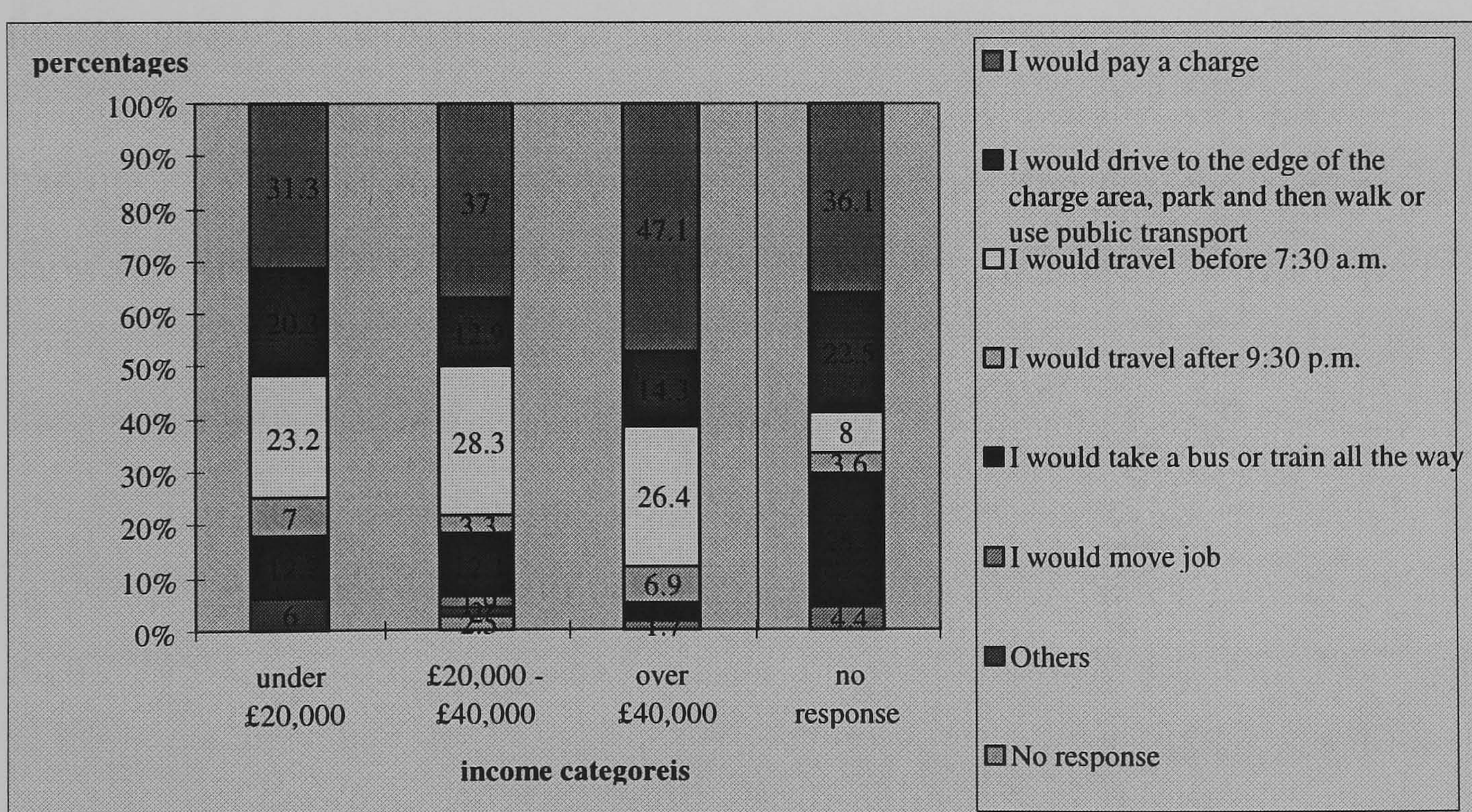

Figure 7-12 **Responses to 50 pence per day by income**

Figure 7-13 displays the responses to the charge £1.00 per day by age. With £1.00 charge, the willingness to pay increases, as levels of income increases, but the increasing rate is smaller than that at the 50 pence per day. Drivers are more likely to depart earlier as the levels of income increases. The percentage of those who choose the park and ride (option 2) decreases, while the percentage of those who would use public transport increases as the levels of income increases.

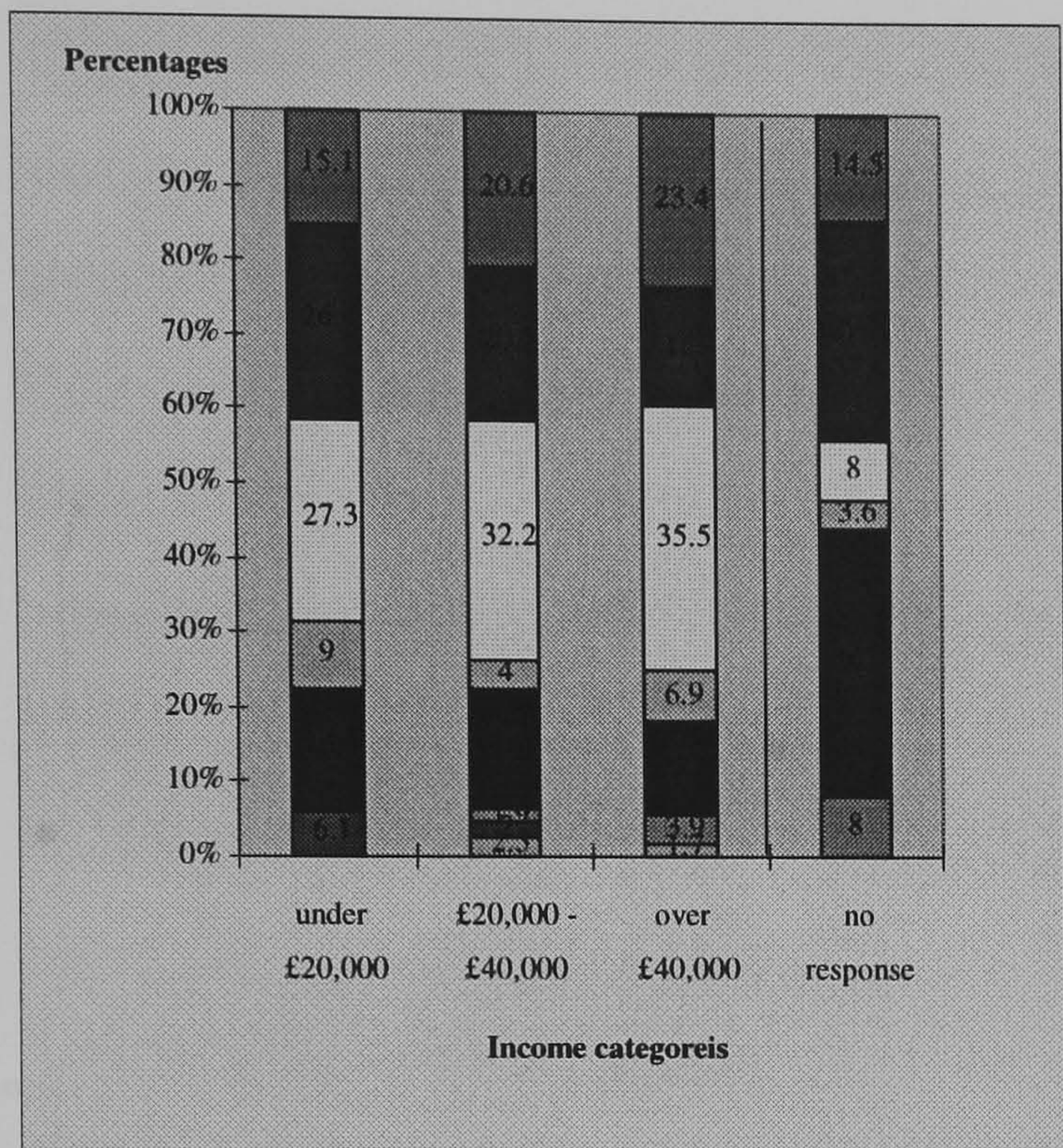

Figure 7-13 Responses to £1.00 per day by income

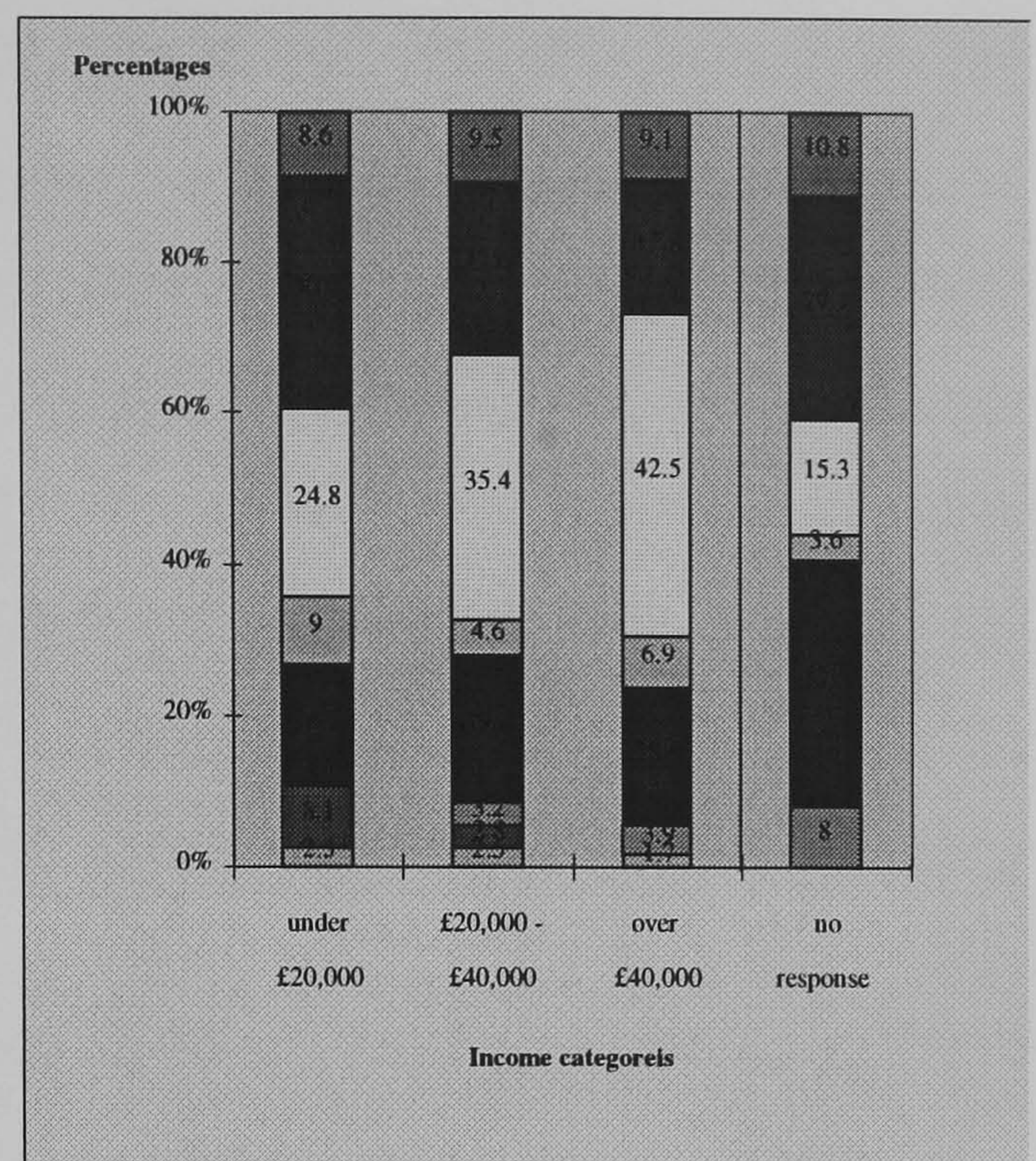

Figure 7-14 Responses to £2.00 per day by income

Figure 7-14 shows the responses to £2.00 charge per day. At the charge level of £2.00 per day, the percentages of those who would pay a charge is similar regardless of the income levels of the respondents. Those who would travel earlier to avoid the £2.00 per day increases rapidly as the level of income of the respondents increases. The percentage of those parking and using public transport increases, as the income levels of the respondents increases.

Those who earned under £20,000 are sensitive to the increases of charge levels. They would consider traveling earlier to avoid a charge, but this seems not to be affected by the increases of the charges. They would also consider parking and using public transport, or switching to public transport. This results indicate that they are more willing to give up car use to avoid charges.

Those who earned between £20,000 and £40,000 are more sensitive to the increases of charge levels than those who earned under £20,000. The first alternative to avoid charge is traveling earlier and this become greater, as the levels of charges increases. The percentage of those choosing parking and using public transport increases sharply and it become the second alternative to avoid charge to them. Many respondents would also consider using public transport.

Those who earned over £40,000 are less sensitive to low charges, while they become sensitive to the high charges and the willingness to pay a charge drops from 47.1% to 9.1% as the charge level increases from 50 pence to £2.00 per day. They would prefer to travel earlier to avoid a charge more than any other alternative. At the charge 50 pence per day, half of them would pay a charge, but when the charge become £2.00 per day half of them would travel earlier. This results indicate that they are more willing to change their travel pattern rather than to give up car use. They would also consider parking and using public transport or switching to public transport.

Table 7-5 Responses to different levels of road user charges by income levels

Charge Levels	Income Categories	Options[3] (%)								
		1	2	3	4	5	6	7	9	total
50 pence per day	under £20,000	31.3	20.3	23.2	7.0	12.2	0	6.0	0	100
	£20,000 - £40,000	37.0	12.9	28.3	3.3	12.1	1.9	2.0	2.5	100
	over £40,000	47.1	14.3	26.4	6.9	3.5	1.8	0	0	100
	no response	36.1	22.5	8.0	3.6	25.3	4.4	0	0	100
£ 1.00 per day	under £20,000	15.1	26.4	27.3	9.0	16.2	0	6.1	0	100
	£20,000 - £40,000	20.6	20.7	32.2	4.0	16.0	1.9	2.0	2.5	100
	over £40,000	23.4	16.0	35.5	6.9	12.5	3.9	0	1.7	100
	no response	14.5	29.7	8.0	3.6	36.1	8.0	0	0	100
£ 2.00 per day	under £20,000	8.6	30.9	24.8	9.0	16.2	0	8.1	2.5	100
	£20,000 - £40,000	9.5	22.6	35.4	4.6	19.4	3.2	2.8	2.5	100
	over £40,000	9.1	17.8	42.5	6.9	18.1	3.9	0	1.7	100
	no response	10.8	29.7	15.3	3.6	32.5	8.0	0	0	100

[3] The legends of options were omitted in Table 6-5 which are the same as those in Figure 6-7.

7.4.4 Comments about the Road User Charges

Drivers who chose the 'others' option specified their response to road user charges, and these could be categorized into four groups. The main findings were :

1. Some drivers consider car sharing with friends or colleagues in response to the road user charges.
2. Some drivers gave comments that they would consider parking and walking or using public transport on condition of satisfying certain criteria such as enough parking space, secure car park, safety for women driving alone, as well as frequent and good public transport services to the city center.
3. A few drivers consider using public transport, provided that the service levels of public transport such as reliability, frequency and regularity are improved. Some of them pointed out that introducing a road user charge should accompany improvement of existing public transport or provision of alternative public transport.
4. Some drivers whose journey to work is linked to child care or school arrangement said they have limited choice because they must use the car for child care and they could not change their departure time.
5. Some drivers, whose company pay the costs of the journey, or who use the car for a company use, expected their company to pay the charge, therefore the charge does not effect their travel behavior.

7.5 Summary

This chapter reported the qualitative and attitudinal analysis of the main survey results from the first and the third part of the questionnaire.

According to the results of the respondents' socio-economic characteristics, the sample of commuters is evenly distributed across gender, age and income categories. Most of them were in full time employment and paid their petrol cost.

The results of estimating the cost of the hypothetical routes indicated that some drivers consider the car operating cost much more in congested traffic. The estimated cost caused by the congestion was 9.9 pence per mile.

As a results in section 7.3, most drivers have used VMS and radio traffic information before and they agreed that it was useful. Few drivers had used any in-vehicle guidance systems but many thought they would be useful.

The final part of this chapter is a discussion of the responses given in the third part of the questionnaire. Overall, if a charge was introduced drivers would consider paying it. As the level of charge increases, to avoid a charge drivers would consider traveling earlier, parking and using the public transport second and finally using public transport.

The responses to the charges were also discussed depending on the sex, age and income of the respondents. In order to avoid a charge, male drivers seem slightly more likely to change their departure time than females, while females seem to prefer using the public transport slightly more than males. The results of the responses to the charges by age indicated that there were different patterns of responses to the charges depending on age. Those who were between 25 and 54 are very sensitive to the increase of charges and they would consider the changing departure time as the first alternative to avoid a charge. The younger drivers were more willing to switch to the public transport to avoid charges than the other age groups. The results of the responses to the charges by income levels indicated that those who have higher income levels over £40,000 are less sensitive to the low charges, while they become sensitive to the high charges more than other income groups and they would prefer to travel earlier to avoid a charge. Those who earned under £20,000 are also sensitive to the increases of the charges but their other responses seem not to be affected by the increases of the charges. As the levels of income increases, drivers are less likely to give up their car use and prefer to travel earlier.

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Finally, the comments and opinions of respondents to road user charges were summarized. These indicated the possible alternatives to the road user charges and requirement for road user charges.

Chapter 8

Analysis of SP Data from the Main Survey

8.1 Introduction

The previous chapter 7 reported the descriptive analysis of the attitudinal results from the main surveys. In this chapter, the SP survey results from the main survey will be analysed.

First this chapter develops a serial of models in order to find a best fitting model for the main survey results. Several models have been developed depending on different variables, different combination of variables and on whether a utility function is linear or non-linear. Among those models, a model will be selected. Secondly, the selected model is analysed in detail and the results are discussed. Thirdly, model segmentation is made by socio-economical characteristics of drivers in order to investigate whether their characteristics influence route choice. Finally, the main survey was repeated in Seoul to investigate the response to traffic information and road user charges and to explore the influence of cultural difference on route choice. The results of the Seoul survey are discussed, comparing with those from the main survey in Leeds.

The next section briefly summarises the SP data from the main survey which will be analysed in this chapter. Section 8.3 reviews a modelling approach which will be adopted in this chapter. Section 8.4 reports the process of model development. From section 8.4.2 to section 8.4.8 seven alternative models will be estimated: a linear model with dummy variables; a linear model with a continuous total delay variable; a linear model with normal delay and extra delay time variables; a non-linear model with total delay variable, a non-linear model with normal delay and extra delay variables; a non-linear model with an ASC; and a non-linear model with a distance variable. Section 8.4.9 compares the model estimate and selects the best model for this study. Section 8.4.9.2 presents a detail discussion about the results of the selected model. Section 8.5 presents the results of models segmented by sex, age, and income of the respondents. Section 8.6 reports the results of the Seoul survey and the comparison of the results between Leeds and Seoul. Finally, section 8.7 summarises the main findings and recommends a further study based on the main findings.

8.2 Brief Data Description

The SP design was discussed in chapter 5 and chapter 6 but is summarised here for convenience. As the main survey, a SP approach was used with a hypothetical network. This SP experiment offered the respondents the choice of two routes. Route1 is short, 4 miles and goes through the city centre. The normal travel time of route1 is about 25 minutes, of which about 10 minutes is spent in slow moving traffic during peak time. Route 1 is charged. Route 2 is a longer bypass (10 miles) but there is no delay expected. The travel time is normally about 35 minutes. Route 2 is free. A total of 2626 observations was obtained. For the general survey design see section 5.3.4.

In the experiment, the respondents were informed of the distance and normal travel time, as well as being given 'real time' information about observed traffic condition, about the charge and about any extra delay expected on a specific day. The observed traffic conditions at the decision point through the windscreen is shown as the picture. The information about extra delay time and charges are given on Variable Message Signs (VMS). For the representation of information see section 5.3.3 and for the example of the questionnaire see appendix 3.

The three kinds of road user charge systems were used in this study: fixed charge; total time-based charge; and delay time-based charges. With fixed charge, each vehicle is charged a fixed amount, which might in practice be based on average traffic condition data in some previous time period. With total time-based charges, the charge is directly proportion to the travel time spent in the charged area. With delay time-based charges, vehicles are charged directly in proportion to the delay they experience within the charged area. See section 5.3.3.

In order to represent the differences between the types of charges, the charge information for fixed charges is given as an accurate indicator of the charge, while the information for total time-based charges and delay time-based charges is given as an estimate of the charge with a range reflecting the uncertainty of travel time or delay. The difference between estimates of total time-based charge and delay time-based charge is that the total time-based charge has a narrow range of estimates while delay time-based charge has a wide range of estimates. This is because delay time is more unpredictable than total travel time.

8.3 Model Estimation Method

8.3.1 Random Utility Theory

Discrete Choice models are based on choices made by individuals. It assumes that the probability of an individual choosing a given alternative is a function of their socio-economic characteristics and the relative attractiveness of the option (Ortuzar and Willumsen 1994).

The random utility theory is the common and usual theoretical base of discrete choice models (Ortuzar and Willumsen 1994). Random utility models assume 'rational behaviour'. This means that individuals act rationally, possess perfect information, and their decision process is a consistent and calculated decision process in which the individual follows his or her own objectives (Ben-Akiva and Lerman 1985).

Random utility (U_i) comprises a deterministic component (V_i) and a stochastic component(ε_i).

$$U_i = V_i + \varepsilon_i \qquad \textbf{(8-1)}$$

The deterministic component, V_i is a function of observable and measurable attributes, x_i. The function is commonly assumed to be linear in combining variables.

$$V_i = \sum_k \theta_{ik} x_{ik} \qquad \textbf{(8-2)}$$

where θ_{ik} is a vector of parameters to be estimated and x_{ik} is a vector of observed data relating to alternative i. The parameters θ_{ik} are assumed to be constant for all individuals (fixed-coefficients models) but may vary across alternatives (Fowkes and Wardman 1988; Ortuzar and Willumsen 1994).

The stochastic part ε_i is called error term or random term and reflects the uncertainty or randomness. Manski (1973) identified four distinct sources of randomness, as quoted in Ben-Akiva and Lerman (1985).

- Unobserved Attributes
- Unobserved Taste Variations
- Measurement Errors
- Instrumental Variables

The choice probability that an individual p chooses alternative $i \in A(n)$ is given by

$$\begin{aligned} Pr_{ip} &= Pr\{U_{ip} > U_{jp} \quad \forall j \neq i,\ i, j \in A(n)\} \\ &= Pr\{V_{ip} + \varepsilon_{ip} > V_{jp} + \varepsilon_{jp}\ \forall j \neq i,\ i, j \in A(n)\} \\ &= Pr\{\varepsilon_{jp} - \varepsilon_{ip} < V_{ip} - V_{jp},\ \forall j \neq i,\ i, j \in A(n)\} \end{aligned} \qquad \textbf{(8-3)}$$

where p refers to individual respondent, $p=1,2,\ldots,P$ and $A(n)$ is a choice set includes all the alternatives.

Different assumptions about the random term ε_i produce specific models. Multinominal Logit Model (MNL) is derived from the assumption that errors of utility function are identically and independently Gumbel distributed. Multinominal probit (MNP) model can be derived from the assumption that the errors of the random utility are multivariate normal distributed (Wardman 1987). For more detailed discussion about these models the reader is referred to Ben-Akiva and Lerman (1985), Wardman (1987), and Ortuzar and Willumsen (1994).

8.3.2 Multinominal Logit Model (MNL)

The most popular and the simplest analysis technique for the discrete choice model is the logit model due to its easy application and the availability of estimation packages (Pearmain and Kroes 1990; Wardman 1987). The model was first introduced in the context of binary choice models. The subsequent generalization to more than two alternatives is referred to as the multinominal logit model (Ben-Akiva and Lerman 1985).

It is based on assumption that the random terms ε_i are mutually Independent and Identically distributed across all alternatives and across all respondents. This is known as the IID (Independent and Identically Distributed). The distribution of the error terms is assumed to take Gumbel distribution with fixed variance (Bates 1984; Ben-Akiva and Lerman 1985).

The probability of choosing an alternative i within choice set A(n) is given by

$$P_i = \frac{exp(\beta V_i)}{\sum_{j\in A(n)} exp(\beta V_j)} \qquad \textbf{(8-4)}$$

where, β is a scale parameter that is related to the variance σ^2 of the error term ($\beta = \frac{\pi}{\sqrt{6}\sigma}$) and is usually normalised to be equal to one as it cannot be estimated separately from the coefficients (Ortuzar and Willumsen, 1994).

The parameters can be estimated using a maximum likelihood approach, applying equation **(8-4)** to the observed choice of each observation for each individual and maximising the sum of the logged probabilities across people. The log-likelihood functions for estimating parameters thus becomes

$$L(\theta) = ln \sum_{p=1}^{P} \frac{exp(V_i)}{\sum_{j \in A(n)} exp(V_j)} \qquad \textbf{(8-5)}$$

8.4 Unsegmented Models

8.4.1 Alternative Models to be Examined

Logit models were estimated in order to explain the effects of the delay information and the road user charges on route choice. The utility for any route i consists of relevant variables representing individual's travel situations, traffic information characteristics and charging regimes. Variables relevant to travel situation and traffic information in utility functions were: total normal travel time variable, *ttime*; free travel time variable, *fttime;* total delay, *tdelay*; normal delay variable, *ndelay;* extra delay variable, *exdelay* for traffic information; travel distance variable, *distance*; and a dummy variable for heavy traffic observed through the windscreen, *htraffic*. The effects of different charging regimes were represented by special variables: *fcharge* for fixed charges; *ttcharge* for total time-based charges; and *dtcharge* for delay time-based charges.

As explained in Chapter 4, in order to reflect the uncertainty of travel time or delay time, the time-based and delay time-based charges were given with ranges. In this section, the models were estimated on the median value of the charges in the case of total time-based charge and delay time-based charges.

In this section, in order to develop the best fitting model for the analysis of the main survey results, seven alternative models were estimated depending on: different presentation of delay variables; different combinations of the variables; and forms of utility functions (e.g. linear or non-linear).

Among the variables, the parameter, *htraffic* was insignificant and had wrong sign in many case. The model was therefore re-estimated excluding this variable.

Seven models were estimated:

- Linear model with dummy variables for different amounts of extra delay
- Linear models with total delay variable
- Linear model with separate variables for normal delay and for extra delay
- Non-linear models with quadratic total delay variables
- Non-linear model with separate variables for normal delay and extra delay
- Non-linear model with ASC
- Non-linear model with distance variable

8.4.2 Linear Model with Dummy Variables for Different Amounts of Extra Delay

8.4.2.1 Initial Model

A simple linear model was estimated in order to investigate effects of the amount of extra delay on route choice by using dummy variables. Variables used in utility functions were: total normal travel time, *ttime*; dummy variables for the amount of extra delay on VMS, *5mdelay*; *10mdelay*; and *15mdelay*; and charge related variables: *fcharge* for fixed charges; *ttcharge* for total time-based charges; and *dtcharge* for delay time-based charges.

The utility functions for this model are:

$$U_{route1} = \alpha * ttime_1 + \beta_1 * DI * 5mdelay_1 + \beta_2 * DI * 10mdelay_1 + \beta_3 * DI * 15mdelay_1$$
$$(+\beta_4 * htraffic) + \gamma_1 * fcharge + \gamma_2 * ttcharge + \gamma_3 * dtcharge$$

$$U_{route2} = \alpha * ttime_2 + \beta_1 * DI * 5mdelay_2 \qquad (8\text{-}6)$$

Where :

ttime	**In-vehicle normal travel time(minutes)**
5mdelay$_i$	**5 minutes delay information on route *i***
10mdelay$_1$	**10 minutes delay information on route 1**
15mdelay$_2$	**15 minutes delay information on route 1**
htraffic	**dummy variable for the heavy traffic situation at the decision point: 1 when local traffic is slow moving htraffic , 0 otherwise**
fcharge	**fixed charge(pence)**
ttcharge	**total time-based charge(pence) : the mid point of range**
dtcharge	**delay time-based charge(pence) : the mid point of range**
DI	**Information Dummy: 1 when information is given, 0 otherwise**

Table 8-1 Linear Model with dummy variables

	Model 1		Model 2	
	Coefficient	T-ratio	Coefficient	T-ratio
ttime(min)	-0.157	-4.5	-0.162	-8.3
5mdelay$_1$	-1.374	-2.5	-1.454	-4.7
5mdelay$_2$	-0.439	-3.8	-0.442	-3.8
10mdelay$_1$	-1.801	-3.4	-1.883	-6.8
15mdelay$_1$	-3.089	-7.8	-3.143	-12.2
htraffic	-0.031	-0.2		
fcharge(pence)	-0.027	-10.2	-0.028	-14.3
ttcharge(pence)	-0.023	-9.0	-0.024	-12.7
dtcharge(pence)	-0.025	-9.6	-0.025	-14.0
Number of observation	2626		2626	
Final Likelihood	-1496.2		-1496.2	
Rho-Squared w.r.t. zero	0.178		0.178	

Model estimates are shown in **Table 8-1** for two models. The results for model 1 are satisfactory but the coefficient, *htraffic* is insignificant. Model 2 excludes this variable. The results are now wholly satisfactory. The value of rho-squared in the model is reasonably high, and all parameters have the intuitive signs and are significant.

The parameter, *ttime*, indicates that drivers become more sensitive to the increases of normal travel time.

The 5 minutes delay parameters, $5mdelay_1$ and $5mdelay_2$ are separately estimated depending on the routes in order to investigate whether the same delay information might have different influence on route choice depending on the characteristics of the route. The $5mdelay_1$ is given on the route 1 which is short and going through the city centre, always congested and charged. The other parameter, $5mdelay_2$ is given to the long, uncongested bypass route which is free. The difference of two parameters, $5mdelay_1$ and $5mdelay_2$ shows that drivers are less likely to choose the route 1 even if the same amount of 5 minutes delay information is given on both routes. This indicates that the road characteristics influence drivers route choice in response to extra delay information.

The size of parameters increases, as the amount of delay time increases, i.e. from 5mdelay, 10mdelay, to 15mdelay. This indicates that drivers are more likely to change their route as the amount of delay increases on their routes.

Values of extra delay times are estimated and summarised in **Table 8-2** based on model 2. The value of extra delay time is expressed in units of normal travel time and it explains the way drivers perceive extra delay time compared with normal travel time. The value of extra delay (notified via VMS) on route 1 varies from 9.0 to 19.4 minutes as delay time increases from 5 minutes to 15 minutes.

Table 8-2 Value of extra delay time per minute of normal travel time (from model 2 in Table 8-1)

Extra delay time given as VMS information	normal travel time*	ratio**
5 minutes extra delay on route1	9.0	1.8
5 minutes extra delay on route2	2.8	0.5
10 minutes extra delay on route1	11.6	1.2
15 minutes extra delay on route1	19.4	1.3

***value of delay time expressed in units of normal travel time[1]**
**** ratio : Value of delay divided by the normal travel time[2]**

This is illustrated in **Figure 8-1** which shows the non-linearity of value of delay time. The curve shows a mixed form of concave and convex. This indicates that drivers tend to perceive 5 minutes delay much longer than normal travel time and to change their route with small amount of delay such as 5 minutes delay on congested route. When they are used to delay as delay increase, they valued 10 minutes delay as little higher than normal travel time and stayed on the existing route. However, as extra delay increases over a certain level, such as 15 minutes, it makes them to value delay time much higher than travel time and to become sensitive to them. As will be recalled in section 8.4.6, these findings were consistent with several authors (Huchingson and Dudek 1979; Khattak *et al.* 1993a and b; Wardman *et al.* 1997). The results is also consistent with the findings from the second pilot survey except the value of 5 minutes delay which was there much less than the value of normal travel time (see chapter 6). In the second pilot survey, only one generic parameter was estimated because of the small sample size and the value of 5 minutes delay was diluted by the value of 5 minutes delay on the uncongested alternative route.

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[1] **The value of delay time = the coefficients of each delay time / the coefficients of travel time**
e.g. value of 10 minutes of extra delay on route 1 = -1.883 / -0.1623 = 11.6

[2] **The ratio is calculated by dividing the value of delay by the normal travel time.**
e.g. ratio of 10 minutes extra delay = 11.6 (value of delay) / 10 minutes = 1.16

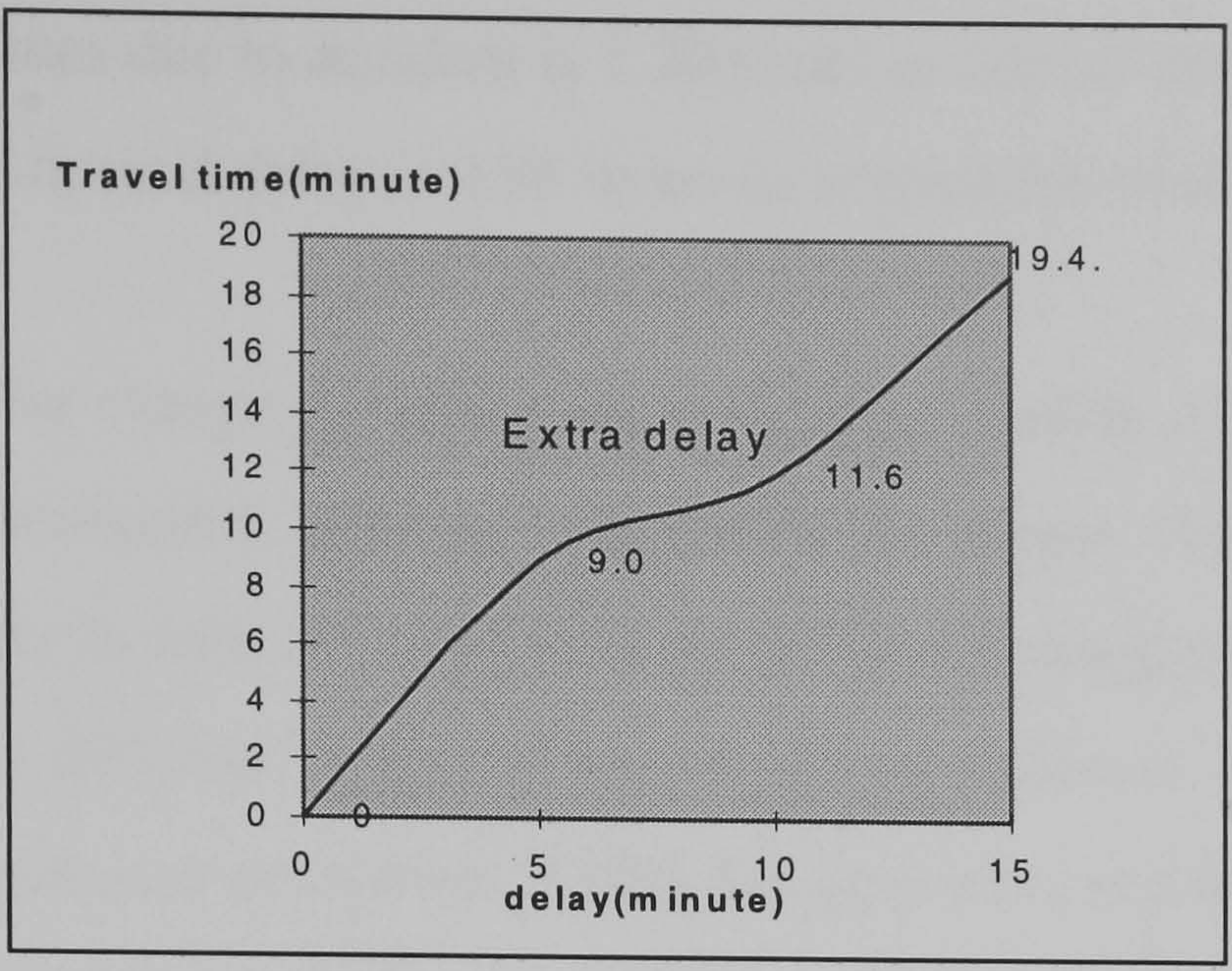

Figure 8-1 Value of extra delay time on route 1 (from model 2 in Table 8-1)

Two different 5 delay minutes parameters, $5mdelay_1$ and $5mdelay_2$ are estimated separately for route1 and route 2, as shown in **Table 8-2**. The values 5 minutes extra delay on route 1 is 1.8 times of normal travel time, while the value of 5 minutes extra delay on route 2 is 0.6 times of normal travel time. This result indicates that drivers value 5 minutes delay which VMS indicated, three times more on route 1 than on the alternative route 2. Therefore, the value of delay time is different depending on the characteristics of routes.

Table 8-3 Value of delay time due to different cause of delay (Source : Wardman *et al.* 1997)

	Road-min	*Cong-min*	*Acc-min*	*Non-min*
5minutes	0.99	1.01	1.20	0.88
10minutes	1.21	1.25	1.48	1.08
15minutes	1.37	1.41	1.67	1.22
20minutes	1.50	1.54	1.82	1.33
25minutes	1.60	1.64	1.94	1.43
30minutes	1.69	1.73	2.05	1.51

Value of delay time is expressed in units of normal journey time
Road-min: delay minutes due to roadwork
Cong-min: delay minutes due to congestion
Acc-min: delay minutes due to accident
Non-min: delay minutes without information

Wardman *et al.* (1997) who investigated the impact of VMS information on route choice also found relevant results in which the values of delay minutes are different depending on the cause of delay, as shown in **Table 8-3**. For instance, the value of 5 minutes delay due to congested situation is 1.01 times as normal travel time and the value of 5 minutes due to accident is 1.20 times as normal travel time, while the value of 5 minutes normal delay is 0.88 times as normal travel time.

Three parameters for charging regimes are significant, shown in **Table 8-2**. Among three charging parameters, *fcharge* parameter is bigger than other charging parameters. In order to find out whether three different charging regimes in model 2 are significantly different, t-statistics tests for the relevant difference between estimated coefficients are conducted. **Table 8-4** presents t statistics of the relevant differences between estimated charge coefficients in the model. The t-static for the difference between two coefficients estimates (α_1, and α_2) is calculated as (Wardman *et al.* 1997)

$$t = \frac{\beta_1 - \beta_2}{\sqrt{Var(\beta_1) + Var(\beta_2) - 2Cov(\beta_1, \beta_2)}} \qquad \textbf{(8-7)}$$

The variance of relative attribute valuations can also be calculated by converting the correlation coefficient for the parameters given by ALOGIT into a covariance as follows (Palmer, 1995)

$$Cov(\beta_i, \beta_j) = \rho_{(\beta_i, \beta_j)} \cdot \sqrt{\left[Var(\beta_i)\,Var(\beta_j)\right]} \qquad \textbf{(8-8)}$$

where

β_i	**is the parameter estimate for attribute i (i= 1,2)**
Var (β_i)	**is the variance of** β_i
Cov(β_i, β_j)	**is the covariance between parameter estimate** β_i **and** β_j
$\rho_{(\beta_i, \beta_j)}$	**is the correlation coefficient for parameter estimate** β_i **and** β_j

Table 8-4 Differences between coefficients in the initial models

Coefficients		Model 2	
β_1	β_2	**t-test**	$\beta_1 - \beta_2$
fcharge	***ttcharge***	**2.941**	**-0.00391**
fcharge	***dtcharge***	**1.980**	**-0.01147**
ttcharge	***dtcharge***	**1.210**	**0.00145**

The t-statistics presented in the **Table 8-4** show that *fcharge* coefficient estimate for the fixed charge is statistically significantly different from the other charge coefficient estimates, *ttcharge* for the time-based charge and *dtcharge* for the delay-based charge at the usual 5% level of significance in Model 2. This suggests that a fixed charge has significantly more influence on route choice than do time-based charges or delay-based charges. The *ttcharge* and *dtcharge* coefficient estimates have similar values and are not statistically and significantly different from each other.

The values of time for each of the charging regimes were estimated from model 2 in **Table 8-1**. The results are shown in **Table 8-5**. It is interesting to note that the value of time for fixed charging is lower than the rest.

Table 8-5 Value of time in terms of different charging regimes (from model 2 in Table 8-1)

	VOT (pence per minute)
Fixed charging	5.8
Total time-based charging	6.7
Delay time-based charging	6.4

8.4.2.2 Alternative Models Including Range Variables

It might be thought that the difference between coefficients for the three charging regimes in the initial models might simply reflect the size of the range rather than any differences in the perception of the charging regimes themselves. In order to explore this issue, the three charging regime variables in model 2 were separated into three charge variables and a range variable. Four new models were estimated including different range variables.

Model 3 was estimated including a variable for absolute ranges of charges which is the difference between lower bound and upper bound of the ranges of charges.

Utility functions for model 3 are

$$U_{route1} = \alpha * ttime_1 + \beta_1 * DI * 5mdelay_1 + \beta_2 * DI * 10mdelay_1 + \beta_3 * DI * 15mdelay_1$$
$$+ \gamma_1 * fcharge + \gamma_2 * ttcharge + \gamma_3 * dtcharge + \xi_1 * arange$$

$$U_{route2} = \alpha * ttime_2 + \beta_1 * DI * 5mdelay_2 \qquad \textbf{(8-9)}$$

Where :

ttime	**In-vehicle normal travel time(minutes)**
5mdelay$_i$	**5 minutes delay information on route *i***
10mdelay$_1$	**10 minutes delay information on route 1**
15mdelay$_2$	**15 minutes delay information on route 1**
fcharge	**fixed charge(pence)**
ttcharge	**total time-based charge(pence) : the mid point of range**
dtcharge	**delay time-based charge(pence) : the mid point of range**
DI	**Information Dummy: 1 when information is given, 0 otherwise**
arange	**absolute range of the charges (pence)**

Table 8-6 shows the results of Model 3. All coefficient estimates have the correct signs and all except the *arange* coefficient estimate are statistically significant even at a 1% level. A very high correlation of coefficient estimates between *dtcharge* and *arange* (0.860) was reported in the logit model results. This suggests that the range of the charges might have different effects on different charging regimes.

Therefore, model 4 was estimated including separate range coefficients, *tarange* for time-based charge and *darange* for the delay-based charge. Utility functions for model 4 are

$$U_{route1} = \alpha * ttime_1 + \beta_1 * DI * 5mdelay_1 + \beta_2 * DI * 10mdelay_1 + \beta_3 * DI * 15mdelay_1$$
$$+ \gamma_1 * fcharge + \gamma_2 * ttcharge + \gamma_3 * dtcharge + \xi_1 * tarange + \xi_2 * darange$$

$$U_{route2} = \alpha * ttime_2 + \beta_1 * DI * 5mdelay_2 \qquad \textbf{(8-10)}$$

ttime	**In-vehicle normal travel time(minutes)**
5mdelay$_i$	**5 minutes delay information on route *i***
10mdelay$_1$	**10 minutes delay information on route 1**
15mdelay$_2$	**15 minutes delay information on route 1**
fcharge	**fixed charge(pence)**
ttcharge	**total time-based charge(pence) : the mid point of range**
dtcharge	**delay time-based charge(pence) : the mid point of range**
DI	**Information Dummy: 1 when information is given, 0 otherwise**
tarange	**absolute range of the charges of the time-based charge (pence)**
darange	**absolute range of the charge of the delay-based charge (pence)**

The model results are reported in **Table 8-6**. All coefficient estimates have the correct signs. All coefficient estimates except *tarange* and *darange* are statistically significant at a 5% level of significance.

Table 8-6 Linear Model 3, 4, 5 and 6 with dummy variables and range variables

	Model 3		Model 4		Model 5		Model 6	
	Coefficient	T-ratio	Coefficient	T-ratio	Coefficient	T-ratio	Coefficient	T-ratio
ttime(min)	**-0.164**	**-8.4**	**-0.164**	**-7.8**	**-0.182**	**-7.5**	**-0.167**	**-5.2**
$5mdelay_1$	**-1.294**	**-4.0**	**-1.294**	**-4.0**	**-1.509**	**-4.8**	**-1.375**	**-3.8**
$5mdelay_2$	**-0.488**	**-4.1**	**-0.489**	**-3.8**	**-0.4591**	**-3.9**	**-0.442**	**-3.7**
$10mdelay_1$	**-1.898**	**-6.8**	**-1.901**	**-6.6**	**-2.079**	**-6.7**	**-1.926**	**-5.1**
$15mdelay_1$	**-3.203**	**-12.4**	**-3.207**	**-11.2**	**-3.356**	**-11.2**	**-3.185**	**-8.4**
fcharge(pence)	**-0.029**	**-13.8**	**-0.029**	**-11.6**	**-0.030**	**-10.9**	**-0.029**	**-8.0**
ttcharge(pence)	**-0.022**	**-10.2**	**-0.022**	**-2.3**	**-0.024**	**-12.5**	**-0.025**	**-12.0**
dtcharge(pence)	**-0.017**	**-3.5**	**-0.017**	**-3.5**	**-0.023**	**-8.8**	**-0.021**	**-7.1**
arange(pence)	-0.018	-1.7						
tarange(pence)			-0.020	-0.3				
darange(pence)			-0.018	-1.6				
range (%)					-0.022	-1.4		
trange(%)							-0.004	-0.1
drange(%)							-0.021	-1.2
Number of observation	**2626**		**2626**		**2626**		**2626**	
Final Likelihood	**-1495.559**		**-1495.559**		**-1496.011**		**-1495.741**	
Rho-Squared w.r.t. zero	**0.178**		**0.178**		**0.178**		**0.178**	

A variable of representing a relative size of range was tested. For the time-based charge, the range was based on travel time ±10%, while for the delay time-based charge, the range was based on the total delay ±20%. The range for the time-based charges cover ±10% of median charges, while the range for delay-based charges cover ±30% of median charges. For more detail, see section 6.4.

Model 5 was estimated including a relative range coefficient, *range*. Utility functions for model 5 are

$$U_{route\,1} = \alpha * ttime_1 + \beta_1 * DI * 5mdelay_1 + \beta_2 * DI * 10mdelay_1 + \beta_3 * DI * 15mdelay_1$$
$$+ \gamma_1 * fcharge + \gamma_2 * ttcharge + \gamma_3 * dtcharge + \xi_1 * range$$

$$U_{route\,2} = \alpha * ttime_2 + \beta_1 * DI * 5mdelay_2 \qquad \textbf{(8-11)}$$

where

ttime	**In-vehicle normal travel time(minutes)**
$5mdelay_i$	**5 minutes delay information on route *i***
$10mdelay_1$	**10 minutes delay information on route 1**
$15mdelay_2$	**15 minutes delay information on route 1**
fcharge	**fixed charge(pence)**
ttcharge	**total time-based charge(pence) : the mid point of range**
dtcharge	**delay time-based charge(pence) : the mid point of range**
DI	**Information Dummy: 1 when information is given, 0 otherwise**
range	**relative range of the charges (%)**

Table 8-6 reports the estimate results. All coefficient estimates have the correct signs and all except the *arange* coefficient estimate are statistically significant.

Model 6 was estimated including separate range coefficients, *trange* for time-based charge and *drange* for the delay-based charge, in order to find out whether the relative range has different effect for each charging regime. Utility functions for model 6 are

$$U_{route1} = \alpha * ttime_1 + \beta_1 * DI * 5mdelay_1 + \beta_2 * DI * 10mdelay_1 + \beta_3 * DI * 15mdelay_1 + \gamma_1 * fcharge + \gamma_2 * ttcharge + \gamma_3 * dtcharge + \xi_1 * trange + \xi_2 * drange$$

$$U_{route2} = \alpha * ttime_2 + \beta_1 * DI * 5mdelay_2 \qquad \textbf{(8-12)}$$

where	
ttime	**In-vehicle normal travel time(minutes)**
5mdelay$_i$	**5 minutes delay information on route *i***
10mdelay$_1$	**10 minutes delay information on route 1**
15mdelay$_2$	**15 minutes delay information on route 1**
fcharge	**fixed charge(pence)**
ttcharge	**total time-based charge(pence) : the mid point of range**
dtcharge	**delay time-based charge(pence) : the mid point of range**
DI	**Information Dummy: 1 when information is given, 0 otherwise**
trange	**relative range of the charges of the time-based charge (%)**
darange	**relative range of the charge of the delay-based charge (%)**

The model results are reported in **Table 8-6**. All coefficient estimates have the correct signs. All coefficient estimates except *trange* and *drange* are statistically significant at a 5% level of significance.

As it can be seen, the range related parameters which were added in Model 3, 4, 5, and 6 were all insignificant. In these new models, range related parameters were separately estimated from the charge related parameters. Therefore, if there is significant difference between charging related parameters in these new models, it may indeicate that the difference is caused by the different effect of each charging regime itself. T-statistics test are conducted for the relevent differences between estimated charge coefficients in models 3, 4, 5 and 6 and results are reported in **Table 8-7.**

For model 3, the *fcharge* coefficient estimate for the fixed charge is statistically significantly different from the other charge coefficient estimates, *ttcharge* for the time-based charge and *dtcharge* for the delay-based charge at this level. The *ttcharge* coefficient estimate is not significantly different from *dtcharge* coefficient estimate at the 5% level of significance. This suggests that fixed charges have significantly more influence on route choice than do time-based or delay-based charge.

For model 4, the *fcharge* coefficient estimate for the fixed charge is not statistically significantly different from *ttcharge* but different from *dtcharge* at the 5% level. The *ttcharge* is also not significantly different from *dtcharge* in the model 4. This result seems to be caused by the low t-ratios of the *ttcharge* and *dtcharge* estimates.

For model 5, the *fcharge* coefficient estimate for the fixed charge is statistically significantly different from the other charge coefficient estimates, *ttcharge* for the time-based charge and *dtcharge* for the delay-based charge at the 5% level. The *ttcharge* coefficient estimate is not significantly different from *dtcharge* coefficient estimate at this level. For the model 6, all three charge related coefficient estimates are not significantly different each other.

Table 8-7 Differences between charge coefficients in Model 3, 4, 5 and 6

Coefficients		Model 3		Model 4		Model 5		Model 6	
β_1	β_2	t-test	β_1 - β_2	t-test	β_1 - β_2	t-test	β_1 - β_2	t-test	β_1 - β_2
fcharge	*ttcharge*	3.040	-0.00702	0.697	-0.00738	-3.503	-0.00681	-1.055	-0.00368
fcharge	*dtcharge*	2.056	-0.01147	2.012	-0.01152	-2.149	-0.00866	-1.770	-0.00721
ttcharge	*dtcharge*	1.188	-0.00445	0.423	-0.00414	-0.684	-0.00185	-0.995	-0.0035

8.4.2.3 Model Comparison

In the previous section, four new models were added. Model 3 and Model 4 were estimated from Model 2 by including variables which represents absolute ranges of charges, while Model 5 and Model 6 were estimated including relative variables.

These models seem to be not much different. In this section, I have tested whether these models were significantly different from Model 2.

First, the value of delay time of these five models were compared. **Table 8-8** presents the value of extra delay time which is expressed in units of normal travel time. This suggests that six models produced very similar results with respect to the value of extra delay time.

Table 8-8 Value of extra delay time per minute of normal travel time

Extra delay	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
5 minutes on route1	**1.8**	**1.6**	**1.6**	**1.7**	**1.7**
5 minutes on route2	**0.5**	**0.6**	**0.6**	**0.5**	**0.5**
10 minutes on route1	**1.2**	**1.2**	**1.2**	**1.1**	**1.2**
15 minutes on route1	**1.3**	**1.3**	**1.3**	**1.2**	**1.3**

Secondly, it is interesting to test whether any particular model is significantly better than another more restricted models. Therefore, the Likelihood Ratio test was conducted.

The Likelihood Ratio Test is used to test a set of restrictions on the parameters of models estimated by maximum likelihood. First, we compare the log likelihood functions for the unrestricted and restricted models of interest (Ben-Akiva and Lerman, 1985).

$$\mathcal{L}^{u} \geq \mathcal{L}^{R} \qquad \textbf{(8-13)}$$

where $\mathcal{L}^{u}$ and $\mathcal{L}^{R}$ denote the value of the log likelihood function at its maximum for the unrestricted and restricted models, respectively. r denote the number of independent restrictions imposed on the parameters in computing $\mathcal{L}^{R}$. The test statistic for the null hypothesis that the restrictions are true is

$$-2(\mathcal{L}^{R} - \mathcal{L}^{u}) \qquad \textbf{(8-14)}$$

which is asymptotically distributed as χ (chi squared) with r degree of freedom. Thus if $-2(\mathcal{L}^R - \mathcal{L}^u)$ is " large" in the statistical sense, we reject the null hypothesis that the restrictions are true.

Table 8-9 presents the likelihood ratio test results. The results show lower likelihood ratio test values than the critical values. Therefore, we can accept the null hypothesis. This result indicates that these five models are not statistically significantly different from each other.

Table 8-9 Likelihood Ratio Test

Models		Final Likelihood		d.f.	Test Results		
Model^u	*Model^R*	$\mathcal{L}^u$	$\mathcal{L}^R$		$-2(\mathcal{L}^R - \mathcal{L}^u)$	$\chi_{0.05}$	Hypothesis
Model 3	*Model 2*	-1495.5594	-1496.9317	1	2.7446	3.84	accept
Model 4	*Model 2*	-1495.5588	-1496.9317	2	2.7458	5.99	accept
Model 5	*Model 2*	-1496.0105	-1496.9317	1	1.8424	3.84	accept
Model 6	*Model 2*	-1495.7405	-1496.9317	2	2.3824	5.99	accept

8.4.2.4 Conclusion

Firstly, one of the important results from the initial model (Model 2) in section 8.4.2.1 was that fixed charges have more effect on route choice than the variable charges (time-based charges and delay-based charges). It was questioned whether charge parameters in model 2 were significantly different or not. The t-statistics results showed that the fixed charge parameter is statistically significantly different from the other charges for the time-based charge and delay-time based charge.

Secondly, estimating new models, model 3, 4, 5 and 6 was started from the doubt in which the difference of charge parameters might be caused only by size of range of charges rather than by the different effect of each charging regimes. Model 3 included a variable for the absolute ranges of the charges and Model 4 included two variables for the absolute ranges of the charges separately for time-based charge and delay-based charge. Model 5 added a variable for the relative range of the charges, while Model 6 had separate variables for the relative range of the charges for time-based and delay-based charges. The results of new models, shown in **Table 8-6**, showed that most of their estimates were very similar results to those of model 2 except the added range parameter. The parameters which were added in these models were all insignificant.

Thirdly, in order to test whether the three charge parameters of these new models were significantly different, t-statistic test were conducted. The *fcharge* coefficient estimate for the fixed charge in model 3 and model 5 is statistically significantly different from the other charge coefficient estimates, *ttcharge* for the time-based charge and *dtcharge* for the delay-based charge at the 5% level. The *ttcharge* coefficient estimate in model 3 and model 5 is not significantly different from *dtcharge* coefficient estimate at the 5% level. In model 4, only *fcharge* coefficient estimate is significantly different from dtcharge, while in model 6, all three charge estimates are not significantly different from each other.

Finally, I compared the five models (Model 2 to Model 6) to choose a better model. The five models had very similar delay related coefficients and also produced very similar results about value of extra delay time. The likelihood ratio tests were conducted to test whether a specific model was different from the others. The results showed that all four new models were not statistically significantly different from Model 2. This indicates that inserting variables in models 3, 4, 5, and 6 does not improve the models.

Therefore, I chose Model 2 in this study because of following reasons. Firstly, Model 2 is simpler model which has fewer parameters than the other model have. Secondly, only Model 2 has all significant parameters. Thirdly, the fixed charge parameter in Model 2 is statistically significantly different from the time-based charge and the delay-based charge parameters. Therefore, the model development is based on Model 2 in the following sections.

The range related variables turned out to be insignificant which indicate that there was no significant influence of ranges on route choice and the new models were not better than the initial model. However, there was some indication that the size of range of charges have influenced route choice slightly. Therefore, it is worth investigating the way drivers' responses to range of charges in detail. An additional survey which focus on the effect of range was conducted and will be discussed in chapter 10 and chapter 11.

8.4.3 Linear Models with Total Delay Variables

In this section, a linear model was estimated. Three changes have been made from the model 2 from the previous section. Firstly, data was transformed from dummy variables to continuous generic variables in order to get the pattern of delay time on route choice. Secondly, generic delay variables were introduced. Thirdly the variable, *ttime* for normal travel time was split into free-flow travel time and normal delay time because normal delay travel time which is included in travel time is expected to have different effect on route choice from normal travel time. The generic and continuous total delay variable is used, which is the sum of normal delay and extra delay reported as information.

Variables used in this model are: free travel time variable, *fttime;* total normal delay variable, *tdelay;* a dummy variable for heavy traffic observed through the windscreen, *htraffic*; *fcharge* for fixed charges; *ttcharge* for total time-based charges; and *dtcharge* for delay time-based charges. The utility functions of this model are:

$$\begin{aligned} U_{route1} &= \alpha * fttime_1 + \beta_1 * tdelay_1 \, (+\beta_2 * htraffic) \\ &\quad + \gamma_1 * fcharge + \gamma_2 * ttcharge + \gamma_3 * dtcharge \\ U_{route2} &= \alpha * fttime_2 + \beta_1 * tdelay_2 \end{aligned} \qquad \textbf{(8-15)}$$

Where
fttime: **In-vehicle normal free-flow travel time(minutes)**
tdelay: **total delay, the sum of normal delay and extra delay (minutes)**
htraffic **dummy variable for the heavy traffic situation at the decision point: 1 when local traffic is slow moving htraffic , 0 otherwise**
fcharge **fixed charge(pence)**
ttcharge **total time-based charge(pence) : the mid point of range**
dtcharge **delay time-based charge(pence) : the mid point of range**

Table 8-10 Linear Model with total delay variable

	Model1		Model2	
	Coefficient	**T-ratio**	**Coefficient**	**T-ratio**
fttime(min)	**-0.136**	**-10.8**	**-0.117**	**-11.0**
tdelay(min)	**-0.168**	**-11.5**	**-0.143**	**-12.5**
htraffic	0.224	2.0		
fcharge(pence)	**-0.030**	**-13.2**	**-0.026**	**-14.2**
ttcharge(pence)	**-0.024**	**-11.8**	**-0.023**	**-12.8**
dtcharge(pence)	**-0.022**	**-12.4**	**-0.024**	**-13.6**
Number of observation	**2626**		**2626**	
Final Likelihood	**-1512.729**		**-1517.408**	
Rho-Squared w.r.t. zero	**0.169**		**0.166**	

A model (model 1 in **Table 8-10**) was estimated and the results are satisfactory except *htraffic* parameter which has a counterintuitive sign. Therefore, the model was re-estimated excluding *htraffic* parameter, model 2 in **Table 8-10**. The results for model 2 are wholly satisfactory; all parameters are significant and have intuitive signs, and the value of rho-squared is reasonably high.

The parameter, *fttime*, indicates that drivers become more sensitive to the free-flow travel time as it increases. The total delay, *tdelay* indicates that as total delay times increase, drivers are more likely to change their route. A number of research (Khattak *et al.* 1993; Bonsall *et al* 1994; and Wardman *et al.* 1997) has found that drivers' willingness to divert to an alternative route increases as delay on their usual route increases.

The value of total delay time are estimated based on the model. It is expressed in units of free-flow travel time. The graph in **Figure 8-2** shows the linear curve of value of total delay time. The value of a minute of total delay time is 1.24 times of a minute of free-flow travel time. For instance, the value of 20 delay minutes is only the same as the value of 25 minutes of free-flow travel time.

This results is slightly underestimated, compared with those from the previous studies. A number of research has found that delay time to be valued more highly than free flow time: the ratios of values of delay time and free flow travel time were: 1.7 for commuters and 1.0 for other journey purposes from Hensher *et al.* (1990); 1.43 from Wardman (1991); and 1.39 from Oscar Faber TPA (1992). This underestimated result may be caused by the linearity of delay time and travel time. The relationship between travel time and delay are expected to be non-linear according to the relative studies, discussed in section 8.4.2 (Huchingson & Dudek 1979; Khattak *et al*, 1993a and 1993b; Wardman *et al*, 1997).

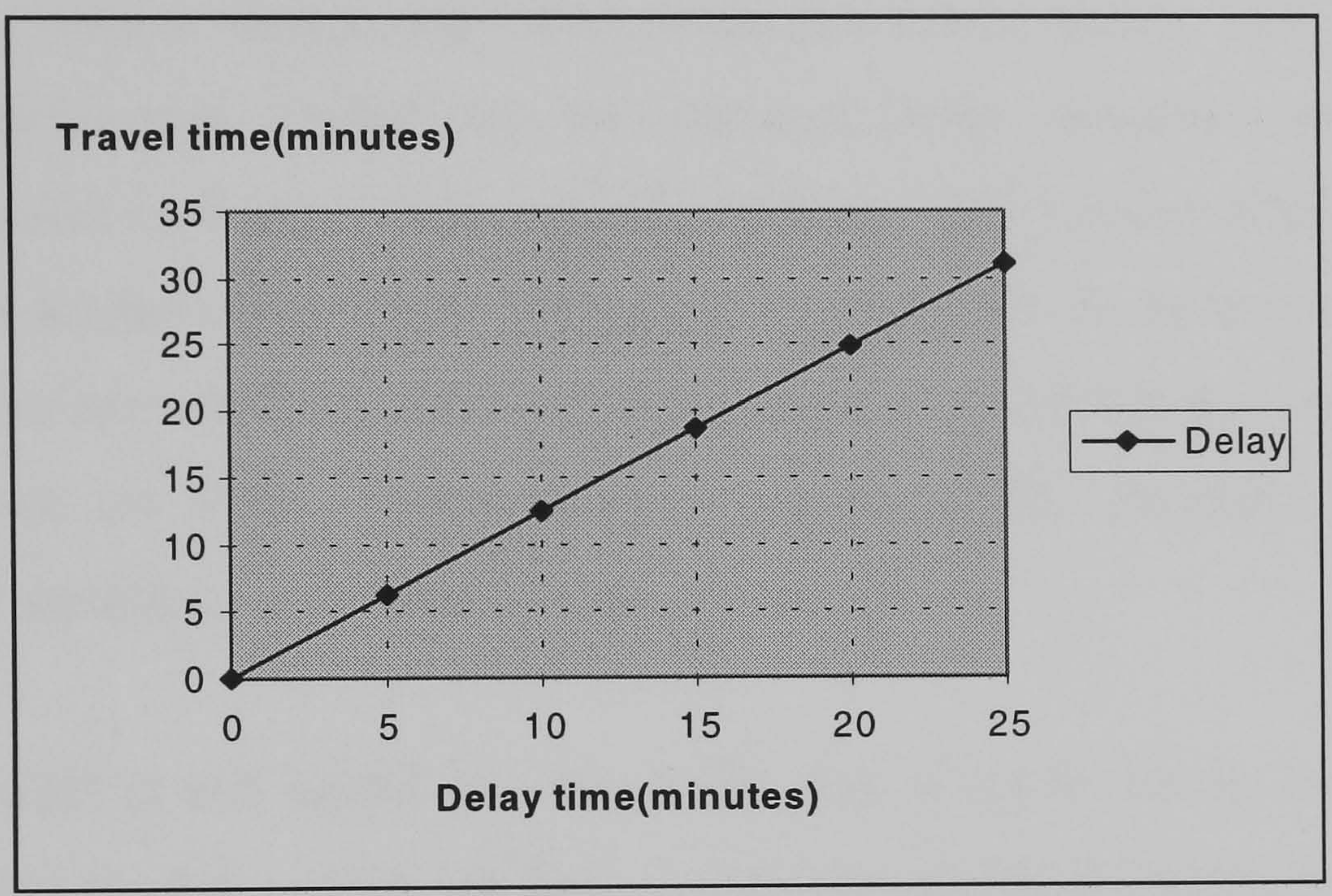

Figure 8-2 Value of total delay time (from model 2 in Table 8-10)

The parameters for charging regimes, *fcharge, ttcharge* and *dtcharge,* indicate that drivers are more likely to change their route as charges increase regardless of charging types. The parameter, *fcharge* is bigger than those of total time-based charge, *ttcharge*, and delay time-based charge, *dtcharge*, which means that drivers' route choice are influenced more by the fixed charges than by total time-based charge and delay time-based charges.

Values of time for each of the charging regimes were estimated from the model parameters in **Table 8-10**. We again note that the lowest values of time are associated with fixed charges.

Table 8-11 Value of times in terms of different types of charging (from model 2 in Table 8-10)

	VOT (pence per minute)
Fixed charging	4.5
Total time-based charging	5.7
Delay time-based charging	6.1

8.4.4 Linear Model with Separate Variables for Normal Delay and for Extra Delay

In this section, a linear model was estimated with the same structure of the model in previous section except with total delay parameter, *tdelay*. The total delay variable, *tdelay* was divided into two different delay variables; normal delay variable, *ndelay* and extra delay variable, *exdelay*. The normal delay is usually included in normal travel time and perceived as a part of normal travel time. However, the extra delay is additional delay which is not expected in usual journey and is given on VMS. Therefore, these separate delay parameters allow to investigate separate effects of each delay on route choice.

Variables used in this model are: free travel time variable, *fttime;* normal delay variable, *ndelay;* extra delay variable, *exdelay* for traffic information; a dummy variable for heavy traffic observed through the windscreen, *htraffic*; *fcharge* for fixed charges; *ttcharge* for total time-based charges; and *dtcharge* for delay time-based charges. The utility functions of this model are:

$$U_{route1} = \alpha * fttime_1 + \beta_1 * ndelay_1 + \beta_2 * exdelay_1 \;\; (+\beta_3 * htraffic) + \gamma_1 * fcharge + \gamma_2 * ttcharge + \gamma_3 * dtcharge$$

$$U_{route2} = \alpha * fttime_2 + \beta_1 * ndelay_2 + \beta_2 * exdelay_2 \qquad \textbf{(8-16)}$$

Where

fttime	**In-vehicle free-flow travel time(minutes)**
ndelay	**normal delay time(minutes)**
exdelay	**extra delay reported as information (minutes)**
htraffic	**dummy variable for the heavy traffic situation at the decision point: 1 when local traffic is slow moving htraffic , 0 otherwise**
fcharge	**fixed charge(pence)**
ttcharge	**total time-based charge(pence) : the mid point of range**
dtcharge	**delay time-based charge(pence) : the mid point of range**

Table 8-12 Linear model with normal delay variable and extra delay variable

	Model 1		Model 2	
	Coefficient	**T-ratio**	**Coefficient**	**T-ratio**
fttime(min)	**-0.141**	**-11.0**	**-0.112**	**-10.4**
ndelay(min)	**-0.260**	**-10.8**	**-0.201**	**-11.1**
exdelay(min)	**-0.111**	**-6.1**	**-0.087**	**-5.0**
htraffic	0.467	3.8		
fcharge(pence)	**-0.034**	**-13.8**	**-0.028**	**-14.4**
ttcharge(pence)	**-0.028**	**-12.3**	**-0.024**	**-12.9**
dtcharge(pence)	**-0.025**	**-13.3**	**-0.025**	**-14.1**
Number of observation	**2626**		**2626**	
Final Likelihood	**-1500.273**		**-1508.538**	
Rho-Squared w.r.t. zero	**0.176**		**0.171**	

The model was estimated and the results are shown in **Table 8-12**. The results for model 1 are satisfactory except that the *htraffic* parameter has a counterintuitive sign. Therefore, the model was re-estimated (model 2) without *htraffic* parameter. The results for model 2 are wholly satisfactory; the value of rho-squared is reasonably high, and all parameters are significant and have intuitive signs.

The parameter, *fttime*, indicates that drivers become more sensitive to the free-flow travel time as it increases. The normal delay parameter, *ndelay*, indicates that as normal delay time increases, drivers are more likely to change their route. The extra delay parameter, *exdelay* indicates that as extra delay time increases, drivers become also more sensitive to the extra delay time on their route choice.

The values of normal delay time and extra delay time are estimated, based on the model estimates and shown in **Figure 8-3.** Drivers value a minute of normal delay as 1.84 times bigger than a minute of normal travel time. A minute of extra delay is considered as 0.79 times bigger in addition to normal delay than a minute of normal flow travel time. For example, 10 minutes of normal delay has the same value of 18.4 minutes of normal travel time and the value of 10 minutes of extra delay time is 7.9 minutes of normal travel time. The graph shows the relationship between normal delay, extra delay, total delay and free flow travel time. The total delay graph is the sum of normal delay and extra delay. The area between the total delay line and normal delay line represents extra delay because the extra delay means an additional delay to normal delay time.

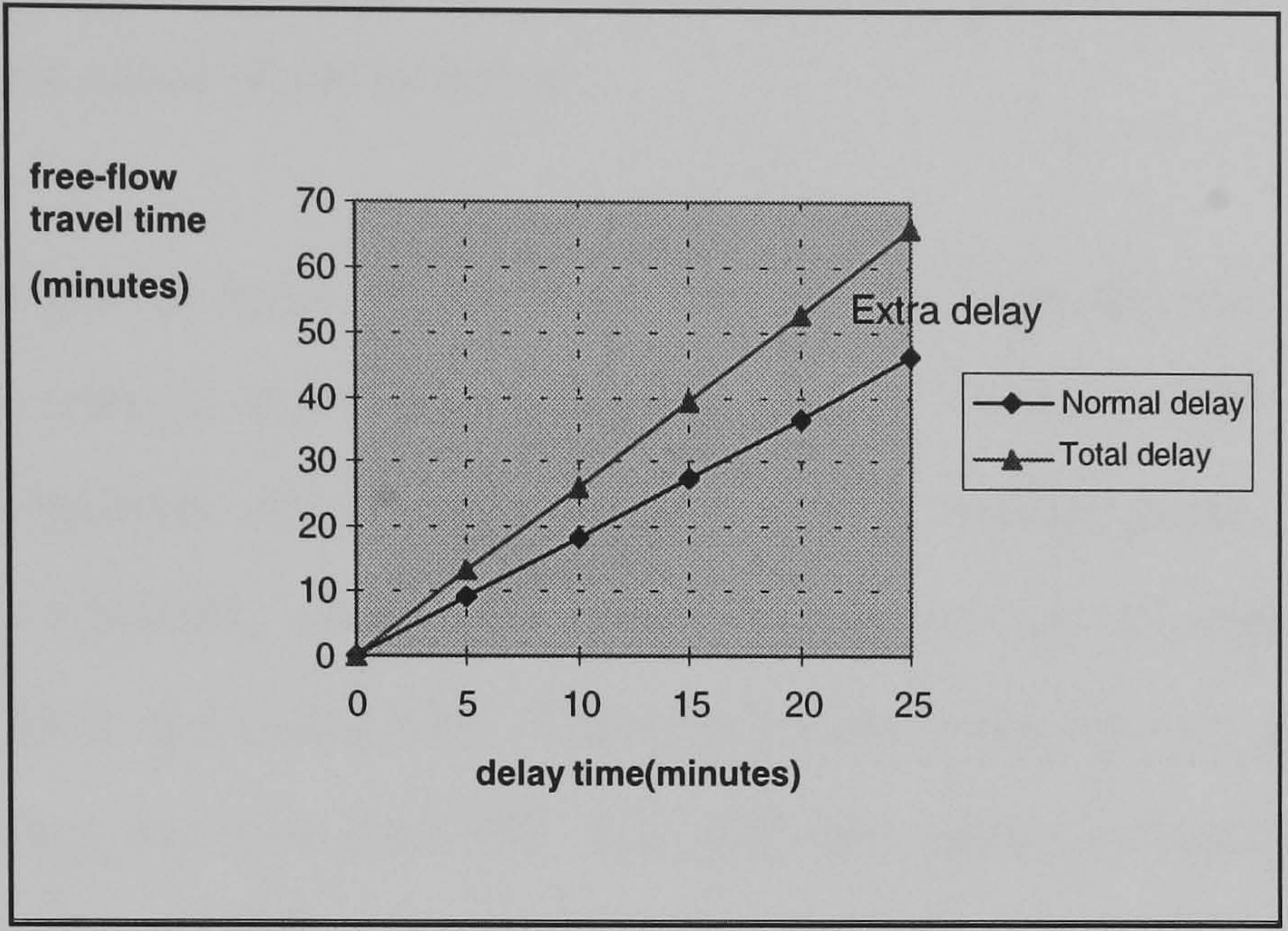

Figure 8-3 Values of normal delay and extra delay (from model 2 in Table 8-12)

The value of delay time of this model with separate delay related parameters, *ndelay* and *exdelay* are higher than total delay parameter, *tdelay*, estimated in the section 8.4.3, which was 1.24 times of normal travel time.

The parameters for charging regimes, *fcharge, ttcharge* and *dtcharge* indicate that drivers are more likely to change their route as charges increase regardless of charging types. The fixed charge has more influence on route choice than total time-based charge and delay time-based charge.

Values of times were estimated from the parameters of model 2 in **Table 8-12**. The results are shown in **Table 8-13**. As before we note that the lowest value of time is associated with fixed charging and the highest with delay time-based charging.

Table 8-13 Values of time in terms of different types of charges

	VOT(Pence per minute)
Fixed charging	4.1
Total time-based charging	5.1
Delay time-based charging	5.6

8.4.5 Non-linear Models with Quadratic Total Delay Variables

In the previous sections, the linear models were estimated using dummy variable or plausible continuous variables. It was found that the models was not able to explain the relationship between value of delay time and travel time and tended to underestimate the value of delay times.

A number of research have found that there is non-linearity between perceived delay time and normal travel time (Huchingson & Dudek 1979; Khattak *et al.* 1993a and b; Wardman *et al.* 1997). In this section, non-linearity is introduced to the total delay variable, *tdelay,* in order to explain the plausible relationship between delay time and travel time. The total delay is the sum of the normal delay and the extra delay, reported on VMS. The variable, *tdelay*, is transformed to be the square values in this model.

Variables used in this model are: free travel time variable, *fttime;* square of total delay variable, $tdelay^2$; a dummy variable for heavy traffic observed through the windscreen, *htraffic*; *fcharge* for fixed charges; *ttcharge* for total time-based charges; and *dtcharge* for delay time-based charges. The utility functions of this model are:

$$\begin{aligned} U_{route1} &= \alpha * fttime_1 + \beta_1 * tdelay_1^{\ 2} + \beta_2 * htraffic \\ &\quad + \gamma_1 * fcharge + \gamma_2 * ttcharge + \gamma_3 * dtcharge \\ U_{route2} &= \alpha * fttime_2 + \beta_1 * tdelay_2^{\ 2} \end{aligned} \tag{8-17}$$

Where	
fttime	**in-vehicle normal free-flow travel time(minutes)**
tdelay²	**the square of total delay, a sum of normal and extra delay (minutes²)**
htraffic	**dummy variable for the heavy traffic situation at the decision point: 1 when local traffic is slow moving htraffic , 0 otherwise**
fcharge	**fixed charge(pence)**
ttcharge	**total time-based charge(pence) : the mid point of range**
dtcharge	**delay time-based charge(pence) : the mid point of range**

Table 8-14 Non-linear model with generic total delay variable

	Coefficient	T-ratio
fttime(min)	-0.103	-11.3
$tdelay^2(min^2)$	-0.005	-12.4
htraffic	-0.220	-2.3
fcharge(pence)	-0.024	-13.8
ttcharge(pence)	-0.020	-12.3
dtcharge(pence)	-0.022	-13.2
Number of observation	2626	
Final Likelihood	-1500.457	
Rho-Squared w.r.t. zero	0.176	

The model estimate results are very satisfactory, even *htraffic* parameter (**Table 8-14**); the value of rho-squared is reasonably high, and all parameters have intuitive signs and are significant. The *htraffic* parameter is also significant and has intuitive sign (this is the only case in this chapter where this is found).

The parameter *fttime* indicates that drivers are less likely to choose the route as free-flow travel time increases. The parameter, *tdelay* indicates that as total delay times increases, the preference of that route decreases.

The estimate of *htraffic* indicates that the observed traffic conditions influence drivers' route choice, i.e. when drivers find heavy traffic at the decision point, they are less likely to choose that route. This result is consistent with that from the two pilot surveys and previous studies. Khattak *et al.* (1993b) reported that drivers generally observed congestion and estimated the length of delay from the queue in front of them. This estimated delay by drivers might support their decision as more information became available. Many other research (Bonsall and Joint 1991; Hato *et al.* 1995; Wardman *et al.* 1997) also found that the drivers responses after receiving information were influenced by the degree of congestion encountered and by visible congestion ahead.

The parameters for charging regimes, *fcharge, ttcharge* and *dtcharge* indicate that drivers are more likely to change their route as level of charges increases. Among three charging regimes, the fixed charge parameter, *fcharge* s bigger than the total time-based charge, *ttcharge* and delay time-based charge, *dtcharge* which indicates that the fixed charge has influenced drivers' route choice more than the other charges do.

Values of time in different types of charges were estimated from the model in **Table 8-14.** The results are shown in **Table 8-15**. We again see the lowest value of time is associated with fixed charging and the highest with delay time-based charging.

Table 8-15 Values of time in terms of different types of charges (from model in Table 8-14)

	VOT(Pence per minute)
Fixed charging	4.3
Total time-based charging	5.5
Delay time-based charging	5.9

The value of total delay time, expressed in units of free-flow travel time, was estimated based on the model in **Table 8-14**. **Table 8-16** and **Figure 8-4** shows the non-linearity of the value of total delay time, which indicates that drivers become more sensitive to the total delay as total delay time increases.

Table 8-16 Value of delay time per minutes of normal travel time (from model in Table 8-14)

Delay minutes	**Values of total delay***	**Ratio****
5 minutes delay	1.25	0.25
10 minutes delay	5	0.5
15 minutes delay	11.25	0.75
20 minutes delay	20	1
25 minutes delay	31.25	1.25

***value of delay time expressed in units of normal travel time**
**** ratio : Value of delay divided by the normal travel time**

This non-linearity of value of total delay time is consistent with the previous studies (Huchingson & Dudek 1979; Khattak *et al.* 1993a and 1993b; Wardman *et al.* 1996). The estimated values of delay time, however, are much underestimated, compared with those from earlier studies (Hensher *et al.* 1990; Wardman 1991; Oscar Faber TPA 1992; Wardman *et al.* 1996) and those from the other sections in this chapter. For instance, the value of 10 minutes delay is only equivalent to the 5 minutes of normal travel time and the value of 20 minutes delay is the same value of normal travel time, which is counterintuitive.

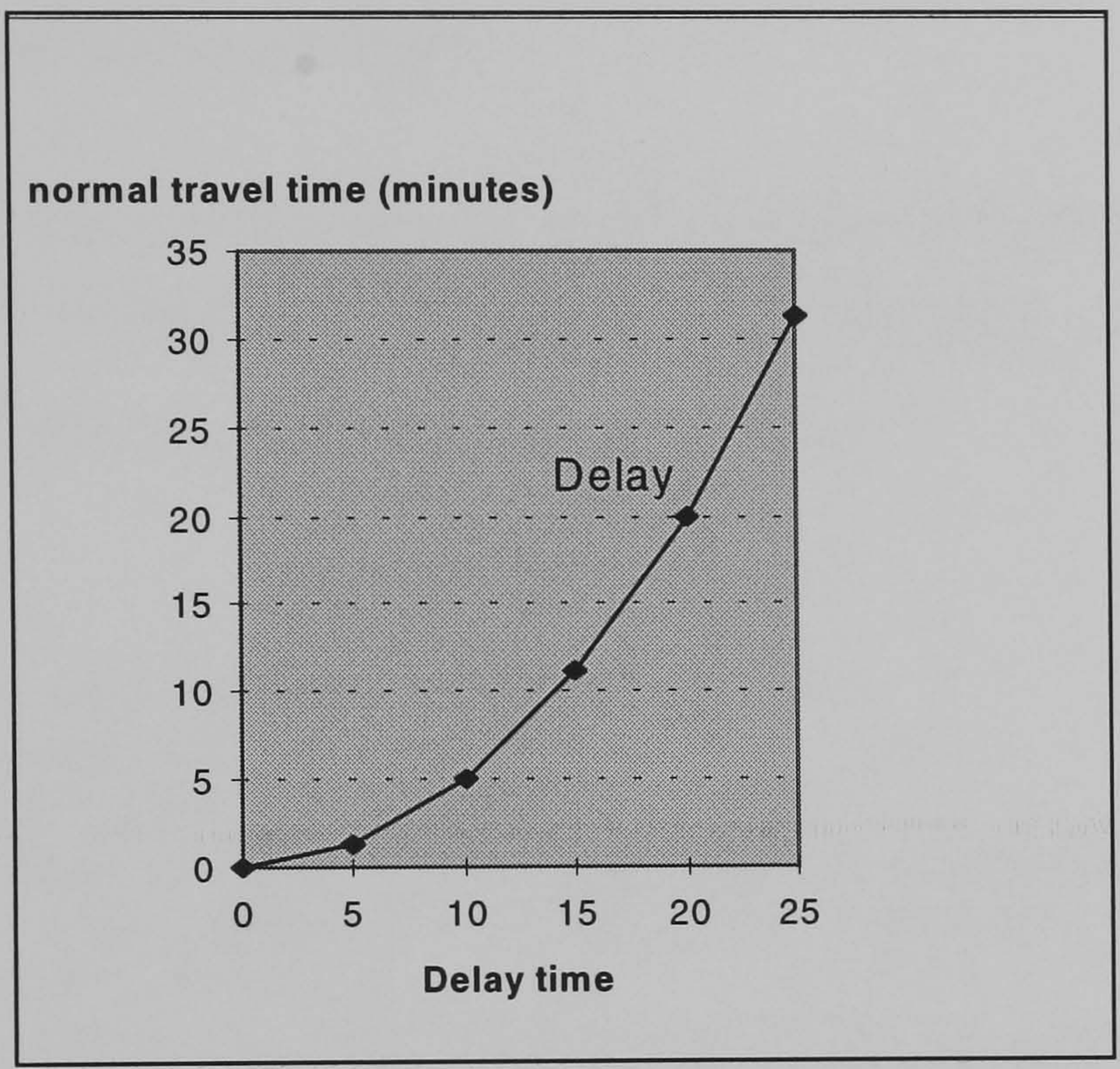

Figure 8-4 Value of total delay time (from model in Table 8-14)

8.4.6 Non-linear Model with Separate Variables for Normal Delay and for Extra Delay

In this section, a non-linear model was estimated using two separate delay variables, *ndelay* and *exdelay*. The normal delay is the usually expected delay in drivers' journeys as a part of normal travel time. The extra delay is an additional delay over and above normal delay and is given as traffic information on VMS. These separate delay parameters allow investigation of the separate effect of each type of delay on route choice. The normal delay parameter, *ndelay* and extra delay parameter, *exdelay* are based on the square of delay time in order to allow for any non-linearity in the relationship between delay and travel time.

Variables used in this model are: the free travel time variable, *fttime;* square of normal delay variable, $ndelay^2$; square of extra delay variable, $exdelay^2$; a dummy variable for heavy traffic observed through the windscreen, *htraffic*; the fixed charges variable, *fcharge*; the total time-based charges variable, *ttcharge* ; and for delay time-based charge variable, *dtcharge*.

The utility functions of this model are:

$$U_{route1} = \alpha * fttime_1 + \beta_1 * ndelay_1^2 + \beta_2 * exdelay_1^2 \, (+\beta_3 * htraffic) + \gamma_1 * fcharge + \gamma_2 * ttcharge + \gamma_3 * dtcharge$$

$$U_{route2} = \alpha * fttime_2 + \beta_1 * ndelay_2^2 + \beta_2 * exdelay_2^2 \qquad (8\text{-}18)$$

Where

fttime	**In-vehicle free-flow travel time(minutes)**
$ndelay^2$	**normal delay(minutes^2)**
$exdelay^2$	**extra delay reported on VMS(minutes^2)**
htraffic	**dummy variable for the heavy traffic situation at the decision point : 1 if local traffic is slow moving htraffic, 0 otherwise**
fcharge	**fixed charge(pence)**
ttcharge	**total time-based charge(pence) : the mid point of range**
dtcharge	**delay time-based charge(pence) : the mid point of range**

Table 8-17 Non-linear model with normal delay and extra delay

	Model 1		Model 2	
	Coefficient	T-ratio	Coefficient	T-ratio
fttime(min)	-0.109	-11.4	-0.103	-11.6
$ndelay^2(min)$	-0.017	-6.4	-0.017	-8.8
$exdelay^2(min)$	-0.008	-6.3	-0.007	-6.3
htraffic	0.459	0.3		
fcharge(pence)	-0.028	-12.7	-0.027	-14.8
ttcharge(pence)	-0.022	-11.4	-0.022	-13.4
dtcharge(pence)	-0.020	-12.2	-0.024	-14.5
Number of observation	2626		2626	
Final Likelihood	-1499.168		-1500.781	
Rho-Squared w.r.t. zero	0.176		0.176	

The results for model 1 in **Table 8-17** are satisfactory except for parameter *htraffic* which has a counterintuitive sign and is not significant. Therefore, model 2 was estimated excluding parameter *htraffic*. The results for model 2 are very satisfactory; all parameters have intuitive signs and significant, and the rho-squared value is acceptable.

The parameter, *fttime* for free-flow travel time indicates that drivers' are less likely to choose the route as travel time increases. The estimates for normal delay minutes, $ndelay^2$ and extra delay, $exdelay^2$ suggest that when the normal delay or extra delay increases, their preference of that route decreases.

The value of normal delay and extra delay time are estimated from model 2 in **Table 8-17** and are summarised in **Table 8-18.** The value of normal delay and extra delay are expressed in units of normal travel time. For example, 5 minutes of normal delay is equivalent to only 4 minutes of travel time and 5 minutes of extra delay is 1.75 minutes of travel time. However, the value of normal delay and extra delay time increase rapidly as delay time increases. So 20 minutes of normal delay is 64 minutes of normal travel time which is the 3.2 time of travel time. 20 minutes of extra delay is 28 minutes of travel time. Wardman *et al.*(1997) also found that additional delays on the VMS were valued more highly than normally expected travel time due to the uncertainty, stress, frustration and the worse driving conditions involved.

Table 8-18 Value of normal delay and extra delay (from model 2 in Table 8-17)

Normal delay			*Extra delay*		
Normal Delay	**Travel time (minutes)**	**Ratio(%)**	**Extra delay**	**Travel time (minutes)**	**Ratio(%)**
5 minutes	**4**	**0.8**	**5 minutes**	**1.75**	**0.36**
10 minutes	**16**	**1.6**	**10 minutes**	**7**	**0.7**
15 minutes	**36**	**2.4**	**15 minutes**	**15.75**	**1.05**
20 minutes	**64**	**3.2**	**20 minutes**	**28**	**1.4**
25 minutes	**100**	**4**	**25 minutes**	**43.75**	**1.75**

The values of normal delay time and extra delay time are also illustrated in **Figure 8-5** which also explains the way drivers value delay time, compared with the free-flow travel time. The total delay means the sum of normal delay and extra delay. The area between total delay curve and normal delay curve represents the extra delay. The curve of the value of normal delay and extra delay are non-linear and concave. This indicates that the value of normal delay time and extra delay time in terms of free travel time increase at an increasing rate as delay time increases. Therefore, drivers thus value delay time more highly and became increasingly sensitive to delay time as it increases.

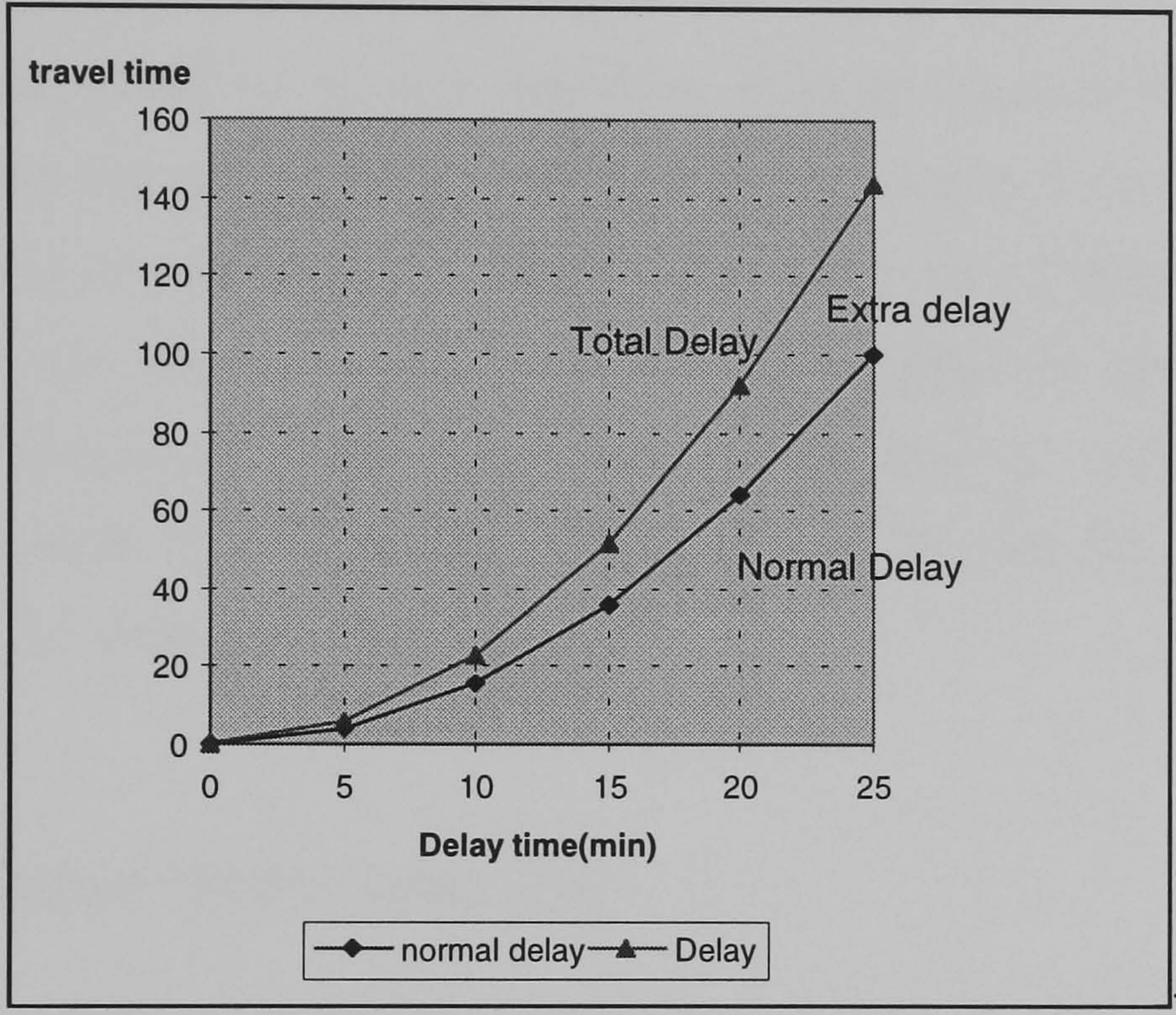

Figure 8-5 Value of normal delay and extra delay (from model 2 in Table 8-17)

The non-linear curve of the value of delay time have also been found by earlier studies. Huchingson and Dudek (1979) found that the relation between length of delay and diversion could bet plotted as a S-shaped curve, in which few drivers were willing to divert in response to minor delays and most drivers were willing to divert as a result of long delay between 30 and 60 minutes delay. Wardman *et al.* (1997) reported that the unit value of expected delay time increases as the amount of delay time increases, at least between 5 and 30 minutes in their study, which indicates that motorists became increasingly sensitive to delay time as it increased. However, Khattak *et al.* (1993a and b) reported that willingness to divert increased with length of delay but at a decreasing rate which meant the convex curve for the value of delay function.

The value of delay time is lower than travel time until normal delay becomes 10 minutes and the extra delay time become 15 minutes. The value of 5 minutes delay time is less than value of normal journey time, while the value of time increases rapidly as the amount of delay increases. It seems that there is a kind of threshold for delay time. Drivers did not value delay time differently from the journey time up to a certain amount of delay time. However, as delay time increases over the certain level, drivers become to value delay time greater than travel time and this trend become greater. The point at which the values begin to diverge may be termed 'delay threshold' for drivers. Estimates from the main survey results in this section and from one of the pilot survey results in section 5.4.3 suggest that the delay threshold is 10 minute for the normal delay time and 15 minutes for the extra delay time on VMS. Khattak *et al*(1993b) also investigated the delay thresholds by length of expected delay in the model and reported that drivers are significantly more likely to divert if the expected delay is at least 20 minutes and larger delay time increased the probability of diversion.

8.4.7 Non-linear Model with ASC

In this section, a non-linear model was estimated including alternative specific constant(ASC), in order to investigate whether there is unobserved preference on route1 or not. In this model, free travel time parameter, *fttime* was excluded because the model did not allow estimation including both free travel time and ASC parameters due to a too strong correlation between them. Variables used in this model are: square of normal delay variable, $ndelay^2$; square of extra delay variable, $exdelay^2$; a dummy variable for heavy traffic observed through the windscreen, *htraffic*; *fcharge* for fixed charges; *ttcharge* for total time-based charges; and *dtcharge* for delay time-based charges.

The utility functions of this model are:

$$U_{route1} = \beta_1 * ndelay_1^{\,2} + \beta_2 * exdelay_1^{\,2} \, (+\beta_3 * htraffic)$$
$$+ \gamma_1 * fcharge + \gamma_2 * ttcharge + \gamma_3 * dtcharge + ASC$$
$$U_{route2} = \beta_1 * ndelay_2^{\,2} + \beta_2 * exdelay_2^{\,2} \qquad \textbf{(8-19)}$$

Where

ndelay	**normal delay(minutes^2)**
exdelay	**extra delay reported on VMS(minutes^2)**
htraffic	**dummy variable for the heavy traffic situation at the decision point: 1 when local traffic is slow moving htraffic , 0 otherwise**
fcharge	**fixed charge(pence)**
ttcharge	**total time-based charge(pence) : the mid point of range**
dtcharge	**delay time-based charge(pence) : the mid point of range**
ASC	**Alternative Specific Constant**

Table 8-19 Non-linear model with ASC

	Model 1		Model 2	
	Coefficient	T-ratio	Coefficient	T-ratio
ndelay^2(min^2)	**-0.017**	**-6.4**	**-0.017**	**-8.8**
exdelay^2(min^2)	**-0.008**	**-6.3**	**-0.007**	**-6.3**
htraffic	0.459	0.3		
fcharge(pence)	**-0.028**	**-12.7**	**-0.027**	**-14.8**
ttcharge(pence)	**-0.022**	**-11.4**	**-0.022**	**-13.4**
dtcharge(pence)	**-0.020**	**-12.2**	**-0.024**	**-14.5**
ASC	**2.016**	**10.9**	**2.024**	**11.6**
Number of observation	**2626**		**2626**	
Final Likelihood	**-1499.168**		**-1500.781**	
Rho-Squared w.r.t. zero	**0.176**		**0.176**	

The estimates for model 1 are shown in **Table 8-19.** The results are satisfactory except parameter *htraffic* which has the counterintuitive sign and is not significant. Therefore, model 2 was estimated excluding parameter *htraffic*. The results for model 2 are very satisfactory; the value of rho-squared is reasonably high, and all parameters have intuitive signs and are significant.

This model has the same coefficients and the same t-ratio values except, ASC, as those of the model in section 8.4.6. It seems that these two models are identical because of perfect correlation between ASC and free travel time, *fttime*, which are incompatible in a model.

As a result, it seems that there is an unobserved strong preference on route1 which is represented by *fftime* or *ASC* parameter. The free travel time parameter, *fttime*, in section 8.4.6 is well representative for the preference on route 1 and this explains why free travel time has a much stronger impact on route choice than normal delay and extra delay have, which is counterintuitive because delay time generally overweighs free travel time to drivers.

8.4.8 Non-linear Model with Distance Variable

In this section, a non-linear model was estimated using distance variables. This is because the distance may explain the unobserved preference on route 1, which was found in section 8.4.7

Estimation of a model including both distance and free travel time variables was attempted, but the model could not be estimated because of a too strong correlation between them. Data manipulation has been made in order to consider free travel time parameter and distance parameter in utility function together and new data set was produced. Estimated model based on the new data set was not satisfactory because this data manipulation did not avoid the correlation problem between them. Instead, a model was estimated only including distance parameter, *distance.* Variables of this model are the same as those of the model in the previous section except *ASC* which is replaced by *distance*.The utility functions of this model are:

$$
\begin{aligned}
U_{route1} &= \delta * distance_1 + \beta_1 * ndelay_1^2 + \beta_2 * exdelay_1^2 (+ \beta_3 * htraffic) \\
&\quad + \gamma_1 * fcharge + \gamma_2 * ttcharge + \gamma_3 * dtcharge \\
U_{route2} &= \delta * distance_2 + \beta_1 * ndelay_2^2 + \beta_2 * exdelay_2^2
\end{aligned}
\qquad (8\text{-}20)
$$

distance	**distance(miles)**
ndelay^2	**normal delay(minutes^2)**
exdelay^2	**extra delay reported on VMS(minutes^2)**
htraffic	**dummy variable for the heavy traffic situation at the decision point: 1 when local traffic is slow moving htraffic , 0 otherwise**
fcharge	**fixed charge(pence)**
ttcharge	**total time-based charge(pence) : the mid point of range**
dtcharge	**delay time-based charge(pence) : the mid point of range**

Estimates for model 1 in **Table 8-20** are unsatisfactory because of *htraffic* parameter, which has the counterintuitive sign and is not significant. The results for model 2, which was re-estimated excluding parameter *traffic*, are very satisfactory, as shown in **Table 8-20.** The value of rho-squared is reasonably high, all parameters have intuitive signs and are significant.

Table 8-20 Non-linear model with distance

	Model 1		Model 2	
	Coefficient	T-ratio	Coefficient	T-ratio
distance(mile)	**-0.328**	**-10.3**	**-0.344**	**-11.6**
$ndelay^2(min^2)$	**-0.017**	**-6.4**	**-0.017**	**-8.8**
$exdelay^2$ (min^2)	**-0.008**	**-6.3**	**-0.007**	**-6.3**
htraffic	0.459	0.3		
fcharge(pence)	**-0.028**	**-12.7**	**-0.027**	**-14.8**
ttcharge(pence)	**-0.022**	**-11.4**	**-0.022**	**-13.4**
dtcharge(pence)	**-0.020**	**-12.2**	**-0.024**	**-14.5**
Number of observation	**2626**		**2626**	
Final Likelihood	**-1499.168**		**-1500.781**	
Rho-Squared w.r.t. zero	**0.176**		**0.176**	

The model estimates are identical to those from section 8.4.6 and section 8.4.7, except *fttime* parameter for the former and ASC for the latter. These three models have the same coefficients of all variables except distance variable, *distance,* free travel time parameters fftime, and the alternate specific variable, ASC. The t-ratios of variables, rho-square values and even the final likelihood values are the same one another. These results are caused by the very strong correlation between distance, free travel time and ASC. In other words, the strong preference on route 1 is well presented by free travel time, distance or ASC. Among three models in section 8.4.6, 8.4.7 and 8.4.8, the model using *fftime* parameter, is preferred because it allows estimation of value of time in terms of various road user charges and estimation of the value of delay time.

8.4.9 Conclusion on Unsegmented Models

8.4.9.1 Comparison of Unsegmented Models

Section 8.4 sets out the model development process to find out the best model for the analysis of survey results. Seven alternative models were estimated and discussed. The linear model was estimated using dummy variables for the amount of extra delay in section 8.4.2. This model included only total normal travel time which did not allow to investigate the effect of normal delay time on route choice. This was also not able to give the pattern of value of delay time due to use of dummy variables. The linear model using continuous total delay variables in section 8.4.3 and one using continuous normal delay and extra delay time variable in section 8.4.4 were estimated. These three models were not capable of explaining the plausible relationship between delay time and travel time, which was expected to be non-linear, and underestimated the value of delay time.

Therefore, in section 8.4.5 the non-linear model was estimated with the square of total delay variable. This was the only case in which has a significant *htraffic* parameter. This model also underestimated the value of total delay time and did not allow the separate estimation of normal delay and extra delay time.

Therefore, in section 8.4.6, the non-linear model was estimated including two separate normal delay and extra delay variables. This model allowed separate estimates of normal delay time and extra delay time parameters. The estimated value of delay time are plausible and the derived non-linear curve of value of delay is consistent with the relevant studies (Huchingson and Dudek 1979; Wardman *et al.* 1997). This model also produced the plausible delay threshold, which was 10 minutes of normal delay and 15 minutes of extra delay. These delay thresholds are also consistent with those from Khattak *et al.* (1993b).

In order to try to improve the model, the non-linear models with ASC in section 8.4.7 and the non-linear model with distance variable in section 8.4.8 were estimated. However, perhaps because of strong correlation between free-flow travel time, distance and ASC, they represented no improvement over the model presented in section 8.4.6.

The model in section 8.4.6 was better than any of the other models. Therefore, it can stand as the preferred model for this study. It is a non-linear model including, as generic variables, the free travel time, the square of normal delay time, the square of extra delay time and charge variables based on the median of the expected charges.

8.4.9.2 Discussion of the Selected Model Results

In the previous section, the best fitting model was selected for this study. In this section, the estimate results of the model will be discussed in detail. For the detailed model estimate results, see **Table 8-17** in section 8.4.6.

The parameter, *fttime* for free-flow travel time indicates that drivers' are less likely to choose the route as travel time increases in section 8.4.6. This parameter explains the strong preference on route 1, as explained in section 8.4.7 and section 8.4.8.

The estimates for normal delay minutes, $ndelay^2$ and extra delay, $exdelay^2$ suggest that when the normal delay or extra delay increases, their preference of that route decreases. A number of research has found that drivers are more likely to divert when the length of delay reported on their usual route increase (Huchingson and Dudek 1979; Mannering 1989; Mahmassani *et al.* 1990; Khattak *et al.* 1991; Khattak *et al.* 1993a and 1993b; Bonsall and Merrall 1995).

According to the results, drivers' route choices are affected more by the normal delay time than by the amount of extra delay time stated on VMS. The reason may be because of the perceived unreliability of VMS information. Drivers may consider the extra delay information as a *possible* delay rather than a *certain* delay and therefore they may take it less seriously. This result differs from that of Bonsall *et al.*(1996). They assessed the impact of VMS information on drivers' propensity to divert to park and ride and reported that extra delays mentioned on VMS had a greater impact on drivers than did normal delay. This difference reflects the different contexts of the choices being investigated and does not give cause for concern.

Among three charging parameters, fcharge is bigger than other charging parameters, shown in **Table 8-17**. Three parameters for charging regimes are significant. In order to find out whether three different charging regimes are significantly different, t-statistics tests for the relevant difference between estimated coefficients were conducted. The t-statistics show that *fcharge* coefficient estimate for the fixed charge is statistically significantly different from the other charge coefficient estimates, *ttcharge* for the time-based charge and *dtcharge* for the delay-based charge at the usual 5% level of significance. This suggests that a fixed charge has significantly more influence on route choice than do time-based charges or delay-based charges. The *ttcharge* and *dtcharge* coefficient estimates have similar values and are not statistically and significantly different from each other.

Table 8-21 Differences between coefficients in model 2 in Table 8-17)

β_1	β_2	t-test	$\beta_1 - \beta_2$
fcharge	*ttcharge*	-3.075	-0.00404
fcharge	*dtcharge*	1.418	0.00168
ttcharge	*dtcharge*	-1.979	-0.00246

The values of time in terms of different charging regimes are estimated based on the model estimate results, as shown in **Table 8-22**. The values of time are: 3.9 pence per minute in terms of fixed charging; 4.5 pence per minute in terms of total time-based charging; and 4.3 pence per minute in terms of delay time-based charging. This result shows that the value of time in terms of the fixed charge is smaller than those of total time-based charge and delay time-based charge and indicates that certainty of charge decreases the value of time. This is presumably due to the fact that total time based charge and delay time are uncertain due to the uncertainty of travel time and delay time. The value of time in terms of road user charges are less valued than would be implied by normal values of time.

Table 8-22 Values of time in terms of different types of charges (from model 2 in Table 8-17)

	VOT (Pence per minute)
Fixed charging	3.9
Total time-based charging	4.5
Delay time-based charging	4.3

Among three different charging regimes, the fixed charge seems to have stronger impact on the route choice than total time-based charge and delay time-based charge. The t-ratio of the fixed charge parameter is also higher than others.

First, the reason the fixed charge had the stronger impact than other charges is discussed by considering the context of choice situation in the survey. As explained in section 8.2 and chapter 4, the differences between these charging regimes were represented by the way the charge information was presented: accurate estimates of the charge given for fixed charges; estimates with narrow ranges were used for time-based charges; and estimates with wide ranges were used for delay time-based charges. The width of the range reflected the relative uncertainty of travel time and delay time.

For example, the first questions from each charging regime are compared. For simplicity, only the route choice and the value of charges are compared. See chapter 6 for the detail choice situations and full set of the questions.

- Question for the fixed charge : Route1 : Route2
  (£0.70 : 0)
- Question for the time-based charge: Route1 : Route2
  (£0.45 ~ 0.55 : 0)
- Question for the delay time-based charge: Route1 : Route2
  (£0.50 ~ 0.90 : 0)

The comparison of these three questions shows that the amount of fixed charge is certain, while in the case of time-based charge and delay-time based charge, charges are given as a range which means there is a possibility to pay less or more.

In the case of the fixed charge, people may take it seriously and are more likely to change their route as the charges increase because of the certain amount of charge, while in the case of total time-based charge and delay time-based charge, people may consider the possibility to pay less and they are less likely to change their route as the charge increases. This tendency was also observed by Kahneman and Tversky (1979) and labelled as 'Certainty Effect' in Prospect Theory. They reported that people underestimated the loss with uncertainty in comparison with the loss that are obtained with certainty. A new survey was conducted in order to investigate the influence of uncertainty of charge on drivers' route choice and will be discussed in chapter 10, along with a further discussion of the relevance of Prospect Theory in chapter 11.

The t-ratio value of the fixed charge parameter, *fcharge*, has a bigger t-ratio value than those of total time-based charge parameter, *ttcharge* and of delay time-based charge parameter, *dtcharge*. See the t-ratio values in **Table 8-17**. This might be thought to indicate that the parameter *fcharge* is more robust than parameters, *ttcharge* and *dtcharge*. However, in general, the difference of t-ratio values is caused by the variation of charge levels because t-ratio value is decided by coefficients and standard errors : t-ratios are bound to be lower if there is more variation in the data.

In this survey, the variation is related to the number of charge levels included in each charging options (see chapter 6). There were three levels of charge rate for each charging regime. In the fixed charge, there are only three charge levels because the charge is fixed. In case of the delay time-based charge and the total time-based charge, the charges are calculated based on charging rate and the travel time or delay time. Therefore, five levels of charge in case of the total time-based charges and in the delay-time based charge. Therefore, the fixed charge parameter has the higher t-ratio values than other charges due to the less levels of charge than other charges because smaller number of levels of charges.

8.5 Segmented Models

8.5.1 Alternative Segmentations

The results of the finally selected model were discussed. In order to investigate the extent to which responses are influenced by socio-economic characteristics of respondents, segmentations are made in this section. The models are based on the selected model in section 8.4.9.2 and based on the median value of the charges. The same data set, used in section 8.4 was also used in this section which contained 2626 SP observations.

The segmentation is made according:

- The sex of the respondents
- The age of the respondents
- The income levels of the respondents

8.5.2 Segmentation by Sex

Two models were estimated depending on the sex and the results are presented in **Table 8-23**. The estimate results of both models are satisfactory: both models have high values of rho-squared and significant coefficients which have intuitive signs.

According to the model estimates, male drivers are more sensitive to all variables than female drivers. The parameters, *fttime*, indicate that male drivers are more likely to change their route than female as free-flow travel time increases on the route. The delay related parameters, *ndelay* and *exdelay* show that the males are more sensitive to the increases of normal delay time and extra delay time on their route choice.

Table 8-23 Models segmented by sex

	Model 1 for Male		Model 2 for female	
	Coefficient	T-ratio	Coefficient	T-ratio
fttime(min)	-0.111	-9.1	-0.095	-7.2
ndelay(min)	-0.018	-6.9	-0.016	-5.5
exdelay(min)	-0.007	-5.1	-0.006	-3.8
fcharge(pence)	-0.028	-11.4	-0.025	-9.4
ttcharge(pence)	-0.025	-10.3	-0.020	-8.5
dtcharge(pence)	-0.025	-10.9	-0.024	-9.6
Number of observation	1511		1115	
Final Likelihood	-855.294		-642.852	
Rho-Squared w.r.t. zero	0.183		0.168	

This is very consistent with the previous studies (Bonsall 1992a, 1992b, 1993, 1995; Caplice and Mahmassani 1992; Conquest *et al.* 1993; Khattak *et al.* 1993; Mannering *et al.* 1994; Bonsall and Merrall 1995; Emmerink *et al.* 1996; Wardman *et al.* 1997) which found female drivers were less sensitive to delay time and more reluctant to divert from their initial chosen route due to traffic information. Khattak *et al.* (1993) explained this tendency using the risk attitude, that is women were more risk-averse in their route choice behaviour than men, because drivers who were more inclined toward "adventure and discovery" are more likely to divert. Emmerink *et al.* (1996) explained this result also due to female' risk-averse attitude and due to the different positions of female drivers in the labour market which caused female's lesser wage, more part-time jobs and so on. Caplice and Mahmassani (1992) reported that female drivers were more likely to listen to radio reports and that female commuters tended to switch departure time more often than males.

The models suggest that females are also less influenced on route choice by the increase of charges than males regardless of different charging regimes. T-statistics for the relevant difference between estimated coefficients were conducted and results are shown in **Table 8-24.** Among three charge parameters, the fixed charge has the strongest effects on route choice regardless of sex. The parameters, *ttcharge*, and *dtcharge*, indicate that male drivers are as much sensitive to the total time-based charge as to the delay time-based charge, while female drivers are more sensitive to the delay time based charge than time-based charge. This is also related to females' risk-averse attitude because there is bigger uncertainty in the case of delay time-based charge.

Table 8-24 Differences between coefficients in the models segmented by sex

Differences between coefficients in Model 1 by male			
β_1	β_2	t-test	$\beta_1 - \beta_2$
fcharge	*ttcharge*	**-1.792****	**-0.00329**
fcharge	*dtcharge*	**-2.253***	**-0.00369**
ttcharge	*dtcharge*	-0.247	**-0.00040**
Differences between coefficients in Model 1 for female			
β_1	β_2	t-test	$\beta_1 - \beta_2$
fcharge	*ttcharge*	**-2.488***	**-0.00471**
fcharge	*dtcharge*	-0.219	**-0.00042**
ttcharge	*dtcharge*	**2.402***	**0.00429**

*** significant for a 5% level of significance **significant for a 10% level of significance**

Value of time in terms of different types of charges are estimated for male and female, as shown in **Table 8-25**. The value of time in terms of fixed charge and delay time-based charge are bigger for female than for male. But the value of time in terms of total time-based charge are bigger for male than for female.

Table 8-25 Value of time between male and female (Pence per Minute)

	VOT for male	VOT for female
Fixed charge	4.0	3.8
Total time-based charge	4.4	4.8
Delay time-based charge	4.4	4.0

8.5.3 Segmentation by Age

A simple segmentation was conducted by the age of the respondents, in order to investigate the extent to which their age has influenced route choice. Two models were estimated depending on whether the drivers were less than 35 years or not. **Table 8-26** presents the model estimates results. The results are satisfactory; the values of rho-squared of both models are reasonably high, and all parameters have intuitive signs and are significant.

According to the model estimates, male drivers are more sensitive to all variables than female drivers. The parameters, *fttime*, indicate that male drivers are more likely to change their route than female as free-flow travel time increases on the route. The delay related parameters, *ndelay* and *exdelay* show that the males are more sensitive to the increases of normal delay time and extra delay time on their route choice.

Table 8-26 Models segmented by Age

	Model 1 for the young*		Model 2 for the old**	
	Coefficient	T-ratio	Coefficient	T-ratio
fttime(min)	-0.119	-8.8	-0.093	-7.8
ndelay(min)	-0.017	-6.0	-0.017	-6.4
exdelay(min)	-0.008	-4.8	-0.006	-4.3
fcharge(pence)	-0.030	-10.9	-0.024	-10.2
ttcharge(pence)	-0.024	-9.6	-0.021	-9.4
dtcharge(pence)	-0.032	-11.8	-0.019	-8.9
Number of observation	1217		1409	
Final Likelihood	-653.482		-830.873	
Rho-Squared w.r.t. zero	0.225		0.149	

* **the young: those who are under 35 years old** ** **the old: those who are over 35 years old**

The model estimation results indicate that the young drivers under 35 years old are more sensitive to most of the variables than the old. The parameter, *fttime,* shows that the young drivers are more sensitive to increases of free-flow travel time than the old. The coefficient, *ndelay*, indicates that the young are sensitive to normal delay as much as the old are. The coefficient *exdelay* indicates that the young people are also more sensitive to extra delay time variation than the old. Allen *et al.* (1993) also reported the consistent results in which the old drivers were more hesitant to divert than younger drivers due to traffic information and they were three times more refusing ultimately to divert than younger drivers.

The charge parameters, *fcharge, ttcharge* and *dtcharge* indicate that the preference on route1 decrease more rapidly for the young drivers than for the old drivers as the charges on route 1 increase. In particular, the difference of *dtcharge* parameters between the young and the old is distinctive, which indicates that the young drivers are much more sensitive to the increase of delay time-based charges. T-statistics for the relevant difference between estimated coefficients were conducted and results are shown in **Table 8-27**.

Table 8-27 Differences between coefficients in the models segmented by age

Differences between coefficients in Model 1 for the young			
β_1	β_2	**t-test**	β_1 - β_2
fcharge	*ttcharge*	**-2.785***	**0.02436**
fcharge	*dtcharge*	1.033	**0.03191**
ttcharge	*dtcharge*	**3.975***	**0.03191**
Differences between coefficients in Model 1 for the old			
β_1	β_2	**t-test**	β_1 - β_2
fcharge	*ttcharge*	**-1.819*****	**0.02100**
fcharge	*dtcharge*	**-3.135***	**0.01920**
ttcharge	*dtcharge*	-1.590	**0.01901**

***significant for a 1% level of significance ***significant for a 10% level of significance**

The overall results implicate that the young drivers are more sensitive to free flow travel time, extra delay time, and any types of charges. These results may be explained by the risk attitude, because the young are less risk-averse than the old. The big difference of parameter, *dtcharge* between the young and the old, explains this trend well in which young drivers are much more sensitive to the delay time-based charge. This is because the delay time-based charges are more uncertain than other charges and the young drivers are less risk-averse than the old drivers.

Values of time in terms of different types of charges are calculated based on the model estimates, as shown in **Table 8-28**. According to the results, the young drivers have higher values of times in terms of fixed charge and total time-based charges, and lower value of time in terms of delay time-based charges than the old drivers. The latter is explained because the young drivers are less risk-averse and they might not value the delay time-based charge high due to bigger uncertainty of the delay time-based charge than in the fixed charge and time-based charge.

Table 8-28 Value of time between the young and the old (Pence per Minute)

	VOT for the young	**VOT for the old**
Fixed charge	4.0	3.9
Total time-based charge	5.0	4.4
Delay time-based charge	3.7	4.9

8.5.4 Segmentation by Income Levels

Three models segmentation were made by three different levels of income in order to investigate the extent to which the level of income of drivers has any influence on their route choice behaviour. Responses without income levels were excluded and a total of 2377 observations were used in these models. Annual income levels are categorised into three levels: the low income under £20,000; the middle income level between £20,000 and £40,00; and the high income level over £40,000. Three models are estimated depending on three different levels of income: Model 1 for low level of income; model 2 for middle level of income; and model 3 for high level of income.

The overall results of model estimates, as shown in **Table 8-29** are satisfactory despite the small sample sizes of model 1 and model 3. The value of rho-squared for model1 is much higher than any other models in this chapter in spite of a very small sample size. The values of rho-squared for model 2 and model 3 are also reasonably high. All parameters of three models have intuitive signs and are significant.

Table 8-29 Models segmented by levels of income

	Model 1		Model 2		Model 3	
	Coefficient	T-ratio	Coefficient	T-ratio	Coefficient	T-ratio
fttime(min)	-0.138	-5.6	-0.109	-9.0	-0.100	-5.1
ndelay(min)	-0.017	-3.6	-0.018	-6.8	-0.021	-5.0
exdelay(min)	-0.012	-4.0	-0.006	-4.3	-0.005	-2.1
fcharge(pence)	-0.035	-7.0	-0.028	-11.3	-0.023	-6.2
ttcharge(pence)	-0.027	-5.9	-0.023	-10.1	-0.023	-6.1
dtcharge(pence)	-0.041	-7.6	-0.023	-10.4	-0.022	-6.2
Number of observation	444		1415		518	
Final Likelihood	-209.751		-830.368		-304.209	
Rho-Squared w.r.t. zero	0.319		0.153		0.153	

Model 1: for the low level of income
Model 2: for the middle level of income
Model 3: for the high level of income

The parameter, *fttime* indicates that the lower level of income they have, the more sensitive to the free flow travel time. The parameter, *ndelay,* shows that drivers who have the higher level of income are more sensitive to the normal delay than others. However, the parameter, *exdelay* indicates that those who have lower level of income, they are more sensitive to extra delay information on VMS which is not consistent with Khattak *et al* (1993a and b) who found that drivers with higher income were more willing to divert in response to traffic information.

The charge parameters of three models indicate that the lower level of income drivers have, the more are they more likely to change their route as the level of charge increases. T-statistics for the relevant difference between estimated coefficients were conducted and results are shown in **Table 8-30.**

The effect of charges on drivers' route choice appears differently depending on their levels of income. The higher level of income they have, the less they are sensitive to the amount and types of charges. Those who have high level of income are almost indifferent to any types of charges, while those who have low income level are more sensitive to the charges. In particular, lower income people are very much sensitive to delay time-based charge which has a wider range (i.e. bigger uncertainty). This results will be investigated in detail in chapter 10.

Table 8-30 Differences between coefficients in the models segmented by income

Differences between coefficients in Model 1 for the low level of income			
β_1	β_2	**t-test**	$\beta_1 - \beta_2$
fcharge	*ttcharge*	**-2.273***	**0.02675**
fcharge	*dtcharge*	**1.660*****	**0.04120**
ttcharge	*dtcharge*	**3.724***	**0.04120**
Differences between coefficients in Model 2 for the middle level of income			
β_1	β_2	**t-test**	$\beta_1 - \beta_2$
fcharge	*ttcharge*	**-2.564****	**0.023**
fcharge	*dtcharge*	**-2.760***	**0.02307**
ttcharge	*dtcharge*	0.044	**0.02307**
Differences between coefficients in Model 3 for the high level of income			
β_1	β_2	**t-test**	$\beta_1 - \beta_2$
fcharge	*ttcharge*	0.023	**-0.05922**
fcharge	*dtcharge*	0.022	**-0.06913**
ttcharge	*dtcharge*	0.022	**-0.00761**

***significant for a 1% level of significance**
**** significant for a 5% level of significance**
*****significant for a 10% level of significance**

Values of time are calculated and presented by the income groups in **Table 8-31**. Those who have a high level of income also have a higher value of time than the others in terms of fixed charge. The value of time in terms of total time-based charge decreases as level of income increase. Drivers who have a middle level of income have the biggest value of time, in terms of delay time-based charges.

Table 8-31 Value of time depending on levels of income (Pence per Minute)

	VOT for low income	VOT for middle income	VOT for high income
Fixed charge	3.9	3.9	4.3
Total time-based charge	5.1	4.7	4.3
Delay time-based charge	3.4	4.7	4.5

8.6 Replication of the Main Survey : Seoul Survey

In order to validate the method and findings from the Leeds survey, the methodology was replicated in Seoul in March 1998. Although the overall design of the Seoul survey was the same as those of the main survey, described in chapter 5 and chapter 6, there were several changes to reflect the difference of travel pattern and traffic conditions between Leeds and Seoul. The SP design was slightly changed considering the average journey time for the commuters in the morning, the average journey distance for commuting trip, and their value of time. The charge levels were also converted into the Korean currency, Won.

8.6.1 Data Collection and Descriptive Results

The Seoul survey was conducted in March 1998. The interviewers visited several companies located in Seoul city centre and handed out the questionnaires to car commuters personally. They collected the questionnaires a week later. A total of 150 questionnaires were distributed and collected.

Respondents were asked about their experience of using different types of traffic information systems and their perception about the usefulness of these systems. VMS and radio traffic information were considered. About 66 % of respondents have had experience with VMS, of whom 87% thought it was useful. Approximately 87% of respondents had listened to radio traffic messages and 80% of them said it was useful. These results indicate that drivers in Seoul were familiar with traffic information systems and considered them useful.

The respondents were asked about their attitudes to road user charges. It was assumed that road user charging had been introduced for use of roads in Seoul city centre during morning peak hours. Three levels of charge were given: 1000 won, 1500 won and 2000 won[3]. About half of the respondents would consider travelling earlier regardless of charge levels. As the level of charges increased, they would also consider switching to public transport.

The respondents were asked to estimate their own petrol costs for hypothetical routes 1 and 2 in the SP experiments (see chapter 7). The average estimates of petrol costs were 2274 won for route 1 and 3134 won for the route 2. This means that the estimate of petrol cost on route 1 was 227.4 won per km, while that on route 2 was 125 won per km. These results indicate that most drivers already perceive the additional cost caused by congestion. In the Seoul survey, the perceived additional cost was 102.4 won per km (40 pence per km).

8.6.2 Model Estimation Results

The SP results were analysed using binary logit models to predict route choice as a function of information content, route attributes, types of road user charge, level of charges and socio-economic characteristics of the respondents. The Seoul survey data contained a total of 1350 SP choice observations, of which 1276 was available for the modelling.

The final model from section 8.4.6 was used in this application of the Seoul data. However, the results were not satisfactory: the normal delay parameter was not significant and had counterintuitive sign. Therefore, the normal delay variable was excluded. A variable for the perceived petrol cost was, however, included (see

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3 **£1.00 was equivalent to about 2,500 won at the time when the survey was undertaken.**

equation 8-18). The question about the perceived petrol cost had been included in the Leeds survey, but it was not included in the modelling reported in section 8.4 and 8.5 because it had yielded insufficient data. The utility functions of this model are:

$$U_{route1} = \alpha * fttime_1 + \beta_1 * exdelay_1^2 + \varphi_1 * pcost_1$$
$$+\gamma_1 * fcharge + \gamma_2 * ttcharge + \gamma_3 * dtcharge$$
$$U_{route2} = \alpha * fttime_2 + \beta_1 * exdelay_2^2 + \varphi_1 * pcost_2 \tag{8-21}$$

fttime	**In-vehicle free-flow travel time(minutes)**
exdelay^2	**extra delay reported on VMS(minutes^2)**
pcost	**perceived petrol cost(won)**
fcharge	**fixed charge (won)**
ttcharge	**total time-based charge(won) : the mid point of range**
dtcharge	**delay time-based charge(won) : the mid point of range**

The model estimation results from equation 8-21 were acceptable; as can be seen in **Table 8-32** all parameters have intuitive signs, most of them are significant, and the rho-squared value is acceptable considering the small sample size and many variables.

Table 8-32 Model estimates for the Seoul data

	Model	
	Coefficient	**T-ratio**
fttime(min)	**-0.00989**	**-1.0**
pcost(won)	**-0.00015**	**-3.2**
exdelay^2***(min)***	**-0.00301**	**-2.6**
fcharge(won)	**-0.00047**	**-6.2**
ttcharge(won)	**-0.00024**	**-3.4**
dtcharge(won)	**-0.00034**	**-4.2**
Number of observation	**1276**	
Final Likelihood	**-815.638**	
Rho-Squared w.r.t. zero	**0.078**	

The parameter, *fttime* for free-flow travel time indicates that drivers' are less likely to choose the route as travel time increases. The extra delay parameter, *exdelay*^{2} suggest that they are also sensitive to the extra delay information on VMS signs as the extra delay increases. The parameter, *pcost*, indicates that preference for the route tend to decrease as the perceived petrol cost on the route increases.

All charge estimates, *fcharge, ttcharge* and *dtcharge* indicate that if a charge is introduced on a route, drivers are less likely to choose the route. Among three kinds of the road user charges, drivers are more sensitive to the fixed charge than total time-based charge and delay time-based charge. This is consistent with the results from the main Leeds survey, discussed in section 8.4.9.2. T-statistics for the relevant difference between estimated coefficients were conducted and results are shown in **Table 8-33.**

Table 8-33 Differences between coefficients in the Seoul model

β_1	β_2	t-test	$\beta_1 - \beta_2$
fcharge	*ttcharge*	**-3.544***	**0.000237**
fcharge	*dtcharge*	**-1.852*****	**0.000335**
ttcharge	*dtcharge*	1.488	**0.000337**

***significant for a 1% level of significance**

*****significant for a 10% level of significance**

The values of time in terms of different charging regimes are estimated based on the model estimate results. The values of time are: 21 won (0.8 pence) per minute in terms of the fixed charging; 41.2 won (1.6 pence) per minute in terms of total time-based charging; and 29.0 won (1.2 pence) per minute in terms of delay time-based charging. The value of time in terms of perceived cost is 65.9 won (2.6 pence) per minute. This result shows that the value of time in terms of the fixed charge is smaller than those of total time-based charge and delay time-based charge and indicates that certainty of charge decreases the value of time. As in the Leeds study, this indicates that the values of time in terms of road user charges are less valued than would be implied by normal values of time in terms of perceived costs.

8.6.3 Model Segmentation

In order to investigate the extent to which responses are influenced by socio-economic characteristics of respondents, segmentations were made by age and income. It was not possible to do segmentation by sex, because most of respondents of Seoul were males. The model in section 8.6.2 was used, based on the median value of the charges. However, the parameter, *fftime* for free-flow travel time was excluded because it had counterintuitive signs and was not significant.

8.6.3.1 Segmentation by Age

Two models were estimated; model 1 for the young drivers under 35 years old and model 2 for the drivers over 35 years old. **Table 8-34** presents the model estimation results.

The results of Model 1 show that all parameters have intuitive signs and their t-ratios are low, but the rho-square values are reasonable. In case of model 2, the values of rho-squared was low but all parameters have intuitive signs and most of them are significant.

Table 8-34 Models segmented by Age

	Model 1 for the young*		**Model 2 for the old****	
	Coefficient	**T-ratio**	**Coefficient**	**T-ratio**
pcost (won)	**-0.00008**	**-1.4**	**-0.00026**	**-3.2**
exdelay(min)	-0.00128	-0.8	**-0.00576**	**-3.4**
fcharge(won)	**-0.00036**	**-3.6**	**-0.00053**	**-4.9**
ttcharge(won)	-0.00013	-1.4	**-0.00039**	**-3.6**
dtcharge(won)	**-0.00045**	**-3.9**	-0.00022	-1.9
Number of observation	**730**		**600**	
Final Likelihood	**-451.935**		**-388.021**	
Rho-Squared w.r.t. zero	**0.107**		**0.067**	

* **the young: those who are under 35 years old** ** **the old: those who are over 35 years old**

The model estimation results indicate that the old drivers over 35 years old are more sensitive than the young drivers to increases of the extra delay on VMS and the perceived petrol cost. The charging parameters indicate that the younger drivers are more sensitive to the delay time based charge than to the fixed charge and the time-based charges, while that the old drivers are much more sensitive to the fixed charge than to other charges. T-statistics for the relevant difference between estimated coefficients were conducted and results are shown in **Table 8-35.**

Table 8-35 Differences between coefficients in the models segmented by age

Differences between coefficients in Model 1 for the young			
β_1	β_2	t-test	$\beta_1 - \beta_2$
fcharge	*ttcharge*	**-2.753***	**0.000127**
fcharge	*dtcharge*	0.876	**0.000447**
ttcharge	*dtcharge*	**3.327***	**0.000447**
Differences between coefficients in Model 1 for the old			
β_1	β_2	t-test	$\beta_1 - \beta_2$
fcharge	*ttcharge*	-1.577	**0.000381**
fcharge	*dtcharge*	**-3.350***	**0.000215**
ttcharge	*dtcharge*	**-1.715*****	**0.000215**

***significant for a 1% level of significance**
*****significant for a 10% level of significance**

8.6.3.2 Segmentation by Income levels

In order to investigate the extent to which their income levels have influenced route choice, model segmentation was made. Two models were estimated depending on the different levels of income: Model 1 for those earned under 2,000,000 won (£800) per month and model 2 for those earned 2,000,000 won or more per month. **Table 8-36** presents the model estimation results. The model estimation results are acceptable; all the parameters have intuitive signs, most of them are significant, and the rho-square values are reasonable.

Table 8-36 Models segmented by levels of income

	Model 1 (under £800)		Model 2 (£800 or more)	
	Coefficient	T-ratio	Coefficient	T-ratio
pcost (won)	-0.00011	-1.3	**-0.00023**	**-3.5**
exdelay(min)	-0.00257	-1.9	**-0.00345**	**-2.3**
fcharge(won)	**-0.00048**	**-5.1**	**-0.00053**	**-5.3**
ttcharge(won)	**-0.00027**	**-3.1**	**-0.00021**	**-2.4**
dtcharge(won)	**-0.00027**	**-2.9**	**-0.00036**	**-3.4**
Number of observation	922		746	
Final Likelihood	**-571.214**		**-476.463**	
Rho-Squared w.r.t. zero	**0.106**		**0.079**	

The model estimation results indicate that the drivers who earned more than 2,000,000 won per month are more sensitive to the perceived petrol cost, and extra delay time on VMS signs than the others. The charging parameters indicate that the fixed charge has the strongest impact on their route choice regardless of levels of incomes. The low income drivers are sensitive to the time-based charge as much as to the delay time-based charges, while the high income drivers are more sensitive to delay time-based charge. T-statistics for the relevant difference between estimated charge related coefficients are reported.

Table 8-37 Differences between coefficients in the models segmented by income

Differences between coefficients in Model 1				Differences between coefficients in Model 2			
β_1	β_2	t-test	$\beta_1 - \beta_2$	β_1	β_2	t-test	$\beta_1 - \beta_2$
fcharge	*ttcharge*	-2.469**	0.000269	*fcharge*	*ttcharge*	-3.801*	0.00021
fcharge	*dtcharge*	-2.543**	0.000265	*fcharge*	*dtcharge*	1.879***	0.00036
ttcharge	*dtcharge*	-0.040	0.000265	*ttcharge*	*dtcharge*	1.723***	0.00036

*significant for a 1% level of significance; ** significant for a 5% level of significance
***significant for a 10% level of significance

8.6.4 Comparison of the survey results between Seoul and Leeds

This section briefly summarises the results from the Seoul survey and compares them with those from the main survey in Leeds.

Drivers in both Seoul and in Leeds were familiar with traffic information systems and considered them useful like those in Leeds. However, the drivers' responses to the road user charges were different between Leeds and Seoul. If a charge was introduced, the first response of drivers in Seoul was travelling earlier to avoid charges regardless of the charge levels and as the levels of charge increased they would consider using public transport. While drivers in Leeds would consider paying a charge first and as the charge levels increased, they would consider travelling earlier to avoid charges. See section 7.4, section 7.5 and section 8.6.1.

Drivers in both Leeds and Seoul have perceived the additional cost caused by congestion. The perceived additional cost caused by the congestion were 9.9 pence per mile (= 6.2 pence per km) in Leeds and 102.4 won (4 pence) per km in Seoul. See chapter 7 and section 8.6.1

The key findings from the Seoul SP data were that drivers were more likely to change their route as the extra delay on VMS increased and as the levels of charges increased. Among three charging regimes, the fixed charge has more influence on route choice than the time-based charges and the delay time-based charges. These results were also found from the main Leeds survey results. See section 8.4.6. section 8.4.9.2. and section 8.6.2.

Although the key findings were the same, the model segmentation results by the age and income levels showed that drivers responses patterns were slightly different. In Leeds, the old drivers were less sensitive to the extra delay time and charges, while in Seoul the old drivers were much sensitive to the extra delay time and charges. In Leeds, the lower income drivers were more sensitive to extra delay, while in Seoul it was the high income drivers who were more sensitive to extra delay. In Leeds, low income drivers are more sensitive to the increases of charges, whereas in Seoul higher income drivers are more sensitive. These different results seem to be caused by the cultural difference. These results echo those of Bonsall (1992b) who investigated the response to VMS and IVG system and found that although the aggregate findings were generally same across the several cities, the disaggregated results were different.

8.7 Summary and Implication for Further Study

This chapter has presented the analysis of the SP data from the main survey, including the model development process. This also reported the results and analysis of the Seoul Survey data.

Seven models were estimated and compared in order to find out the best fitting model for the SP survey in section 8.4. As a result, the finally selected model was the non-linear model in section 8.4.6. This model included the free flow travel time, the square normal delay, the square extra delay, and three charging regimes variables. This model gave a good explanation of the value of the normal delay and value of the extra delay time. The value of normal delay time and extra delay time in terms of free travel time increased at an increasing rate as delay time increased. This produced the plausible delay threshold, which was 10 minutes of normal delay and 15 minutes of extra delay. This also produced the plausible values of times in terms of the three charging regimes.

According to the model estimate results in section 8.4.9.2, drivers' route choice is affected by free-flow travel time, length of normal delay, extra delay indicated on VMS and by road user charges. Drivers valued delay time more highly than normal travel time and became increasingly sensitive to delay time as it increased. Drivers' route choices were affected more by the normal delay time than by the amount of extra delay time stated on VMS. Among the three different types of road user charges, the fixed charge has the strongest effect on route choice. Drivers were more likely to change their route due to the fixed charge than to the total time-based charges and delay time-based charges. The reason is that drivers tended to underestimate the uncertain charge of the total time-based charge and delay time-based charge.

In section 8.5, three segmentations were made according to the sex, age and income levels of respondents. Results showed that drivers' sex, age and income levels have influenced their route choice significantly in response to traffic information and charges. Female and old drivers were less likely to change their route due to normal delay and extra delay information on VMS than male and the younger drivers. Female and the old drivers were also less influenced on route choice by the increase of the charges than male and the young drivers. Drivers who had higher level of income were more sensitive to the normal delay information and those who had the low level of income are much more likely to change their route as the level of charge increases.

The main survey was repeated in Seoul. The results and analysis were reported in section 8.6. The key findings in which drivers were more likely to change their route as the length of extra delay increased and drivers' route choice were more influenced by the fixed charge than by the time-based charge and by the delay time based charges. These key findings were the same as those from the main survey in Leeds.

The charges for time-based charge and for delay-based charges were given with ranges. In section 8.4.2.2. four models were estimated in order to investigate the effect of the ranges of the charges. The results showed that there was no significant influence of ranges on route choice. Therefore, all models in this chapter were based on the median value of charges. Although the effect of ranges on route choice was not significant, there was some indication that the size of range of charges have influenced route choice slightly. It is also interesting to investigate the way drivers' responses to range of charges. Therefore, in order to explore the way and the extent to which uncertainty of charges influence drivers' decision in detail, an additional survey was conducted and will be discussed in chapter 10 and chapter 11.

Chapter 9

Model Estimation with Re-sampled Data

9.1 Repeated measurement problem

A frequently quoted advantage of SP experiments, noted in chapter 5 is that it is possible to collect several observations from each respondent. This makes it possible to collect sufficient data with a relatively small number of respondents and a limited survey budget. This also enables investigation the way a respondent responds to different trade-offs (e.g. Bates 1984; Jones 1989; Pearmain and Kroes 1990).

All simple methods for analysing SP choice data require the assumption that each observation is independent. This assumption is not strictly valid when several repeated choices are made by each respondent. Repeated measurement problem have been generally either ignored in practice or confined to upward biased t-ratios, implying increased significance of explanatory variables (Ortuzar *et al.* 1997; Bates 1997).

The data on which the analyses in chapter 8 are based were derived from SP surveys in which each respondent provided up to nine data points. The results of the SP survey were analysed using the simple logit models which ignores the repeated measurement problem.

This chapter aims to investigate whether and the extent to which this repeated measurement problem affects model estimates. This also tests whether the robustness of the simple model estimates in which there is a possibility of biased results due to the repeated measurement problem.

The next section reviews alternative approaches to deal with the repeated measurement problem. Section 9.3 applies Kocur's method and Jackknife methods to reestimate the models discussed in chapter 8 and then discusses the results, and compares them with those obtained in chapter 8. Section 9.4 summarises the results and draws a conclusion.

Simple estimation methods such as those described in chapter 8, have been used in most previous studies but ignore the repeated measurement problem. They are here called the "uncorrected method".

9.2 Alternative Approaches

9.2.1 Alternative Approaches

A number of researchers (e.g. Cirillo *et al.* 1996; Ouwersloot and Rietveld 1996) have suggested correction methods against the upward biasing of t-ratios. The best known method involves dividing the t-statistic's of the uncorrected method by the square root of the number of repeated number of questions by each respondent (Kocur *et al.* 1982; Khattak *et al.* 1993a). This is an easy and simple method. The coefficients are the same as those from the uncorrected method. But it reduces the value of t-ratios to reflect the influence of the repeated measurement problem on the significance of the estimates. This approach is based on the assumption that the amount of information from repeated choices by each respondent is only the same as the amount of information from only one observation from each respondent. This method is said to be a conservative approach which is the other extreme to the uncorrected method. It tends to overcorrect the value of the standard errors (Abdel-Aty *et al.* 1995, 1997). In this thesis, it is refined to as "Kocur's method".

Ouwersloot and Rietveld (1996) also applied a method to correct the repeated measurement problem. These method treat each observation separately, estimates separate models based on each subgroup one by one and combines these estimates to produce an overall parameter estimate using a 'minimum chi-square' method.

Since only one observation per respondent is used in each model, there is no longer a correlation problem due to repeated observations. This approach seems to be ideal to cure the repeated observation problem. It is, however, very complicated to perform and requires a lot of computing.

Another potential approach is based on re-sampling. The purpose of re-sampling is to find out the true variance of the estimates affected by the repeated measurement problem and to observe the way coefficients change as the number of sub-samples changes. In general, smaller data samples would have more variance. The difference between the estimates obtained from small samples gives a more reliable estimate of the overall variance. Selecting the particular form of sample reduction gives the most efficient means of calculating the variance differences. Therefore, it is necessary to observe the differences between small-sample estimates that are also affected by the repeated measurements problem.

Two example of re-sampling are "Jackknife" and "Bootstrap". Jackknife uses the same data set as the original data set but deletes small parts of the data in each Jackknife sample. Bootstrap creates a completely new sample each time for each Bootstrap sample by drawing randomly with replacement within the sample. Therefore, Jackknife requires less computational work than Bootstrap does (Wonnacott and Wonnacott 1990; Cirillo *et al.* 1996;). It was also reported by Shao and Tu (1995) that the Bootstrap variance estimator was down-biased and was not as efficient as the Jackknife variance estimator.

Cirillo *et al.* (1996) applied Jackknife and Bootstrap to logit model estimates using two real data sets and a simulated data set which had repeated measurement problem. The results of applying the Jackknife method confirmed that the uncorrected model produced good estimates of coefficients values. They suggested that the Jackknife method was theoretically slightly preferable to the Bootstrap method. They recommended Jackknife for practical work because it is easy to implement and produce smoother estimates at low re-sampling rates.

9.2.2 Jackknife and Kocur's Method

The Jackknife method and Kocur's method will be applied in this chapter to deal with the repeated measurement problem. The uncorrected estimates ignore the repeated measurement problem, while the Kocur's method is based on assumption that amount of information from repeated choices by each respondent is the same as that of information when each respondent give only one choice. Thus the uncorrected estimates and the Kocur's estimates are at opposite ends of the spectrum. The Jackknife approach is between these too extremes.

The Jackknife method is selected because of following reasons. First, the other methods are too complicated and require a lot of computation, while Jackknife is available as a software program even though it also requires a lot of computation. Secondly, several studies (Ouwersloot and Rietveld 1996; Cirillo *et al.* 1996) recommended the Jackknife method for an application to a logit model. Before applying this method, the next section briefly explains the way Jackknife works and its general properties.

9.2.3 Jackknife

This section gives detailed explanation about the way the Jackknife technique works, heavily based on Bissell and Ferguson (1975), Shao and Tu (1995) and Cirillo *et al.* (1996). The idea of Jackknife is to re-use the sample several times by dividing it into subgroups and by recombining these to assemble an estimate of the unknown parameter which has good sampling properties and perhaps more importantly, to produce an estimate of the variance of this statistic.

The Jackknife method proceeds as follows. Suppose that there is a random sample, $X_1, X_2, \ldots, X_n$ and the value of parameter, θ_0 is to be estimated.

First, the sample is divided into r sub-groups (at random if $r < n$) of each of size h. The maximum possible number of sub-groups should be used, although $r = n$ (which implies $h = 1$) may not always be computationally feasible.

Jackknife uses re-sampling vector $P_{(i)}$, where ith sub-group is deleted

$$P_{(i)} = (\frac{1}{n-1}, \frac{1}{n-1}, \ldots, 0, \frac{1}{n-1}, \ldots, \frac{1}{n-1}) \qquad \textbf{(9-1)}$$

It removes the first sub-group of data and re-estimates the first partial estimates, θ_{-1} from the remaining observations. Replacing the first sub-group, this estimation procedure is repeated after removing the second sub-group to obtain θ_{-2}. After repeating this procedure r times, r partial estimates for each subgroup, $X_1, X_2, \ldots, X_r$, are produced and the jth estimates used the $h(r-1)$ observations.

$$\theta_{-1}, \theta_{-2}, \theta_{-3}, \ldots, \theta_j, \ldots, \theta_{-n-1}, \theta_{-n}$$

$$X_1, X_2, X_3, \ldots, X_j, \ldots X_{n-1}, X_n \qquad \textbf{(9-2)}$$

Then, the following formula is used to combine these partial estimates to get the Jackknife estimates.

$$\theta_{*Jack} = r\theta_0 - (r-1)\overline{\theta} = \theta_0 + (r-1)(\theta_0 - \overline{\theta}) \qquad \textbf{(9-3)}$$

where

$$\overline{\theta} = \frac{1}{r}\sum_{j=1}^{r}\theta_{-j} \qquad \textbf{(9-4)}$$

θ_{*Jack}	:	**the final Jackknife estimate**
θ_{-j}	:	**the *j*th partial Jackknife estimate**
θ_0	:	**the uncorrected estimate**
$\overline{\theta}$	:	**the mean of partial Jackknife estimates**
r	:	**the number of sub-samples**

The Jackknife variance estimator (σ^2_{JACK}) is ;

$$\sigma^2_{JACK}(\theta) = \frac{n-1}{n}\sum_{i=1}^{n}\left(\theta_{-j} - \overline{\theta}\right)^2, \qquad \textbf{(9-5)}$$

Bissell and Ferguson (1975) summarised the general properties of the Jackknife method as follows:

The magnitude of the bias of θ, determines whether the bias reducing property is useful in an application of Jackknife. The efficiency of the procedure depends on the form of the bias. The bias of practical estimators is usually approximately inversely proportional to sample size and the Jackknife will often produce a substantial improvement. The Jackknife estimate will generally have smaller bias than the uncorrected estimate θ_0, and often smaller variance also.

Jackknife often reduces variance slightly, especially if a large number of subgroups are used. Even if the variance is not actually reduced, the reduced bias is usually sufficient to effect an improvement in terms of mean squared error.

It is desirable to make r as large as possible. It improves the power of significance tests and reduce the expected length of confidence intervals, as well as make variance standard much more stable. A large r also tends to reduce the bias in standard errors which often seems to slightly overestimate variance when r is small.

It can be a useful exercise in examining the robustness of an estimates from using the uncorrected methods.

In the past, a major disadvantage of Jackknife was the amount of computation required for its application (Bissell and Ferguson 1975). Fortunately the **JACKKNIFE**[1] software recently developed by Hague Consulting Group makes the Jackknife produce much more straightforward to apply.

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[1] **To differentiate the JACKKNIFE software from the Jackknife method, the former is expressed in upper case.**

9.3 Application of Jackknife and Kocur's Method

In this section, the Jackknife method and Kocur's method were applied and the results of the Jackknife and of Kocur's method were compared with those of the uncorrected method.

9.3.1 Data and Software

The data from the main SP survey results were used in this application. The original valid number of data was a total of 2626 from 281 individuals' responses which contained maximum of nine observations from each respondent. A detailed description of data was given in chapter 6 and chapter 8.

The Jackknife method allows analysis of data which includes the same number of the repeated observations from each respondent. Observations which had come from respondents who yielded fewer than 9 observations were therefore excluded. The resulting valid number of observation was 2554. In order to compare the results from Jackknife with those from the uncorrected method, the uncorrected model was re-estimated using 2554 observations.

The Jackknife method has been implemented using a program "**JACKKNIFE**" and used in conjunction with a program "**Alogit**", which were developed by Hague Consulting Group. The program, "**JACKKNIFE**", allows the choice of the number of sub-samples and modifies the control file of the estimation program to skip certain observations. Then "**Alogit**" program is then used to estimate sub-models based on the each sub-sample. Finally, "**JACKKNIFE**" combined all the sub-models to produce final Jackknife estimates.

9.3.2 Application Results

As discussed in section 9.2.3, the number of sub-samples is important in Jackknife implementation because it improves the power of significance test and make variance standard stable. The ideal number of sub-samples is the number of samples (i.e. $r = n$). It was recommended to make the number of sub-samples, r as large as possible by Bissell and Ferguson (1975). It, however, was also suggested by Cirillo *et al.* (1996) for users to try different numbers of sub-samples and choose the lowest values of r where the estimates stabilise for the efficiency of the model estimates.

The program "**JACKKNIFE**" allows the number of sub-samples only between 2 and 99. In this study, total eleven models were estimated each with a different number of sub-samples; 5, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 99 which were chosen randomly.

The final model from section 7.4.6 was used for this application of which the utility function is follows.

$$U_{route1} = \alpha * fttime_1 + \beta_1 * ndelay_1^2 + \beta_2 * exdelay_1^2$$
$$+\gamma_1 * fcharge + \gamma_2 * ttcharge + \gamma_3 * dtcharge$$

$$U_{route2} = \alpha * fttime_2 + \beta_1 * ndelay_2^2 + \beta_2 * exdelay_2^2 \qquad \textbf{(9-6)}$$

Where

fttime	**In-vehicle free-flow travel time(minutes)**
ndelay^2	**normal delay time(minutes^2)**
exdelay^2	**extra delay reported on VMS(minutes^2)**
fcharge	**fixed charge(pence) : the mid point of the range**
ttcharge	**total time-based charge(pence) : the mid point of the range**
dtcharge	**delay time-based charge(pence) : the mid point of the range**

Model estimate results of the uncorrected model, the Kocur method and Jackknife are presented in the three tables: Jackknife estimates with 5, 10, 20, and 30 sub-samples in **Table 9-1**, those with 40, 50, 60, and 70 sub-samples in **Table 9-2** and with 80, 90, 99 sub-samples in **Table 9-3**.

Table 9-1 Comparison of uncorrected method, Kocur's and Jackknife method (1)

	Uncorrected method		Kocur's	Jackknife 5 sub-samples		Jackknife 10 sub-samples		Jackknife 20 sub-samples		Jackknife 30 sub-samples	
	Coefficient	T-ratio	T-ratio	Coefficient	T-ratio	Coefficient	T-ratio	Coefficient	T-ratio	Coefficient	T-ratio
fftime	-0.104	-11.6	3.87	-0.102	-8.42	-0.103	-10.32	-0.103	-11.31	-0.103	-10.33
ndelay	-0.017	-8.5	2.84	-0.016	-6.26	-0.016	-7.37	-0.016	-8.29	-0.016	-8.47
exdelay	-0.007	-6.4	2.13	-0.007	-4.93	-0.007	-5.64	-0.007	-6.95	-0.007	-6.85
fcharge	-0.027	-14.8	4.93	-0.026	-6.26	-0.026	-9.06	-0.026	-10.80	-0.026	-9.81
ttcharge	-0.023	-13.4	4.47	-0.022	-9.71	-0.022	-12.95	-0.022	-11.99	-0.022	-12.48
dtcharge	-0.024	-14.4	4.80	-0.024	-9.19	-0.024	-10.10	-0.024	-11.96	-0.024	-9.38

Table 9-2 Comparison of uncorrected method, Kocur's and Jackknife method (2)

	Uncorrected Estimates		Kocur's	Jackknife 40 sub-samples		Jackknife 50 sub-samples :		Jackknife 60 sub-samples		Jackknife 70 sub-samples	
	Coefficient	T-ratio	T-ratio	Coefficient	T-ratio	Coefficient	T-ratio	Coefficient	T-ratio	Coefficient	T-ratio
fftime	-0.104	-11.6	-3.87	-0.103	-9.10	-0.103	-8.99	-0.103	-9.89	-0.103	-11.11
ndelay	-0.017	-8.5	-2.84	-0.016	-7.12	-0.016	-7.72	-0.016	-8.72	-0.016	-7.75
exdelay	-0.007	-6.4	-2.13	-0.007	-7.06	-0.007	-8.03	-0.007	-7.33	-0.007	-8.37
fcharge	-0.027	-14.8	-4.93	-0.026	-10.04	-0.026	-8.89	-0.026	-10.44	-0.026	-9.73
ttcharge	-0.023	-13.4	-4.47	-0.022	-11.32	-0.022	-11.75	-0.022	-12.23	-0.022	-11.42
dtcharge	-0.024	-14.4	-4.80	-0.024	-9.98	-0.024	-9.27	-0.024	-10.04	-0.024	-10.24

Table 9-3 Comparison of uncorrected method, Kocur's and Jackknife method (3)

	Uncorrected Estimates		Kocur's	Jackknife 80 sub-samples		Jackknife 90 sub-samples		Jackknife 99 sub-samples :	
	Coefficient	T-ratio	T-ratio	Coefficient	T-ratio	Coefficient	T-ratio	Coefficient	T-ratio
fftime	-0.104	-11.6	-3.87	-0.103	-10.95	-0.103	-10.57	-0.103	-9.78
ndelay	-0.017	-8.5	-2.84	-0.016	-7.91	-0.016	-8.59	-0.016	-7.75
exdelay	-0.007	-6.4	-2.13	-0.007	-7.96	-0.007	-7.62	-0.007	-7.81
fcharge	-0.027	-14.8	-4.93	-0.026	-10.11	-0.026	-9.09	-0.026	-9.25
ttcharge	-0.023	-13.4	-4.47	-0.022	-12.55	-0.022	-12.40	-0.022	-12.06
dtcharge	-0.024	-14.4	-4.80	-0.024	-10.22	-0.024	-9.53	-0.024	-10.01

First, the results of Kocur's method show that the t-ratio values are much lower than those of the uncorrected method and Jackknife estimates. This indicates that Kocur's method underestimates the significance of the coefficients. Therefore, the assumption of Kocur's method (that the amount of information from repeated observation by each respondents is the only same as that of information when each respondent give only one choice) is clearly too strong.

Secondly, the Jackknife estimates show that, regardless of the numbers of sub-samples, most coefficients of Jackknife estimates are very close to those of uncorrected model estimates and that two coefficients of the Jackknife, *exdelay* and *dtcharge* are the same as those of uncorrected method. These results indicate that the coefficients of the uncorrected model estimates were very accurate despite of the repeated measurement problem.

Thirdly, t-ratio values of the Jackknife estimates are slightly lower than those of uncorrected model estimates, which indicates that the uncorrected method slightly overestimated the significance of the parameters.

Finally, as the number of sub-samples increases, there is little difference in coefficients of the Jackknife, while their t-ratio values are diminishing and stabilised.

In order to show the difference at a glance between Jackknife estimates and uncorrected model estimates and to test the significant difference of them, a test statistic was used to examine equality of parameters between the models. This statistics is discussed by Schulman (1992). As explained in chapter 8, the critical values for acceptance of the null hypotheses are 1.96% for a 5% level of significance and 2.575 for a 1% level of significance.

As shown in **Table 9-4**, the test results of coefficients equality between the uncorrected model estimates and Jackknife estimates accept the null hypothesis in which the coefficient between two models are equal at the ± 5% level of significance. This means that coefficients of two models are not significantly different and indicates that uncorrected estimates of these two coefficients are accurate regardless of the repeated measurement problem. In particular, Jackknife estimates of two parameters, *exdelay* and *dtcharge* are exactly the same as the uncorrected model estimates, which mean that these two parameters are very accurate and not influenced by the repeated measurement problem at all.

Table 9-4 Test for significant difference of individual parameters between uncorrected model estimates and Jackknife estimates

	Test results between Uncorrected and Jackknife method										
	5*	10*	20*	30*	40*	50*	60*	70*	80*	90*	99*
fftime	0.133	0.075	0.078	0.075	0.069	0.069	0.073	0.078	0.077	0.076	0.072
ndelay	0.308	0.339	0.360	0.363	0.332	0.347	0.368	0.348	0.352	0.366	0.348
exdelay	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
fcharge	0.220	0.294	0.331	0.311	0.316	0.290	0.324	0.309	0.317	0.295	0.298
ttcharge	0.352	0.414	0.398	0.406	0.386	0.394	0.402	0.388	0.408	0.405	0.399
dtcharge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

***Number of sub-samples**

As results of these analysis, the Jackknife estimates confirm that the coefficients of the uncorrected estimates are accurate, but that their significance is slightly overestimated. As the number of sub-samples increases, the Jackknife estimates are stabilised.

9.3.3 Comparison of Standard Errors

In addition to the comparison of the coefficients and the t-ratios between uncorrected model estimates and Jackknife estimates, standard errors between them and standard error ratios were also compared in order to show the error estimates of them.

Table 9-5 reports the standard errors of the uncorrected original model and those of Jackknife estimates. The error estimates from the uncorrected model and Jackknife estimates are consistently very low except *fftime* parameter. The last row in the table presents the mean values of the standard errors over all coefficients in the models and indicates that the overall standard errors of the uncorrected model and Jackknife estimates are very similar regardless of the size of the sub-samples, even though there is some variation between parameters. **Figure 9-1** shows that as the number of sub-samples increase, the standard errors of Jackknife estimates tend to stabilise.

Table 9-5 Comparison of Standard Errors between Uncorrected Model and Jackknife estimates

# of samples	original	5	10	20	30	40	50	60	70	80	90	99
fftime	0.010	0.013	0.011	0.010	0.011	0.012	0.012	0.010	0.009	0.009	0.010	0.011
ndelay	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.002	0.002	0.002	0.002	0.003
exdelay	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
fcharge	0.002	0.004	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003
ttcharge	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
dtcharge	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.002
Mean of *s.e.*	0.003	0.004	0.004	0.003	0.003	0.004	0.004	0.003	0.003	0.003	0.003	0.004

Table 9-6 presents the relative standard errors ratios which were quotients of standard error of each parameter of Jackknife estimates by those of uncorrected model estimate.

$$\text{standard error ratio} = \frac{\text{standard error of jackknife estimates}}{\text{standard error of uncorrected model estimates}} \quad \textbf{(9-7)}$$

Table 9-6 Standard Error Ratios of Jackknife estimates to uncorrected model estimates

# of samples	5	10	20	30	40	50	60	70	80	90	99
fftime	1.30	1.11	1.03	1.08	1.21	1.24	1.16	1.03	1.05	1.09	1.13
ndelay	1.10	0.97	0.90	0.89	1.07	0.98	0.92	1.03	1.01	0.93	0.95
exdelay	1.16	0.98	0.86	0.85	0.95	0.78	0.87	0.76	0.80	0.84	0.80
fcharge	1.90	1.36	1.15	1.33	1.20	1.40	1.37	1.46	1.41	1.57	1.34
ttcharge	1.26	1.06	1.02	1.01	1.01	1.02	1.05	1.12	1.02	1.03	0.94
dtcharge	1.36	1.21	1.13	1.24	1.24	1.32	1.43	1.41	1.41	1.51	1.24
Mean of *s.e.*	1.33	1.11	1.02	1.08	1.16	1.18	1.15	1.11	1.10	1.14	1.10

The results show that the values are consistently more than 1 and close to 1 which indicates that the uncorrected model estimates are accurate but slightly underestimate the errors. These results are also illustrated in **Figure 9.2**

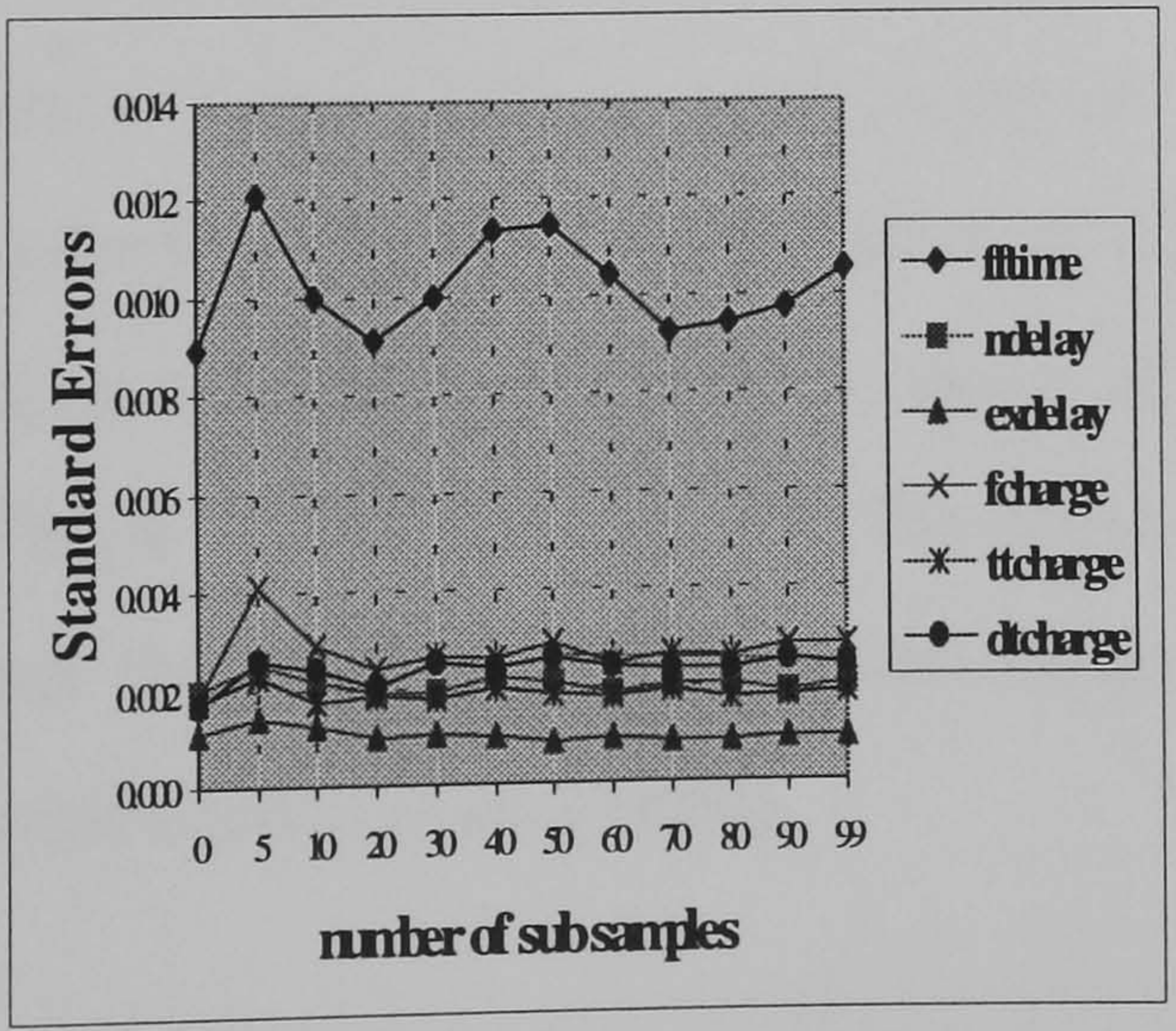

Figure 9-1 Comparison of standard errors

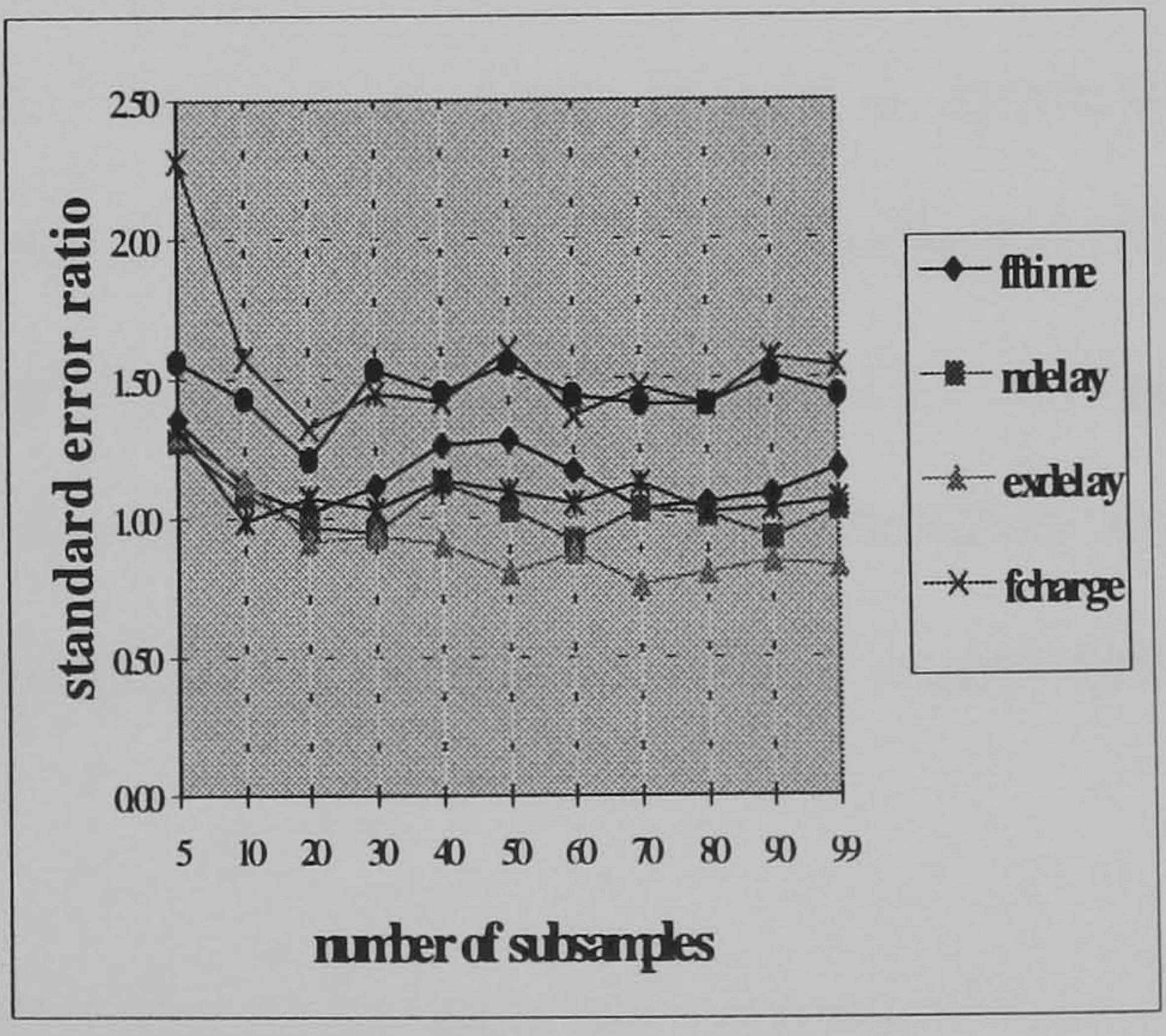

Figure 9-2 Comparison of standard error ratio

(The number 0 in the X-axis means the uncorrected model estimates)

9.4 Summary and Conclusion

This chapter has dealt with the "repeated measurement problem" which is caused by allowing several observations from each respondent and inflates the significance of explanatory variables.

Several different approaches to correct the repeated measurement problem were reviewed: Kocur's method (Kocur *et al.* 1981), the approach by Ouwersloot and Rietveld (1996), and Jackknife and Bootstrap method (Cirillo *et al.* 1996).

Among those approaches, the Jackknife method and Kocur's method were applied to the main SP results in order to treat the repeated measurement problem. The Jackknife method was implemented using a program '**JACKKNIFE**'. The model from section 7.4.6 was used for this application and the eleven Jackknife models were estimated with 5, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 99 of sub-samples.

The model estimate results of Jackknife method and Kocur's method were compared with those of the uncorrected estimates in order to test whether there was repeated measurement problem or not and the extent to which this problem affected the model estimates. The standard errors between the uncorrected model estimates and Jackknife estimates were also compared.

The results reveals that the t-ratios of Kocur's are much lower than those of the uncorrected method and Jackknife estimates, indicating that Kocur's method underestimates the significance of the coefficients. Jackknife method produced the almost same coefficients as those of the uncorrected model but the lower t-ratios. These results indicate that the coefficients of the uncorrected method are accurate but that their significance are somewhat overestimated. This result is consistent with Cirillo *et al.* (1996).

Therefore, I conclude from this finding that the repeated measurement problem does exist in my data, but that it does not affect the model estimation results significantly in this study. Therefore, the uncorrected model estimates are good enough to predict the route choice behaviour despite repeated observations. Thus there is no need to estimate model using Jackknife or Kocur's method and the models estimated using the uncorrected method can stand.

Chapter 10
Additional Survey on Response to Uncertain Charges

10.1 Introduction

In the main survey, the difference of time-based charge and delay-based charge was presented by the different size of ranges of charges in order to reflect the relative degree of uncertainty of travel time or delay time. An interesting question arises from this point about the way in which the uncertainty of charges influence drivers' route choice. It may also be interesting to investigate whether drivers focus on either the median value of a charge or the size of the range of a charge, when they face a choice between different ranges of charges. The results of these investigations are presented in this chapter.

An additional SP survey was conducted in Leeds city car parks. The basic concept, key features and principles of the SP method were discussed in detail in chapter 5. The first purpose of this survey was to explore the way and the extent to which drivers' route choice was influenced by uncertain charges. The second was to investigate the effect of providing charge information on route choice. The third was to investigate the effect of socio-economic characteristics on the drivers response to uncertain charges.

The next section briefly summarises the survey design and the structure of the questionnaires used. Section 10.3 reports the data collection and results from the first part of the questionnaires including respondents' characteristics and travel patterns, as well as drivers' experience with traffic information systems. Section 10.4 reports the descriptive analysis of the survey results. The effect of providing charge information on drivers' route choice will be described in section 10.4.1. From section 10.4.2 to section 10.4.4, the effect of a median value of charges and a range of charges on route choice will be discussed. Section 10.4.3 discusses the effect of socio-economic characteristics of drivers on their responses to uncertain charges. In section 10.5, the process of estimating logit models is discussed. This investigates the way in which uncertain charges influence drivers' route choice. Finally, section 10.6 summarises the results and suggests a further study based on the main findings.

10.2 Survey Design

10.2.1 Network and Journey Scenarios for Survey

A hypothetical network was used in the additional SP survey. This is because, as discussed in section 5.3.4.4, it is simple and easy to design and also enables exclusion of the effect of respondents' experience and preference on a specific route.

Figure 10-1 shows a hypothetical journey from home to work. The workplace is the other side of the city centre. It is assumed that the respondent is driving from home to work on a normal working day in the morning.

Figure 10-1A hypothetical network

There are two routes available in the SP network. Both are about 4 miles long, and go through the city centre. The normal travel time on each route is approximately 30 minutes. The travel distance and travel time in this survey were designed based on the characteristics of typical commuter journeys in Leeds, in order to make the survey design credible for the respondents.

In this questionnaire, respondents are asked to imagine that charges have been introduced for driving through the city. The charge payable is proportional to the time spent on the streets. For example, if the rate is 10 pence per minute and a driver takes 10 minutes, then he would be charged £ 1.00. The charges would be automatically deducted from the credit stored in a prepaid smart card in the vehicle (see the example of the questionnaire in appendix 4).

10.2.2 Survey Design and Structure of Survey Questionnaire

The questionnaire had two parts. The first part included general questions about characteristics of the drivers and their travel patterns. It also contained questions which asked for the drivers' experience with VMS signs and radio traffic information and whether they found them useful. (This information was identical to that sought in the first part of the main questionnaire as described in chapter 7)

The second part of the questionnaire consisted of two sections of questions. The first section gave respondents the choice of two routes: route 1 which had charge information and route 2 without charge information. The purpose of this question was attempt to determine the effect of charge information on drivers' route choice.

The second section included SP survey questions designed to investigate the influence of a range of charges on drivers' route choice. Respondents were asked to make a route choice decision between a certain charge and an uncertain charge in order to investigate the effect of uncertainty of charges on route choice. There were three sets of questionnaires depending on the level of base charges on route 1 (£1.00, £1.50 and 2.00). To avoid overloading the respondents, each respondent was asked only one of the three sets. **Table 10-1** summarises the SP design. For more details see the example of the questionnaire in appendix 4.

Six SP questions were used. The first three of them (a, b and c) varied the range of charges on route 2 with the same median value of charge between two routes, while the next three (d, e and f) varied the ranges of the charges as well as the median value of the charges on route2. This design was used to determine the effect of the range of the charge and the effect of the median value of the charge on route choice.

Table 10-1 SP design for the additional survey

Set 1 for the £ 1.00 base charge							
		Route 1	**Route2**				
		Charge Information	**Charges Information**	**degree of uncertainty**	**ranges (pence)**	**Median values**	**Difference of median**
section1	a	£1.00	£0.90-£1.10	±10%	20	£1.00	0
	b	£1.00	£0.80-£1.20	±20%	40	£1.00	0
	c	£1.00	£0.70-£1.30	±30%	60	£1.00	0
section2	d	£1.00	£0.85-£1.05	±10%	20	£0.95	-£0.05
	e	£1.00	£0.70-£1.10	±20%	40	£0.90	-£0.10
	f	£1.00	£0.80-£1.40	±30%	60	£1.10	+£0.10
Set 2 for the £ 1.50 base charge							
		Route 1	**Route2**				
		Charge Information	**Charges Information**	**degree of uncertainty**	**ranges (pence)**	**Median values**	**Difference of median**
section1	a	£1.50	£1.35-£1.65	±10%	30	£1.50	0
	b	£1.50	£1.20-£1.80	±20%	60	£1.50	0
	c	£1.50	£1.05-1.95	±30%	90	£1.50	0
section2	d	£1.50	£1.30-£1.60	±10%	30	£1.45	-£0.05
	e	£1.50	£1.10-£1.70	±20%	60	£1.40	-£0.10
	f	£1.50	£1.15-£2.05	±30%	90	£1.60	+£0.10
Set 3 for the £ 2.00 base charge							
		Route 1	**Route2**				
		Charge Information	**Charges Information**	**degree of uncertainty**	**ranges (pence)**	**Median values**	**Difference of median**
section1	a	£2.00	£1.80-£2.20	±10%	40	£2.00	0
	b	£2.00	£1.60-£2.40	±20%	80	£2.00	0
	c	£2.00	£1.40-£2.60	±30%	120	£2.00	0
section2	d	£2.00	£1.75-£2.15	±10%	40	£1.95	-£0.05
	e	£2.00	£1.50-£2.30	±20%	80	£1.90	-£0.10
	f	£2.00	£1.50-£2.70	±30%	120	£2.10	+£0.10

10.3 Data Collection and Overview of Results

10.3.1 Data Collection

The survey was conducted at the beginning of December 1997. The questionnaires were distributed to car commuters who arrived at car parks in Leeds city centre during the morning peak between 7:00 am and 9:00 am. Questionnaires were only distributed to commuters because one of main purposes of a road user charge is to tackle the congestion problem usually during the morning peak time, and commuters will be the most affected by the charges. Questionnaires were handed out personally to the respondents and they were asked to complete them and post back their answers in a freepost envelop which was provided.

Three hundred questionnaires were handed out and 160 were returned. This implies a response rate of 53.3% which is higher than usual for this type of survey method. A total of 1120 choice observations were obtained.

10.3.2 Respondents' Characteristics and Travel Patterns

The respondents' socio-economic characteristics and travel patterns are summarised in **Table 10-2**. This sample has similar patterns of distribution to those of the sample from the main surveys. This sample also seems to well represent the characteristics of the population of Leeds commuters. (see section 8.2)

As can be seen, slightly more men than women responded to the survey. Only 13% of respondents were not within the age range 25 and 54 years old. The income distribution shows that 51% of respondents had annual incomes between £20,000 and £40,000 and 31% indicated an income of more than £40,000. 93% of respondents were in full time employment.

Table 10-2 Respondents' characteristics and travel patterns

		Number of respondents	(%)
Sex	**Male**	90	56%
	Female	70	44%
Age	**Under 24**	17	11%
	25 - 34	75	47%
	35 - 54	64	40%
	Over 55	4	3%
Income	**under £ 20,000**	18	11%
	£20,000 - £ 40,000	82	51%
	Over £ 40,000	50	31%
	No response	10	6%
Employment	**Full time**	148	93%
	Part time	10	6%
	Others	2	1%

10.3.3 Experience with Traffic Information Systems

Respondents were asked about their experience of using traffic information systems such as VMS information and radio messages about traffic conditions. They were also asked whether they found them useful or not.

About 82% of respondents said they had had experience with Variable Message Signs (VMS) before, and of those 33% had used them frequently. Among the 82%, 77% thought that they were useful. These results indicate that responses to the traffic information on VMS are based on the fact that the respondents are familiar with VMS and think them useful. 83% of respondents had made use of radio messages about traffic conditions and 80% of them said they had found them useful. The percentage of respondents who had used VMS before was higher in the additional survey (82%) than in the main survey (73%), as was the percentage of respondents who had listened to radio messages about traffic conditions (80% for this additional survey and 67% for the main survey. See section 7.4.). **Table 10-3** presents these figures.

Table 10-3 Experience with traffic information systems

	Experience with information				Usefulness of information			
	Frequent	A little	Never	No response	Yes	somewhat	No	No response
VMS	53	78	24	5	58	65	19	18
(%)	33%	49%	15%	3%	36%	41%	12%	11%
Radio	55	79	25	1	62	66	21	11
(%)	34%	49%	16%	1%	39%	41%	13%	7%

10.4 Descriptive Analysis of Survey Results

10.4.1 Effect of Providing Charge Information on Route Choice

The first question of the second part of the survey was designed to investigate the extent to which providing charge information influenced drivers' route choice. In this case there were charges on both routes. It was assumed that a traffic information system had been introduced on route 1, which provided an estimate of charges and so helped drivers to decide which route to use. No charge information was available on route 2, so drivers would not know how much the charge on route 2 would be. However, in order to help them to estimate their charges on route 2 by themselves, the charge rate and normal travel time on route 2 were given to them. This feature was designed deliberately so that the charge estimated for route 2 would be approximately the same as the charge on route 1. Therefore, the only difference between the two routes was whether precise charge information was given or not. For an example of this question, see appendix 4.

Approximately 78% of drivers chose route 1 for which information was provided regardless of levels of charges. **Table 10-4** presents the results. This result indicates that drivers prefer avoiding uncertain charges, even though there may be a possibility of paying less on route 2. This result also indicated that providing charge information encourages drivers to choose the routes for which information is provided in preference to those for which it is not provided.

Table 10-4 Effects of charge information on route choice

Route1	Route2	Route Choice(%)	
Charge information	Charge information	Route1	Route2
£1.00	Not available	79%	21%
£1.50	Not available	72%	28%
£2.00	Not available	80%	20%
Average		78%	22%

Route 1 : charge information is given Route 2 : charge information is not given

10.4.2 Effect of Ranges of Charges on Route Choice

The survey also included a hypothetical choice between two routes with precise and certain charge information being provided on route 1, while a range of possible charge (i.e. an imprecise charge) was provided on route 2. First three questions were designed deliberately so that the median values of charges estimated for route 2 was the same as the (known) charge on route 1. The ranges of the charges on route 2 varied across questions (from ±10% to ±30% of the median value of the charges, see appendix 4). **Table 10-5** summarises respondents' route choice in response to different ranges of the charges.

Table 10-5 Effects of ranges of charge on route choice

Route 1	Route2				Route choice(%)	
Charge Information	Charges Information	Degree of uncertainty	Ranges (pence)	Median values	Route1	Route2
£1.00	£0.90-£1.10	±10%	20	£1.00	76%	24%
£1.00	£0.80-£1.20	±20%	40	£1.00	76%	24%
£1.00	£0.70-£1.30	±30%	60	£1.00	71%	29%
£1.50	£1.35-£1.65	±10%	30	£1.50	65%	35%
£1.50	£1.20-£1.80	±20%	60	£1.50	68%	32%
£1.50	£1.05-£1.95	±30%	90	£1.50	61%	39%
£2.00	£1.80-£2.20	±10%	40	£2.00	72%	28%
£2.00	£1.60-£2.40	±20%	80	£2.00	72%	28%
£2.00	£1.40-£2.60	±30%	120	£2.00	59%	41%

It can be seen from the above table that most drivers chose route 1 which had precise and certain charges. This result indicates that drivers prefer to avoid the uncertainty of charges. However, as the degree of range of charges on route 2 increased, drivers' preference for route 1 decreased slightly. This indicates that the percentage of drivers choosing route 2 was slightly affected by the size of the ranges. As the range of charge on route 2 increased from ± 20% to ± 30% (through interestingly, not from ± 10% to ± 20%), the percentage of drivers choosing route 1 decreased slightly. It seems that drivers' route choices are influenced not only by the relative size of the range of the charges but also by the absolute value of the range of the charges. The response to uncertain charges are slightly different depending on the base charge levels. As it can be seen in **Table 10-5**, those who face £1.00 base charge levels are more likely to choose route 1.

10.4.3 Effect of Socio-economic Characteristics on Route Choice

In order to investigate whether the socio-economic characteristics of drivers influence their responses to uncertain charges, the results of section 1 were analysed by the sex, age and income levels of the respondents. It was found that there is significant difference in drivers' responses by sex and income, but no distinctive difference in responses by age.

10.4.3.1 Response to Uncertain Charges by Sex

Table 10-6 summarises the route choice responses to the different range of charges on route 2 by sex. The average percentage of those choosing each of the routes is presented in the table regardless of the base of the charge levels.

Table 10-6 Route choice in responses to uncertain charge by sex

	Male			Female		
Range on Route 2	Route 1(%)	Route 2(%)	Total(%)	Route 1(%)	Route 2(%)	Total(%)
10%	68.9	31.1	100	75.7	24.3	100
20%	65.6	34.4	100	80.0	20.0	100
30%	56.7	43.3	100	71.4	28.6	100
Average	63.7	36.3	100	75.7	24.3	100

The last row of the table shows the average percentage of choosing routes by sex. This indicates that both of male and female drivers are more likely to choose the route1 than route 2. However, the average percentage of choosing route 1 is much higher for females than for males. This indicates that female drivers are more likely choose the route1 to avoid uncertain charges than are males. This may be related to females' risk averse attitude.

10.4.3.2 Responses to Uncertain Charges by Income Levels

The questions about income levels were voluntary. 60 responses without income levels were excluded in the analysis. Annual income levels were categorised into three levels: low income under £20,000; middle income between £20,000 and £40,000; and high income over £40,000. **Table 10-7** summarises response to uncertain charges by income levels.

Table 10-7 Responses to uncertain charges by income Levels

Income level	Range on Route2	Route 1		Route 2		Total
		numbers	%	numbers	%	%
Low	Average	37	68.5	17	31.5	100
Middle	Average	170	69.1	76	30.9	100
High	Average	105	70.0	45	30.0	100
Low	**Range level**	**Route 1**	**%**	**Route 2**	**%**	**Total**
	10%	17	94.4	1	5.6	100
	20%	11	61.1	7	38.9	100
	30%	9	50.0	9	50.0	100
Middle	**Range level**	**Route 1**	**%**	**Route 2**	**%**	**Total**
	10%	58	70.7	24	29.3	100
	20%	61	74.4	21	25.6	100
	30%	51	62.2	31	37.8	100
High	**Range level**	**Route 1**	**%**	**Route 2**	**%**	**Total**
	10%	33	66.0	17	34.0	100
	20%	37	74.0	13	26.0	100
	30%	35	70.0	15	30.0	100

The first three rows in the table summarise the mean percentage of respondents choosing route by levels of income. It can be seen that regardless of income levels, most respondents chose route 1. As respondents levels of income increase, they are even more likely to choose route 1.

The rest of the table summarises the route choice in response to the different range of charges by levels of incomes. As the range of the charges increases, the preference of low income people for route 1 decreases rapidly (but note the small sample size). For middle income people and the high income people, there is no clear trend in route choice as the range of the charge increases.

In order to investigate whether there is a strong correlation between sex and income, which might influence the route choice, a correlation test was conducted. A very small negative correlation was found between income and sex which was -0.0206 (960 cases and 0.523 significance).

10.4.4 Effect of Median Values of Charge on Route Choice

Section 10.4.2 and 10.4.3 analysed the first three questions (question section 1 : a, b and c) of the six SP questions which vary only the range of the charges on route 2. This section analyses the other three questions (question section 2: d, e and f) which vary the range of the charges *and* the median value of the charge on route 2 (see **Table 10-1** for the SP design).

Comparison of the responses between these two sections of questions indicates the effect of the range of the charges and the median value of the charges on the route choice. **Table 10-8** summarises the respondents' route choice in response to different ranges of charges and different median values of charges. The charges on route 1 were the same between the two sections. The ranges of the charges on route 2 were also the same between them. The only difference between section 1 and 2 was the median value of charge between routes.

Table 10-8 Effect of median values of charge and effect of ranges on route choice

	Question section 1 (a, b and c)					Question section 2 (d, e and f)				
Route 1	**Route 2**		%			**Route 2**		%		
charge	**Median**	**range**	**route1**	**route2**	**total**	**median**	**range**	**route1**	**route2**	**total**
£1.00	**£1.00**	±10%	76%	24%	100	**£0.95**	±10%	47%	53%	100
£1.00	**£1.00**	±20%	76%	24%	100	**£0.90**	±20%	35%	65%	100
£1.00	**£1.00**	±30%	71%	29%	100	**£1.10**	±30%	100%	0%	100
£1.50	**£1.50**	±10%	65%	35%	100	**£1.45**	±10%	53%	47%	100
£1.50	**£1.50**	±20%	68%	32%	100	**£1.40**	±20%	46%	54%	100
£1.50	**£1.50**	±30%	61%	39%	100	**£1.60**	±30%	81%	19%	100
£2.00	**£2.00**	±10%	72%	28%	100	**£1.95**	±10%	54%	46%	100
£2.00	**£2.00**	±20%	72%	28%	100	**£1.90**	±20%	38%	62%	100
£2.00	**£2.00**	±30%	59%	41%	100	**£2.10**	±30%	82%	18%	100

As it can be seen, as the median values of charges on route 2 decreases, the percentage of choosing route 2 rapidly increase and vice versa. Comparison of results from section 1 and section 2 indicates that when median values of the charges on routes are different, the percentages choosing each route are quite different between them even though the same ranges of the charges on route 2 are given. This indicates that drivers are very sensitive to the median values of charges. This result also indicates that drivers' route choices are influenced more by the median value of the ranges of the potential charges than by the size of the overall ranges of the charges.

10.5 Model Estimation Results

In order to investigate the extent to which ranges of charge and median values of charge influence route choice, binary logit models were estimated. Three variables in utility functions were used in several models: median values of charges (pence);

relative range of charges on route 2 (%); and absolute value of the range of the charges on route 2 (pence).

10.5.1 Effects of the Median Value and the Ranges of the Charges on Route Choice

Two models were estimated in order to investigate the effects of the median value of the charges and the ranges of the charges on route choice. Model 1 was estimated using the relative size of the range of the charges, while Model 2 was estimated using the absolute value of the range of the charges.

The utility functions of Model 1 are

$$U_{route1} = \alpha * mcharge_1$$
$$U_{route2} = \alpha * mcharge_2 + \beta * prange_2 \qquad (10\text{-}1)$$

Where :
mcharge **coefficient for the median value of charge (pence)**
prange **coefficient for relative range of charge on route 2 (%)**

The utility functions of Model 2 are

$$U_{route1} = \alpha * mcharge_1$$
$$U_{route2} = \alpha * mcharge_2 + \beta * arange_2 \qquad (10\text{-}2)$$

Where :
mcharge **coefficient for the median value of charge (pence)**
arange **coefficient for absolute value of range of charge on route 2 (pence)**

The estimated model results of Model 1 and Model 2 are summarised in **Table 10-9**. The model estimates of both models are satisfactory; the values of Rho-squared are acceptable considering their small sample sizes and all parameters have intuitive signs and are significant.

Table 10-9 Effects of median value and range of charges on route choice

	Model 1		Model 2	
Variable	Coefficient	T-ratio	Coefficient	T-ratio
mcharge	-0.089	-7.2	-0.087	-7.2
prange	-0.031	-8.8		
arange			-0.009	-8.2
N observation	960		960	
Final. Likilihood	-593.478		-599.6829	
Rho-Squared w.r.t. zero	0.108		0.099	

mcharge: coefficient for the median value of charge (pence)
prange : coefficient for relative range of charge on route 2 (%)
arange: coefficient for absolute value of range of charge on route 2 (pence)

The coefficient, *mcharge* of Model 1 and Model 2 have negative signs, which indicates that drivers are less likely to choose a route as the median value of charge on the route increases. The relative range coefficient of Model 1, *prange* shows that as the relative range of charge (%) on route 2 increases, the attractiveness of the route tends to decrease. The absolute range coefficient of Model 2, *arange* also indicates that drivers' preference on the route decreases, as the absolute value of range of charge on route 2 increases. These two findings about the relative and absolute ranges of charges explained that because route 2 has charges with ranges, route 1 was preferred to route 2. However, this does not explain the tendency in which as the range of charge increases, the preference on route 1 slightly decreases, as shown in the descriptive analysis in section 10.4. For the explanation of this tendency, Prospect Theory will be introduced in Chapter 10.

Model 1 seems to be slightly better than Model 2 because it has slightly higher final likelihood ratio and Rho-squared than does Model 2. The *prange* coefficient of Model 1 also has a higher t-ratio value. Therefore, Model 1 will be used for the further investigation in next section.

10.5.2 Segmentation

The descriptive analysis in section 10.4 showed that drivers' route choices in response to changes in the ranges of charges are influenced by respondents' sex and income levels and they are also different depending on basic charge levels. In order to prove the influence on response to ranges of charges by respondents' socio-economic characteristics and by the charge levels, three model segmentation were conducted by sex, levels of income and charge levels. This section reports these segmentation results.

10.5.2.1 Segmentation by Sex

Two models were estimated depending on the sex and the estimate results are summarised in **Table 10-10**. The model estimate results are satisfactory; the values of Rho-squared are acceptable. All parameters have intuitive signs and are significant.

Table 10-10 Models segmented by Sex

	Model 1m		Model 1f	
Variable	**Coefficient**	**T-ratio**	**Coefficient**	**T-ratio**
mcharge	**-0.095**	**-5.9**	**-0.084**	**-4.3**
prange	**-0.022**	**-5.0**	**-0.044**	**-7.6**
N observation	**540**		**420**	
Final. Likilihood	**-341.509**		**-246.038**	
Rho-Squared w.r.t. zero	**0.088**		**0.155**	

Model 1m: **model for male respondents**
Model 1f: **model for female respondents**

The ***mcharge*** parameters of Model 1m and Model 1f indicate that drivers are less likely to choose the route as the median value of charge increases and males are more sensitive than females to the increase of the median value of charges. The ***prange*** parameters of the models have negative signs which indicates that as the range of the charges on route 2 increases, the attractiveness of the route decreases. Comparison of ***prange*** parameters of two models indicates that females are much more sensitive to the increases of the range of charges. This results are consistent with those of descriptive analysis in which female drivers are less likely to choose the charge with range to avoid uncertain charges. This is also related to the female drivers' risk averse attitude, compared with male drivers.

10.5.2.2 Segmentation by Income Levels

Three models were estimated by three different levels of income group: Model I1 for low level of income under £20,000; Model I2 for the middle income level between £20,000 and £40,000; and Model 3 for high level of income over £40,000. 60 responses without income levels were excluded and a total of 900 observations were used in these models. The estimate results are summarised in **Table 10-11**.

Table 10-11 Models segmented by Levels of Income

	Model I1		Model I2		Model I3	
Variable	**Coefficient**	**T-ratio**	**Coefficient**	**T-ratio**	**Coefficient**	**T-ratio**
mcharge	-0.140	-3.5	-0.071	-4.3	-0.117	-4.9
prange	-0.021	-2.0	-0.028	-6.0	-0.042	-6.1
N observation	108		492		300	
Final. Likilihood	-65.2295		-310.876		-172.991	
Rho-Squared w.r.t. zero	0.129		0.088		0.168	

Model I1: for the low level of income
Model I2: for the middle level of income
Model I3: for the high level of income

The overall results of model estimates are satisfactory despite of small sample sizes of model 1. The values of Rho-squared for model 1 and 3 are relatively high in spite of the small sample size.

The parameter, ***mcharge*** indicates that the drivers who have low income levels are much more sensitive to the median value of charges than are others. The parameter,

prange indicates that as higher level of income they have, the more they are sensitive to the increases of the range of the charges.

10.5.2.3 Segmentation by the Charge Levels

There were three sets of SP designs depending on the level of base charges on route 1 (£1.00, £1.50 and £2.00, see **Table 10-1**). Tabulation in section 10.4 showed that drivers' route choice responses were slightly different depending on the charge levels. Therefore, three segmented models were estimated based on the design and the estimate results are reported in **Table 10-12.**

Table 10-12 Models segmented by charge levels

	Model C1		Model C2		Model C3	
Variable	Coeff	T-ratio	Coeff	T-ratio	Coeff	T-ratio
mcharge	-0.178	-5.2	-0.066	-3.4	-0.078	-4.2
prange	-0.057	-5.6	-0.027	-4.9	-0.026	-4.9
N observation	210		354		396	
Final. Likilihood	-108.389		-226.0509		-251.497	
Rho-Squared w.r.t. zero	0.255		0.079		0.084	

Model C1: based on £1.00 base charge
Model C2: based on £1.50 base charge
Model C3: based on £2.00 base charge

Model estimate results are satisfactory: the values of Rho-squared are acceptable and all coefficients of three models are significant and have intuitive signs. The results indicate that the effect of the median values of charges and ranges on route choice are slightly different depending on the base charge. Drivers are more sensitive to the median value and the range of charges when the base charge is £1.00. There is no distinctive difference between results of Model C2 and Model C3.

10.6 Summary and Conclusion

The additional SP survey was conducted in Leeds city car parks so as to investigate the effect of uncertain charges on route choice. The main findings from this chapter are :

First, drivers tend to prefer a route with a known charge over one with an unknown (therefore uncertain) charge. This indicated that providing charge information encouraged drivers to choose the routes for which information is provided in preference to those for which it is not provided.

Secondly, drivers also prefer a route with a certain and precise charge over one with uncertain and imprecise charges, which is given with ranges.

Thirdly, when the charges are given as a range, the size of the range of the charge influenced route choice slightly and as the range of the charge increases, the route becomes slightly less unattractive.

Fourthly, when the charges are given as a range, drivers' route choice are influenced more by the median value of the ranges of the potential charges than by the size of the overall ranges of the charges.

Finally, drivers' socio-economic characteristics also influenced their response to uncertain charges. Female drivers were more likely to choose the certain charge route than were male drivers. High income drivers are more sensitive to the uncertain charges than others.

The second and third findings may seem to be inconsistent. In the second finding, drivers show their preference for avoiding uncertain charges, while in the third finding, they also show a tendency of preferring a very uncertain charge, more than a somewhat uncertain charge. In order to explain these inconsistent results, the following chapter will explore Prospect Theory as an explanation of drivers' decision making under uncertainty.

Chapter 11
Interpretation of Results Using Prospect Theory

11.1 Introduction

The descriptive analysis of results in section 10.4 and model estimates results in section 10.5 reported some seemingly inconsistent findings; drivers prefer a route with a precise and certain charge over one with imprecise and uncertain charge, but as the uncertainty of the charges increases, the preference for the route with the certain charge decreases slightly.

These results are in fact consistent with key features of Prospect Theory, which was suggested by Kahneman and Tversky (1979). In this chapter, some of the key features of Prospect Theory are applied to the results from section 10.4 and section 10.5.

The next section briefly summarises the key features of Prospect Theory. Section 11.4 reports the application of Prospect Theory to the results from section 10.4.and 10.5. Section 11.4.1 interprets the way drivers prefer a route with a certain and precise charge over one with a uncertain charge. Section 11.4.2 explains the way drivers' preference for the route increases, as a range of the charge increases. Finally, section 11.5 explains the reasons for the seemingly inconsistent results obtained in chapter 10.

11.2 Violation of Utility Theory

Von Neumann-Morgenstern (1947), as quoted in Schoemaker (1980), have shown that under certain circumstances it is possible to construct a set of numbers for a particular consumer that can be used to predict his/her choices in an uncertain situation and these numbers are the utility which was later to be referred to as expected Utility Theory. They also made a set of assumptions about preference orderings and proved that to obey the axioms one must always prefer the alternative with the highest utility.

The application of expected utility theory to choice between prospects is based on the following tenets.

1. The overall utility of a alternative, ***U*** is the expected utility of its outcomes
2. The domain of the utility function is final states rather than gains or losses
3. In expected utility theory, risk aversion is equivalent to the concavity of the utility function and it is the best known generalisation regarding risky choices.

Expected Utility Theory has dominated the analysis of decision making under risk or under uncertainty and has been widely applied as a descriptive model of economic behaviour (Bell *et al.*. 1988). However, in fact, a number of economic researchers (e.g. Markowitz 1959; Edwards 1962; Kahneman and Tversky 1979; Schoemaker 1980) have found that decision making under uncertainty was very complicated and there were several violation that are inconsistent with expected Utility Theory. They suggested that the traditional Utility Theory does not offer an adequate explanation of decision making under uncertainty.

Therefore, many evaluation models have been devised in order to modify Expected Utility Theory. Markowitz (1959) was the first to propose that utility be defined on gains and losses rather than on final states and also noted risk-seeking in preferences. He proposed that a utility function has convex and concave regions in both the positive and the negative area. Edwards (1962) proposed the replacement of probabilities by more general weights and investigated the models in several empirical studies. Fellner (1965) introduced the concept of a decision weight to explain aversion to ambiguity.

Kahneman and Tversky (1979) showed empirically observed tendencies, Certainty Effect, Reflection Effect and Isolation Effect, and proposed that choices among risky alternatives reveal several effects that are inconsistent with the basic tenets of Utility Theory.

11.2.1.1 Certainty Effects

In Utility Theory, the utilities of outcomes are weighted by their probabilities. Certain outcomes overweigh merely probable outcomes. This is known as "Certainty Effect".

This tendency contributes to risk aversion in choices involving sure gains and to risk seeking in choices involving sure losses. In cases where the possibility of wining are very small, most people choose the prospect that offers the larger gain. This illustrates the common attitudes toward risk or chance that cannot be captured by the expected utility.

In the description that follows I use the following notation. A option is expressed as *(x, p),* where *x* is the expected value of outcome and *p* is the probability. Thus, for example, if there are two options: option (4000, 0.8) and option (3000, 0.25), where 4000 and 3000 are the outcomes and 0.8 and 0.25 are their probabilities. Thus the Certainty Effect indicates that option (3000, 1.0) is much preferred over option (4000, 0.8). However, option (4000, 0.2) is preferred to option (3000, 0.25) because the probability are small, drivers prefer the larger gain.

11.2.1.2 Reflection Effects

The preference between negative prospects is the mirror image of the preference between positive prospects. This phenomenon is known as the "Reflection Effect".

The Reflection Effect implies risk aversion in the positive domains and risk seeking in the negative domains. In the positive domain, the Certainty Effect contributes to a risk averse preference for a sure gain over a probable larger gain. In the negative domain, the same effect leads to a risk seeking preference for a loss that is merely probable over a smaller loss that is certain. For example, option (3000, 1.0) is preferred over option (4000, 0.8), because both are in the positive domain. However while option (-4000, 0.8) is preferred over option (-3000, 1.0) because in this example, both are in the negative domain.

The Reflection Effect also implies that people prefer prospects that have high expected value and small variance. This was assumed by a number of researchers (e.g. Allais 1953; Markowitz 1959), which leads an apparent inconsistency. For example, the option(3,000, 1.0) was preferred over (4,000, 0.8) because (3,000, 1.0) has no variance while (4,000, 0.8) has large variance. Option (-3,000, 1.0) was preferred over option (-4,000, 0.8) because (-3,000, 1.0) has higher expected values and lower variance than (-4,000, 0.8). This makes it necessary that the sure loss should be preferred, that is, the certainty is generally desirable. Thus it appears that certainty increases the aversion to losses as well as the desirability of gains.

11.2.1.3 Isolation Effects

In order to simplify the choice between alternatives, people often disregard components that the prospects share, and focus on aspects where they differ. This phenomenon is referred as the "Isolation Effect". This approach to choice problems may produce inconsistent preferences, because a pair of prospects can be decomposed into common and distinctive components in more than one way and different decomposition's sometimes lead to different preferences. The Isolation

Effects can cause the choice between prospects to be determined by the difference in the perceived gains and losses.

11.3 Prospect Theory

Kahneman and Tversky (1979) developed Prospect Theory, to account for individual decision making processes under risk or uncertainty. The Certainty Effect, Reflection Effect and Isolation Effect are incorporated into Prospect Theory. They postulate that decision makers interpret the choice situation via a decomposition of the choice situation into gains and losses with respect to expected outcomes. This section briefly summarises Prospect Theory, and is heavily based on Kahneman and Tversky (1979).

11.3.1 Editing & Evaluation

There are two phases in the choice process, proposed in Prospect Theory: an early phase of editing and a subsequent phase of evaluation. The editing phase is a preliminary analysis stage which organises and reformulates the options in order to simplify the choice. In evaluation phase, the edited prospects are evaluated and the highest value of prospect is chosen.

11.3.2 Editing

Editing consists of several operations which transform the options and probabilities. The major operations of the editing phase are described below.

Coding

People normally perceive outcomes as gains and losses rather than as final states of wealth or welfare. Gains and losses are defined relative to some neutral reference point. The reference point usually corresponds to the current asset position, in which case gains and losses coincide with the actual amounts that are received or paid. However, the location of the reference point, and the consequent coding of outcomes as gains or losses, can be affected by the formulation of the offered prospects and by the expectations of the decision maker.

Combination

The prospects can be simplified by combining the probabilities associated with identical outcomes.

Segregation

Some prospects contain a riskless component that is segregated from the risky component in the editing phase. For example, option (300, 0.8) and option (200, 0.2) are decomposed into a sure gain of 200 and option (100, 0.8).

Cancellation

The essence of the Isolation Effects is the discarding of components that are shared by the offered prospects. There are two examples of cancellation. First, in the sequential game, respondents apparently ignore the first stage because the first stage was common to both options and they evaluate the prospects with respect to the results of the second stage. Secondly, in a single stage game, people discard the common component of both options (i.e. outcome-probability pairs).

Simplification & Detection of dominance

In order to simplify prospects, people round probabilities or outcomes and discard extremely unlikely outcomes.

This editing phase leads to inconsistent preferences which may not be explained by Utility Theory. For example, the cancellation of common components causes the inconsistencies associated with the Isolation Effect results. Utility Theory assumes that if an individual prefer A to B and prefer B to C, A will be preferred to C (this assumption is known as 'transitivity'). Some intransitivities of choice are explained by a simplification that eliminates small differences between prospects. It is not necessary for the preference order between prospects to be the same across contexts, because the same offered prospect could be edited in different ways depending on the context in which it appears.

The evaluation of choices is formulated in Prospect Theory as a series of equations (Kahneman and Tversky 1979). See appendix 6.

11.3.3 Shift of Reference

There are situations in which gains and losses are coded relative to an expectation or aspiration level that differs from the status quo. A difference between the reference point and the current asset position may also arise because of recent changes in wealth to which one has not yet adapted. A change of reference point changes the preference order for prospects. In particular, Prospect Theory implies that a negative translation of a choice problem, such as arises from incomplete adaptation to recent losses, increases risk seeking in some situations.

11.4 Interpretation of Results using Prospect Theory

This section applies Prospect Theory to the results in section 10.4 and 10.5 and gives an explanation about the reason why people prefer certain charge route to uncertain charge route and the way uncertainty of charges increases drivers' preference on the route.

The essential feature of the present theory is that people make a decision by evaluating changes or differences of outcomes rather than final outcomes. Key concepts from Prospect Theory, discussed in section 11.3, will be applied, transforming the questions context and explain the decision making process.

11.4.1 Preference for the Route with a Certain Charge

One of the main findings from section 10.4 was that people much prefer the route with a precise and certain charge over one with an imprecise and uncertain charge. Considering the context of choice situation and applying Prospect Theory gives an explanation.

For example, three choice questions with a base charge £1.00 on route 1 are considered. For the full detailed set of questions, see section 10.2.2 and an example of the questionnaire in appendix 4.

In the editing phase, the questions are organised and reformulated to simplify the choice questions. By applying a 'Segregation' editing phase to questions, associated with 'Isolation Effect', the charges on both routes were segregated into risky and riskless components.

According to segregation, choice questions are decomposed into a sure loss of £1.00 on both routes and reformulated options. The reference point is defined as the median value of the ranges of the charges on route 2 which is the same value of the charge on route 1. This is because the model estimate results showed that the median value is important impact on their route choice than the ranges. Three questions (question set A: 2a, b and c) and the process of transforming the questions are shown in **Table 11-1**.

Table 11-1 Transformation of choice questions by Segregation

	Initial charge (£)		Values (£) after segregation			
	Route1	Route2	Route1		Route2	
			certain	uncertain	certain	uncertain
Question1	-£ 1.00	-(£0.90-£1.10)	-£ 1.00	0	-£ 1.00	-£0.10 ~ £0.10
Question2	-£ 1.00	-(£0.80-£1.20)	-£ 1.00	0	-£ 1.00	-£0.20 ~ £0.20
Question3	-£ 1.00	-(£0.70-£1.30)	-£ 1.00	0	-£ 1.00	-£0.30 ~ £0.30

In the 'Evaluation' phase, choice based on the transformed options people evaluate and make a choice. As it can be seen, route 1 gives no additional charge except the sure loss, while route 2 has still uncertain charges. Therefore, drivers prefer the route 1 with the sure loss over the route 2 with the uncertain loss. This is consistent with Certainty Effect in which any alternative with certainty outweighs uncertain outcomes. It is also explained in Reflection Effect of Prospect Theory that sure loss is preferred with low variation, explained in section 11.2.1.2.

This shows the way drivers approach the route choice decision between certain and uncertain charges and explains the way drivers prefer the certain charge to the uncertain charge.

11.4.2 Preference for Increase of Uncertainty of Charge

It was also found in section 10.4 that as the range of the charge on a route increases, the preference for the route with uncertain charges slightly increases. However, drivers still prefer the route1 with the certain charge.

The same examples of the questions from the previous section were used, which have the base charge £1.00 on route1. As shown in section 11.4.1, transformed questions after application of 'Segregation' editing phase are shown in **Table 11-1**.

When people make the three sequential choices, they tend to ignore common components. In this example, sure loss of £1.00, which are common between two routes are ignored and respondents focus on the different charges between questions. Application of 'Cancellation' implies that respondents might consider the serial questions in the SP survey not separately but sequential. That is, their decision was based on the difference between questions rather than the difference between route 1 and route2. Thus 'Cancellation' editing phase is applied to the reformulated questions in **Table 11-1**. Three questions become two sequential questions, which are shown in **Table 11-2**.

Table 11-2 Transformation of choice questions by Segregation and Cancellation

	Values of Charges (£) on route 2	
Sequential question 1' (Question 1 vs Question 2)	(+£0.10 ~ -£0.10)	(-0.20 ~ £0.20)
Sequential question 2' (Question 2 vs Question 3)	(+£0.20 ~ -£0.20)	(-0.30 ~ £0.30)

These transformed questions show the way when drivers make a sequential choices, the three separate questions become two relevant questions and they focus on the different charges on route 2 in the different questions. The Reflection Effect in Prospect Theory suggests that in negative domains (of which this is surely one since we are dealing with charges) decision makes will be risk seeking and so prefer the ±30 pence to the ±20 pence. This indicates why as the amount of the uncertainty of the charges on route 2 increases, the preference for route 2 slightly increases.

11.5 Conclusion

This chapter applied Prospect Theory to the seemingly inconsistent results from chapter 10 in order to interpret the results and give an explanation. The inconsistent results were that drivers prefer to avoid an uncertain charge, while they show a tendency of preferring a very uncertain charge.

Section 11.4 explains the way drivers may be interpreting the choice situation and how they make a route choice in response to uncertain charges. The process of editing and reformulating options shows that inconsistency of the two findings are, in fact, caused by different choice context, which drivers approach and interpret differently. In the first finding, described in section 11.4.1, drivers focus on the difference of the charges between routes, while in the second finding, people are considering the change of charges between questions in section 11.4.2. Therefore, it is possible that these two findings contain totally different matters. As Kahneman and Tversky (1979) pointed out, the way people edit and simplify the choice context cause inconsistent preference which Utility Theory can not explain.

According to the results of this chapter, drivers' decision making under uncertainty seem not to be simple like risk-averse or risk-seeking but to be very complicated and flexible, depending on the way drivers interpret the choice situation. Therefore, it is recommended to apply wider related theories to the analysis of the drivers behaviour (which deal with decision making under uncertainty).

One of key features of Prospect Theory is that drivers interpret the choice situation via a decomposition of the choice situation into gains and losses with respect to expected outcomes. We can find examples with ease which Prospect Theory may be applied.

For example, there is a driver who drives everymorning to his work place. If a charge is given to him which is less than he usually paid and expected to be, he may consider the difference of the charges as a gain. This is explained by 'Segregation' editing phase and 'shift of reference point' in Prospect Theory. This may influence his decision making differently.

Chapter 12
Summary and Conclusion

12.1 Introduction

This chapter aims to draw together the findings presented in this study on responses to the variable road user charges and traffic information. Section 12.2 summarises the main findings. Finally section 12.3 draws implications of the study.

12.2 A Summary of the Main Findings

12.2.1 Data Collection and Analysis

This study investigated the drivers' route choice in response to variable road user charges and traffic information. Three SP surveys were conducted to collect data. The main SP survey investigated the effect of traffic information and the variable road user charge on drivers' route choice. An additional survey investigated the extent to which the degree of uncertainty of charge information influenced route choice. The main survey was conducted in Leeds and Seoul, and the additional survey was conducted in Leeds. Logit models were used for analysing the main SP survey data and a regression method was used in the analysis of the additional survey data. See chapter 6, chapter 8 and chapter 11.

12.2.2 Traffic Information Systems and Road User Charges

The traffic information was provided via VMS and related to the expected delay time. Three types of variable road user charges were applied: fixed charges; time-based charges; and delay time-based charges. The main feature of this study was to give information about charges as well as traffic conditions information. Providing information might be seen as necessary for implementing certain types of road user charges when the charge depended on the traffic conditions and was thus difficult to predict.

The difference between these charging regimes was represented by the way the charge information was presented: precise and accurate estimates of the charge were given for the fixed charges; estimates with narrow ranges were used for the time-based charges; and estimates with wide ranges were used for the delay time-based charges. The width of the range of the charges reflected the relative uncertainty of travel time and delay time.

12.2.3 Responses to the Road User Charges

Responses to road user charges were analysed in section 7.5. It was assumed that road user charging had been introduced for use of roads in city centre between 7:30am and 9:30am. Three levels of charge were given, 50p per day, £1.00 per day and £2.00 per day. The dominant choice for the 50 pence per day charge was to pay the charge. However, as levels of charge increased the percentage of people who would travel before 7:30 to avoid a charge increased and became the dominant choice. The results indicated that, if a road user charges were introduced to Leeds, drivers would consider paying relatively modest charges but that they are very sensitive to higher charges. The results also indicate that changing departure time earlier is the most likely means of avoiding the higher charge levels. Drivers would apparently consider parking and using the public transport as the second alternative and using public transport as the third alternative.

The responses to the charges depended on the sex, age and income of the respondents. In order to avoid a charge, male drivers seem slightly more likely to change their departure time than females, while females seem to prefer using the public transport slightly more than do males. The younger drivers were more willing to switch to the public transport to avoid charges than were the old drivers. Those with higher income are not sensitive to charges, until the charge exceeds to the certain levels, at which point they would prefer to travel earlier to avoid the charge. Those who earned under £20,000 are sensitive to all levels of the charges and their strategies for avoiding the charges do not seem to be affected by the levels of the charge.

12.2.4 Responses to Variable Road User Charges and Traffic Information

Drivers' responses to the variable road user charges and traffic information were analysed using logit models based on the SP data from the main survey (See chapter 8).

12.2.5 Response to Traffic Information

Drivers were less likely to choose a route characterised by recurrent delays and the length of delay reported on their usual route increased. Although they were affected by the amount of the length of extra delay time stated on VMS, the effect on route choice of extra delay time on VMS was less than that of normal delay time. The reason might be because of the perceived unreliability of VMS information. Drivers might consider the extra delay information as a *possible* delay rather than a *certain* delay and they might therefore take it less seriously (see section 8.4.9.2.).

12.2.6 Value of Delay Time

The values of normal delay and extra delay time were estimated in section 8.4.6 The value of delay time was expressed in units of normal free-flow travel time. This explained the way and the extent to which drivers valued delay time, compared with the free-flow travel time.

The results indicated drivers valued delay time more highly than free travel time and became increasingly sensitive to delay time as it increased. The curves of the values of normal delay time and extra delay time were non-linear and concave.

The delay threshold were also found at which point the values of delay time began to diverge for drivers. The delay thresholds in this study were 10 minute for the normal delay time and 15 minutes for the extra delay time stated on VMS, based on estimates from the main survey in section 8.4.6. and from one of the pilot survey results in section 6.4.3.

12.2.7 Responses to Variable Road User Charges

Three different types of road user charges were considered in this study: fixed charges; time-based charges; and delay time-based charges. Among them, the fixed charges had a stronger effect on drivers' route choice than did the others (see section 8.4). This results was found in both Leeds and Seoul results.

The values of time in terms of different charging regimes were estimated in section 8.4.9.2. The values of time were 3.9 pence per minute in terms of the fixed charges, 4.5 pence per minute in terms of the total time-based charges and 4.3 pence per minute in terms of the delay time-based charges.

The values of time were different depending on the drivers' characteristics (see section 8.5). The values of time of female drivers in terms of fixed charges and delay time-based charges were bigger than those of males. But the values of time in terms of total time-based charge was bigger for males than for females (see section 8.5.1.). Young drivers have higher values of times in terms of the fixed charges and the total time-based charges, and lower value of time in terms of the delay time-based charges than the old drivers (see section 8.5.2). Those who have high level of income have higher value of time than the others in terms of fixed charge. In terms of delay time-based charges, drivers who have middle level of income have biggest value of time (see section 8.5.3).

12.2.8 Effects of Drivers' Characteristics on Responses

Drivers' characteristics also influence responses to traffic information and variable road user charges, as discussed in section 8.5. Female and the old drivers were less likely to change their route due to normal delay and the extra delay information on VMS than male and the young drivers. The route choice of female and the old drivers were also less influenced than male and the young drivers by the increase of any types of charges. Higher income drivers are more sensitive to the normal delay information than others. Low income drivers are more likely to change their route as the level of charge increase than others.

12.2.9 Effect of Cultural Difference on Responses between Leeds and Seoul

The main survey was repeated in Seoul. The sample size was smaller than that from the main survey in Leeds. The key findings from the Seoul SP data were that drivers were more likely to change their route as the extra delay stated on VMS increased and as the levels of charges increased. Among three charging regimes, the fixed charge has more influence on route choice than the time-based charges and the delay time-based charges. These results were also found in Leeds survey.

Although the overall results were the same as those from the main Leeds survey results, drivers' socio-economic characteristics on route choice were different between Leeds and Seoul. This might be result from the cultural difference between Seoul and Leeds. See section 8.4.6. section 8.4.9.2. and section 8.6.2.

12.2.10 Correction of Repeated Measurement Problem

The SP data from the main survey were analysed using simple logit models in chapter 8. However, it has been recognized by researchers (for example, Cirillo *et al.* 1996; Ouwersloot and Rietveld 1996), that SP methods may suffer from a "repeated measurement problem" which is caused by allowing several observations from each respondent and results in increasing significance of explanatory variables.

In order to treat the repeated measurement problem, the Jackknife method and Kocur's method were applied to the main SP results. The results of these estimations were compared with those of the simple uncorrected logit method, used in section 8.4.6 in order to test whether there was repeated measurement problem or not and the extent to which this problem affected the model estimates. The Jackknife method was implemented using the program '**JACKKNIFE**'.

Kocur's method underestimated the significance of the coefficients. Jackknife produced the almost same coefficients as those of the uncorrected model, while the t-ratios of Jackknife estimates were slightly smaller than those of the uncorrected models. Therefore, the application of the Jackknife method and Kocur's method thus suggested that the coefficients of the uncorrected model were accurate, whereas their significance was somewhat overestimated. We, therefore, concluded that the repeated measurement problem did exist in this data, but that it did not affect the model estimation results significantly in this study. Thus there was no need to estimate model using Jackknife or Kocur's method and the models estimated using the uncorrected method could stand.

12.2.11 Effect of Uncertainty of Charge Information on Route Choice

The additional SP survey explored the extent to which the degree of uncertainty of charge information influenced route choice (see chapter 10 and chapter 11).

12.2.11.1 Effect of Providing Charge Information on Route Choice

Drivers preferred the routes for which information was provided to those for which it was not provided. This indicates that drivers preferred avoiding uncertain charges and that providing charge information encouraged them to choose the route for which charge information was given. See section 10.4.1 and appendix 4.

12.2.11.2 Effects of Ranges of Charge Information on Route Choice

Drivers also preferred the route with a precise and certain charge information over one with an imprecise and uncertain charge information. When uncertain charge information was given with a range, drivers' route choices were influenced more by the median value of range of charge information than by the size of the range of charges. It also appears that drivers are more affected by the absolute size of range of charges than by the relative ranges of charges (%). See section 10.4.3. and section 10.5.2.

Drivers' characteristics influenced their response to uncertain charges; as discussed in section 10.4.4. and section 10.5.3., female drivers were more likely than male drivers to choose the route with the certain charge and low income drivers were more sensitive than high income drivers to the increases of the range of the charges.

12.2.11.3 Interpretation of the Results Applying the Prospect Theory

There was an apparent inconsistency between, on the one hand drivers preference for a route with a precise and certain charge information and the other hand a decreases in this preference as the degree of uncertainty increases. These results are in fact consistent with Prospect Theory, which postulates that drivers interpret the choice situation via a decomposition of the choice situation into gains and losses with respect to expected outcomes.

The application of Prospect Theory to the results from chapter 10 showed the way drivers interpreted the choice situation and made a route choice in response to uncertain charges. It explained that the inconsistency of the two findings were, in fact, caused by different choice context which drivers approached and interpreted differently. In the first finding, drivers focused on the difference of the charges between routes, while in the second finding, people considered the questions sequentially and focused on the change of charges between questions. Therefore, it was possible that these two findings contain totally different matters. As Kahneman and Tversky (1979) pointed out, the way people edit and simplify the choice context cause inconsistent preference which Utility Theory can not explain.

12.3 Implication of This Study

12.3.1 Policy Implications

12.3.1.1 Value of Delay and Delay Threshold

This study estimated the value of normal delay time and of extra delay time as stated on VMS. The threshold of normal delay and of extra delay were also estimated. See section 8.4.6. The value of delay times indicates the extent to which drivers perceive delay time and in particular, the delay threshold is the point at which drivers change their behaviour. These values help to understand drivers behaviour in response to delay and to predict their response to delays stated on VMS signs. There may also help to determine a strategy for providing delay time information. Khattak *et al.* (1993a) recommended giving diversion information only when the delay threshold is approached.

12.3.1.2 Effect of Road User Charges

Smith *et al.* (1994) suggested in their study about the network effects of four road-user charging systems that congestion-based charging (delay-time based charge) reduces congestion substantially at comparatively low levels of charging and would have the best effects in terms of relief of congestion.

However, results of this study found different results from those. Among the different variable road user charging regimes, the fixed charges were found to have a stronger impact on route choice than time-based charges or delay time-based charges (see section 8.4 and section 8.5. and section 12.2.2.3). This indicates that fixed charges may be most likely to induce drivers to change their behaviour. Also, as is well known, the technology required for the fixed charges is cheaper and less sophisticated than that required for variable charges. Therefore, fixed charges may be the best option for the purpose of the efficient use of network by changing drivers' behaviour and in terms of the easy and cheap implementation. However, if the purpose of the charge is to raise the revenue, the fixed charges might be less preferable option than time-based charges and delay time-based charges. It was also found that the fixed charges always had a stronger effect on route choice than the other charges, regardless of sex age and income levels, while total time based charge or delay time based charge were more effective for the male or young drivers. This result indicates that introducing the fixed charge can influence drivers' behaviour equally. Therefore, the fixed charge can be also a feasible policy tool in terms of equity issue.

This study estimated values of time in terms of variable road user charges including the fixed charges, the time-based charges, the delay time based charges, see section 8.4, section 8.5. and section 12.2.2.3. These values will be useful to help to decide optimal charge rates for the each charging regime.

12.3.1.3 Effect of Charge Information

Even though previous studies had suggested combining the road user charges and traffic information systems, there was hardly any literature about the detailed and practical information about charges and about the effect of charge information on drivers'' route choice. This study looked at the combining these systems in more practical ways and in terms of drivers' route choice. In particular, it explored the way of presenting charge information for different charging regimes, the effect of providing charge information on route choice, and the effect of uncertain charge information.

12.3.1.3.1 The Way of Presenting Charge Information for Different Charging Regimes

This is the first study which considered the necessity of introducing charge information for certain types of road user charges and designed the charge information considering the characteristics of each charging regime. The presentation of charge information also involves the source of information and in this study charge information was assumed to be given on VMS. This study also explored how the way of presenting charge information influenced drivers' route choice. This is a very important and practical question to be addressed before introducing certain types of charges such as delay time and time-based charges which is difficult to predict exact price. See chapter 4 and chapter 5

12.3.1.3.2 Effect of Providing Charge Information

This study investigated the effect on route choice of providing charge information (in chapter 10). Drivers were found to prefer the route for which information was provided to those for which it was not provided. This result indicates that drivers preferred avoiding uncertain charges and that providing charge information encouraged drivers to choose the routes for which information was provided in preference to those for which it was not provided.

12.3.1.3.3 Effect of Uncertain Charge Information

This study also explored the effect on route choice of uncertainty of charge information. The degree of uncertainty of charge information was expressed as a range. The result showed that that drivers apparently preferred a route with a precise charge information over one with an imprecise charge information. This indicate that providing accurate information is an important factor to influence drivers' behaviour. It was also found that when the charge information was given with a range, drivers consider the median value of charge much more than the range of the charge. Thus the median value of charge and their range also influences the predictability of the response (See section 10.2 and section 10.4.3 and section 12.4.3).

If charges are variable depending on traffic conditions (e.g. time-based charge or delay time-based charge) it would in practice be difficult to provide accurate estimates of the charge information because of the unpredictable traffic conditions. It may therefore be necessary to provide uncertain charge information. The findings about the effect of uncertainty of charge information will help to understand drivers' response to these uncertain information and may contribute to evaluating the benefits of charge information and designing charge information.

12.3.1.4 Attitudes to Road User Charges

Responses to road user charges, discussed in section 7.5 revealed that many drivers in Leeds (about 37%) would pay a moderate charge (50 pence per day), but as the charge level increased, they would travel earlier. This result indicates that though generally people do think the road user charges are unacceptable, some drivers in Leeds are ready to pay a charge. This indicates that drivers have been changing their attitude to road user charges because they realized the problem due to worsening congestion.

This may be explained by the fact that drivers in Leeds already perceived the additional cost caused by congestion, which was discussed in section 7.3. Drivers were asked to estimate their own petrol costs for the hypothetical routes and the results showed that the perceived additional cost caused by the congestion was 9.9 pence per mile in Leeds. These estimated additional cost may contribute to estimation of perceived congestion cost and also may be useful to deciding the charge levels for the road user charges.

12.3.2 Methodological Implications

12.3.2.1 Repeated Measurement Problem

This study tested the repeated measurement problem in its data analysis. The main SP survey results were analysed using the simple uncorrected method, see chapter 8. Jackknife and Kocur's method were applied in order to correct the repeated measurement problem. The results showed that the data in this study were not much influenced by the repeated measurement problem, thus the analysis based on the uncorrected method could stand.

It s recommended that such a test should become standard procedure. If it turns out that the analysis based on the simple uncorrected method are influenced by the repeated measurement problem, it should be corrected. One way of treating the problem is to re-estimate the model using Jackknife method used in chapter 9. The Jackknife is easy and simple method to correct the problem compared with other methods, see section 9.2. The software 'JACKKNIFE' is available for this procedure.

12.3.2.2 Test of SP Design

It was recommended by several researchers to test the SP design before conducting survey using simulation or pilot surveys. As discussed in chapter 6, this study tested the SP survey design through three pilot surveys and simulations. The main survey results were satisfactory but the initial designs required some significant modification between the pilots.

Thus, it is recommended to test the SP design through not only the simulation test but also pilot surveys. It is necessary particularly in case of testing a new concept which does not exist yet, for example, time-based charge or delay-time charge in this study. This is because simulation is based on the presumed artificial utility values and, although it can establish whether the SP design is capable of estimating these utility values, it cannot indicate whether these are the correct values or whether the respondents are able to understand what is being asked of them. On the other hand, pilot surveys provide more real values which make the design more realistic and they also make it possible to get feedback from the respondents which is useful to improve the survey design. For example, as the results of the initial pilot survey in this study (see chapter 6), it was found that the respondents had difficulty in understanding the delay information and in the next survey more detailed explanation was added. This is an advantages of pilot surveys which a simulation test never can provide.

12.3.2.3 High Response Rate of the Surveys

Three SP survey were conducted and three pilot survey were conducted for the data collection in this study. The response rate of all the survey were very high and the average was more than 40% which was higher than the typical response rate. There are two possible reasons of success of gaining the high response rate. First, the questionnaire should be easy to follow and looks tidy and simple. Secondly, it is recommended to hand out the questionnaire personally and explain very briefly about the purpose of the study, which gives good impression and also draws their interest. All the questionnaires in this study were handed out personally and each time the purpose of this study was briefly explained. Most of the respondents sent back the questionnaires in two days. Many of them answered most of questions and gave comments about their opinion on the study or encouragement.

12.3.2.4 Representation of Local Traffic Conditions

The purposes of it was to give a more realistic decision environment to drivers and Pictures of the network conditions as seen through the windscreen at the decision point was provided in the SP questions to give information about the local traffic conditions (as they might be observed through the windscreen) and to assess whether drivers' observed traffic conditions may influence the effects of traffic conditions information on their route choice decision.

This techniques had previously been used by several researchers (Allen *et al.* 1991; Bonsall *et al.* 1994c; Bonsall and Whelan 1995, Bonsall *et al.* 1995; Wardman *et al.* 1997) and generally it was successful. However, in this study the picture representation of the network conditions did not work at all and turned out to be insignificant. The reason may be because there are too many things for the respondents to consider including traffic information and charge levels, they could not focus on the difference of the picture or because the presentation of congested traffic conditions are not clear enough. Therefore, if picture of local traffic conditions is included in survey, it is recommended to design questionnaire not too complicated so for drivers to consider their difference. It is also recommended that the pictures should be clear enough.

12.4 Recommendations for Further Research

The SP data from the main survey was analysed using logit models. Chapter 8 reported model development process to find out the best fitting model for the data. The finally selected model was based on the square term of delay related parameters, which allowed for any non-linearity in the relationship between delay and travel time (see section 8.4.6). The reason for this was that a number of research has found that there is non-linearity between perceived delay time and normal travel time (for example Huchingson & Dudek 1979; Khattak *et al.* 1993; Wardman *et al.* 1997).

One of model in section 8.4.2.1. which used dummy variables also showed non-linearity of value of delay time. However, the non-linear model with squared term of delay was slightly better than model with dummy variable because the former provided slightly better t-ratio of all parameters and included fewer variables than model with dummy variables. Therefore, the non-linear model with squared term was chosen for the analysis of the main results.

However, the specified squared term may be not the best application. For example, Wardman *et al.* (1997) investigated the issue of the functional form of delay time in the utility expression, that was called the power model. It is difficult to estimate both coefficient (α) and scale factor (λ) at the same time[1]. Therefore, they examined a range of prespecified values of scale factor (λ) and selected the model which provided the best fit. It is more recommendable to test great range of power term and to analyse different poser functions in order to find out the best plausible relationship.

Utility Theory has usually been the basis of analyses of response to traffic information and road user charges. This research has shown that Prospect Theory was a more satisfactory basis for explaining drivers' behaviour in response to the effects of uncertain charge information. Since traffic information and road user charges often contain uncertainty, the wider application of Prospect Theory (and related theories from economics and psychology which deal with decision making under uncertainty) is recommended. This is expected to give more deep understanding of drivers' responses. In this study, the basic tenets of Prospect Theory were used to interpret the some of results in the section, 10.3. The application of this theory can be extended to the study of drivers' behaviour in the response to the uncertain traffic information and road user charges.

As explained in chapter 11, in particular Prospect Theory can explain the inconsistent preference which is caused by the sequential decision making. The example was that a drivers face a charge which is less than he has usually paid and expected, he can consider the difference between the charge and his expected charges, as a gain and it will affect his decision making. In this study the sequential questions were provided

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[1] **Power model enters delay time(D) ina form that allows the unit value of delay time to vary with the amount of delay (Wardman *et al.* 1997).**

$$U_j = \alpha D_j^{\lambda}$$

in the additional survey in chapter 10 to ask the respondents to make choice between different ranges of charges. The results was obtained using the SP approach. It could be interesting to test this kind of sequential decision making using a route choice simulator such as VLADIMIR (Bonsall *et al.* 1993,1997). Using the route choice simulator would make it possible to investigate the dynamic response to sequential situation.

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Appendix 1:

An Example of the Initial Pilot Survey Questionnaire

PART 1

How many times per week do you use your car for the journey to work? ___

How long do you normally spend driving for the journey to work every morning?

___ hours ____minutes

Where do you live and work? (please state the first 4 digits of the postcode)

Home ____________________ Work ____________________

Have you ever used any kind of information systems ? (please tick)

	Frequently	A little	Never
Roadside variable message sign			
Radio messages about traffic conditions			
In-vehicle guidance systems			

Did you find them useful? (please tick)

	Yes	Somewhat	No
Roadside variable message sign			
Radio messages about traffic conditions			
In-vehicle guidance systems			

Are you : male? ___ female?

To which age group do you belong?

under 24 ___ 25 to 34 ___ 35 to 54 ___ over 55 ___

Please indicate total annual income of your household? (voluntary question)

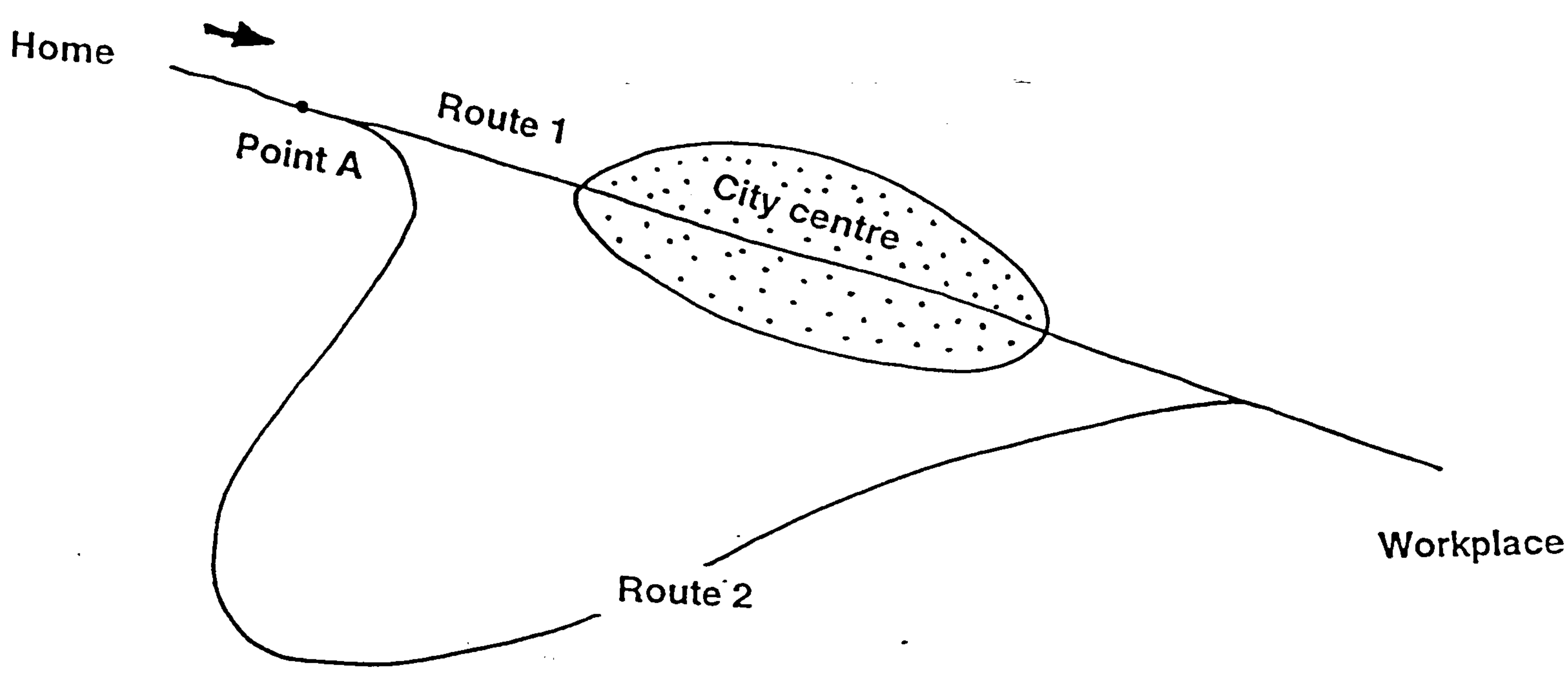
under £20,000 ___ £20,000 to £40,000 ___ over £40,000 ___

PART 2

I would like to know how you would respond to each of series of hypothetical travel choice situations.

Situation

The sketch below shows a journey from home to work. The workplace is the other side of city centre.



Imagine that you are driving from home to work on a normal working day in the morning. When you pass point **A**, you have the choice of two routes to your workplace.

Route 1 is the shortest, 4 miles as the crow flies, and goes through the city centre. The normal travel time is about 20 minutes, of which about 10 minutes is spent in slow moving traffic during peak time.

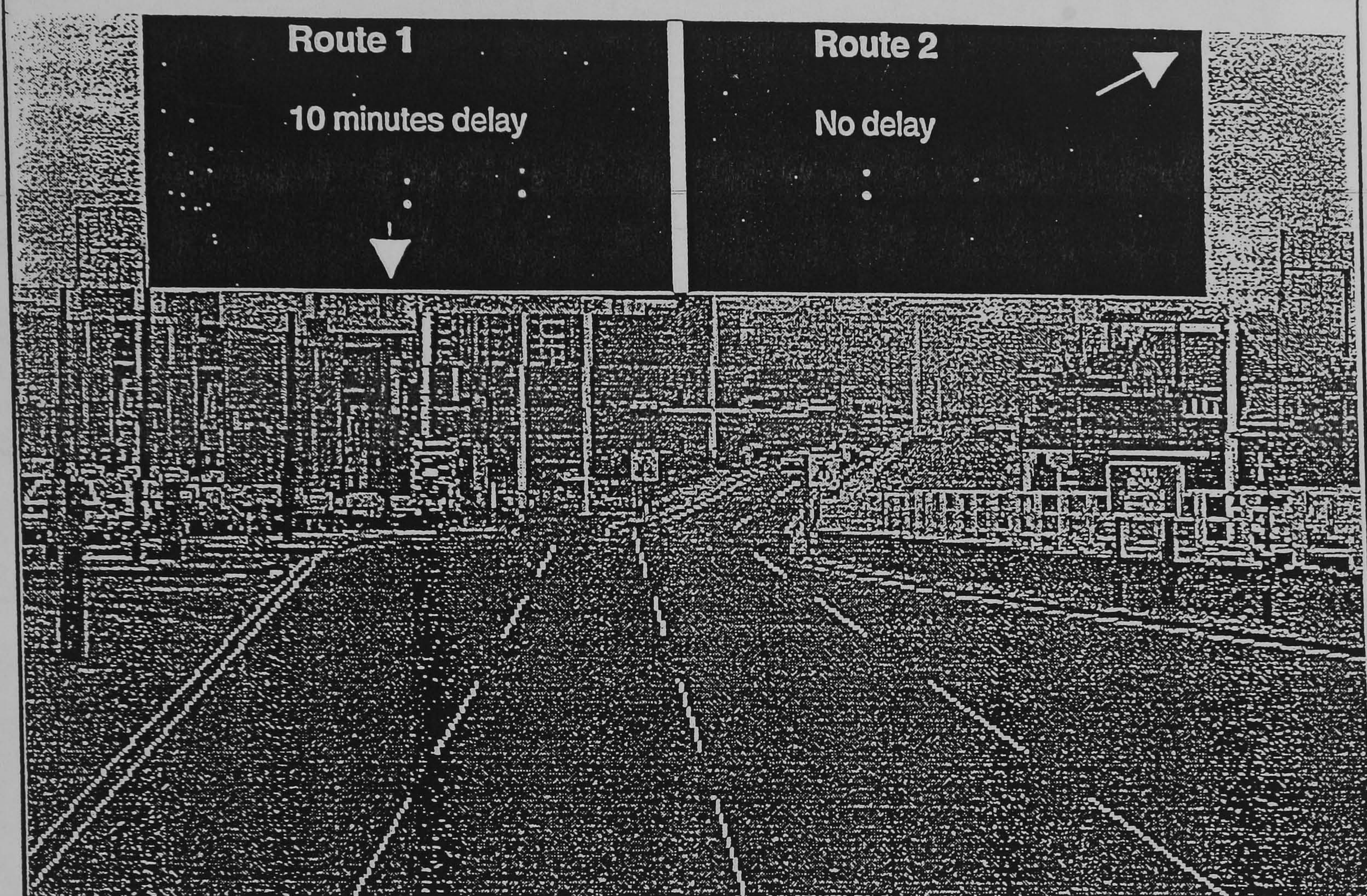
Route 2 is longer, 10 miles in total, but there is no delay expected. The travel time is normally about 35 minutes.

What do you think the cost of petrol for these routes would be?
Route 1(4 miles) ________ **p**
Route 2(10 miles) ________ **p**

SECTION 1 : Example

When you pass point A, you get information from variable message signs about two routes. Which route would you choose?

The picture below shows the view from your car windscreen as you approach point A.



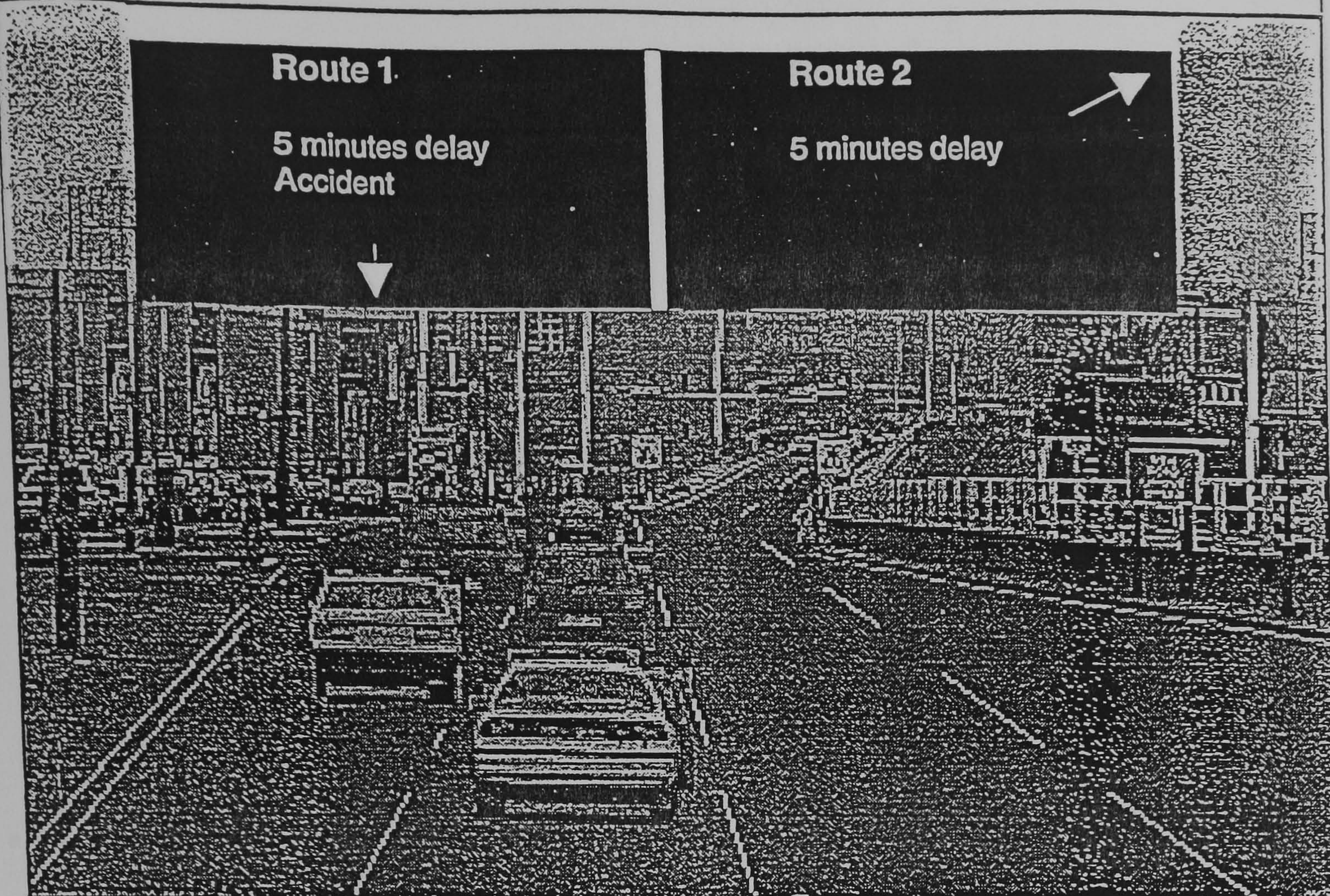
	Distance(mile)	Travel time	Extra delay	Choice
Route 1	4	18~22	10	✓
Route 2	10	33~37	0	

This person chose route 1.

This example shows how to indicate your choice.

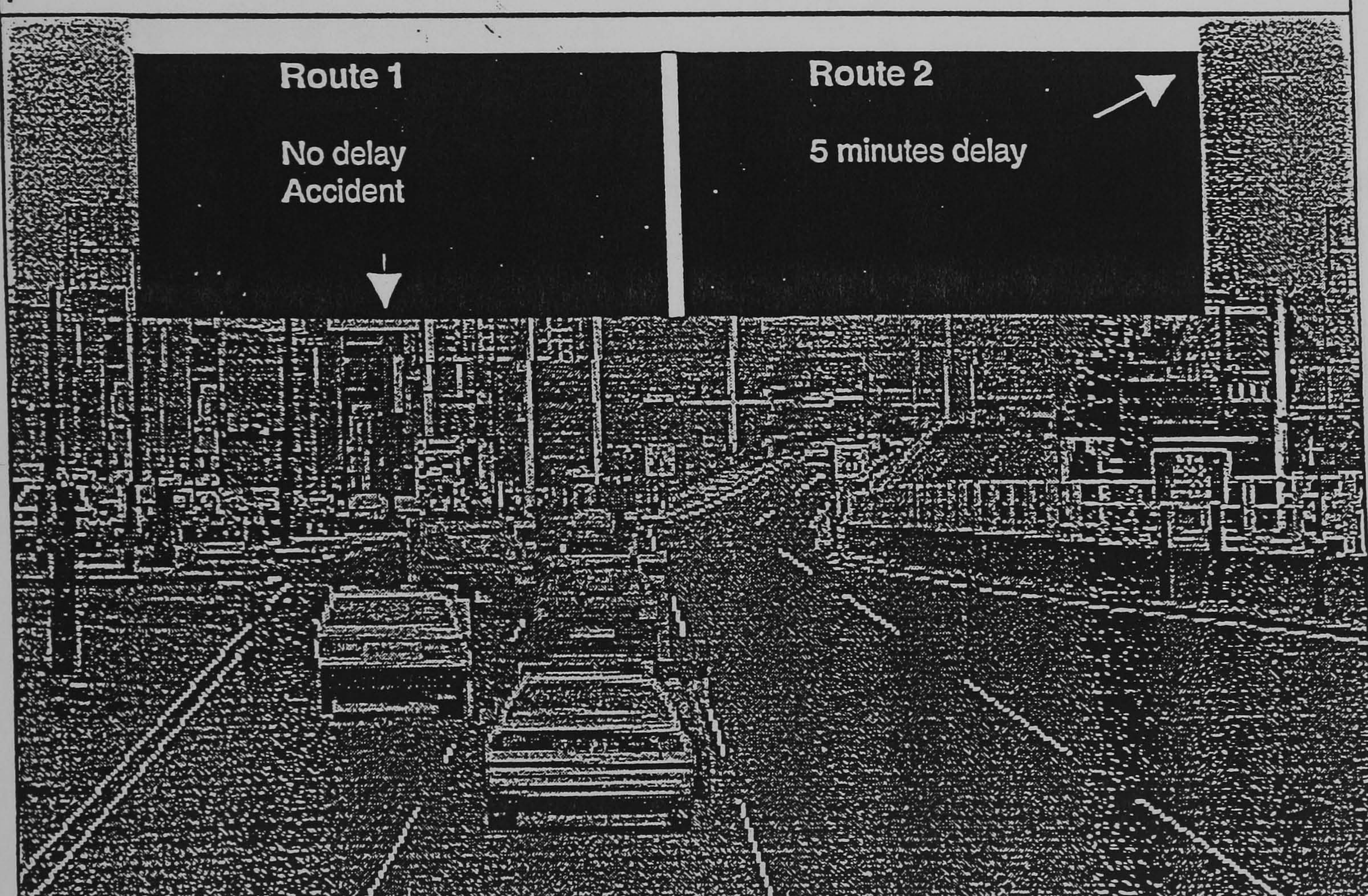
Now please indicate your choice in each of the following situations!

I



	Distance(mile)	Travel time	Extra delay	Choice
Route 1	4	18~22	5	
Route 2	10	33~37	5	

I



	Distance(mile)	Travel time	Extra delay	Choice
Route 1	4	18~22	0	
Route 2	10	33~37	5	

Part 3

Are your work hours: Fixed ___ flexible/variable ____

When do you usually start work? _____:______

Who pays your driving cost? Yourself ___ Your company ___

Let's assume road pricing is introduced to Leeds city centre during morning peak (7:30 a.m. ~ 9:30 a.m.).

1. **Would you be willing to pay a charge for commuting?** Yes ___ No ___

2. *If yes, what is the maximum amount of charge you would be willing to pay per trip?*
£__________

3. If no, what would you do to avoid the charge?

- Change departure time earlier or later _____
- Change route to non-charged road _____
- Change mode to public transport _____

4. If you could avoid paying a charge of £ 1.00, how much earlier or later would you be prepared to start your journey?

- ____________________ minutes earlier
- ____________________ minutes later

SECTION 2

d

1)Introduction

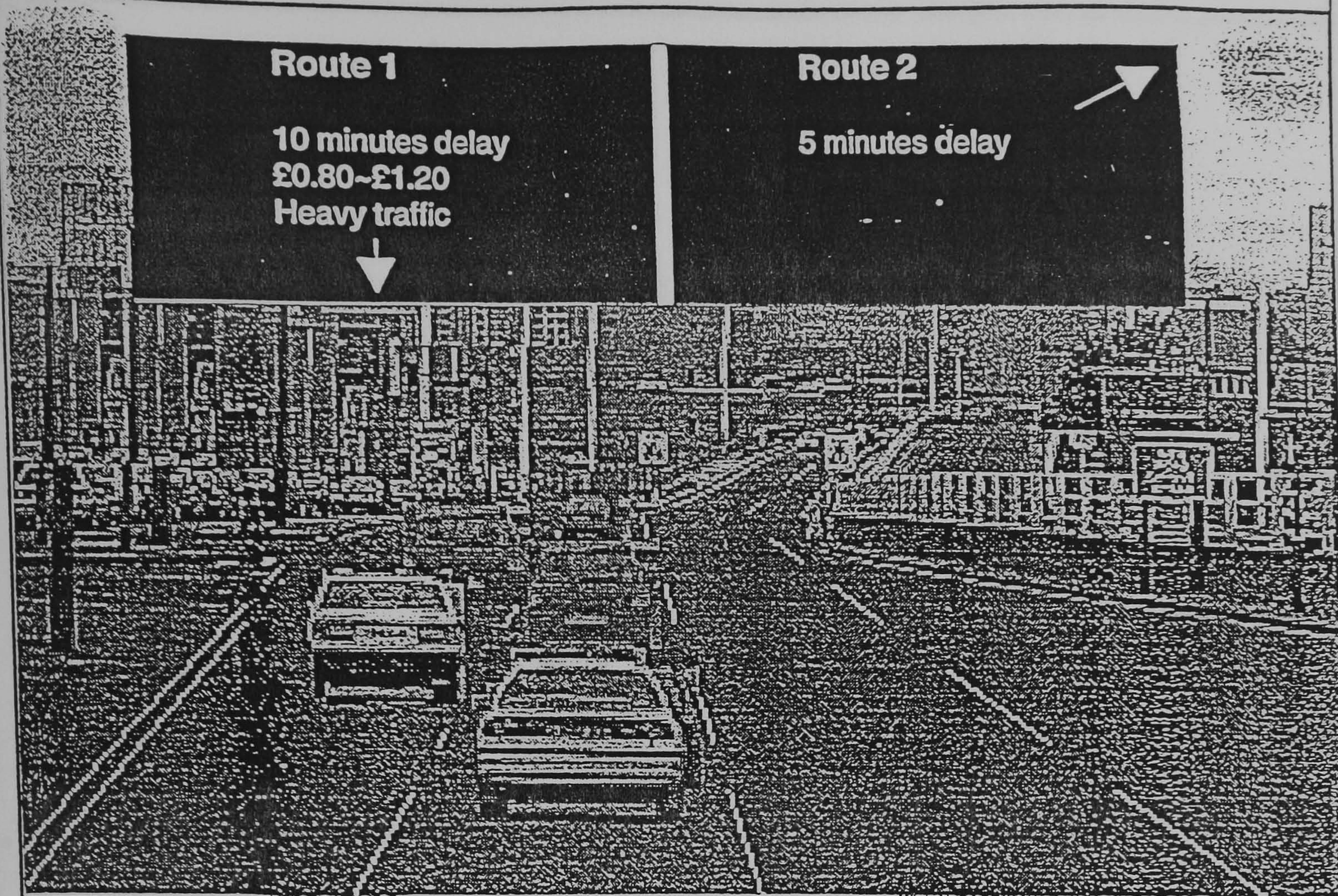
Some local authorities are considering introducing charges for road use. We now want you to imagine that charges have been introduced for using route 1.

The charge is designed to reflect the current congestion pattern and so depends on the amount of time spent driving in slow moving traffic. For example, if a driver spends 12 minutes in slow moving traffic and the charge rate is 10 pence per minutes of delay, then he will be charged £ 1.20.

The charge would be automatically deducted from the credit stored in a prepaid smart card in the vehicle while you are driving. You need not stop to make the payment and there are no toll gate.

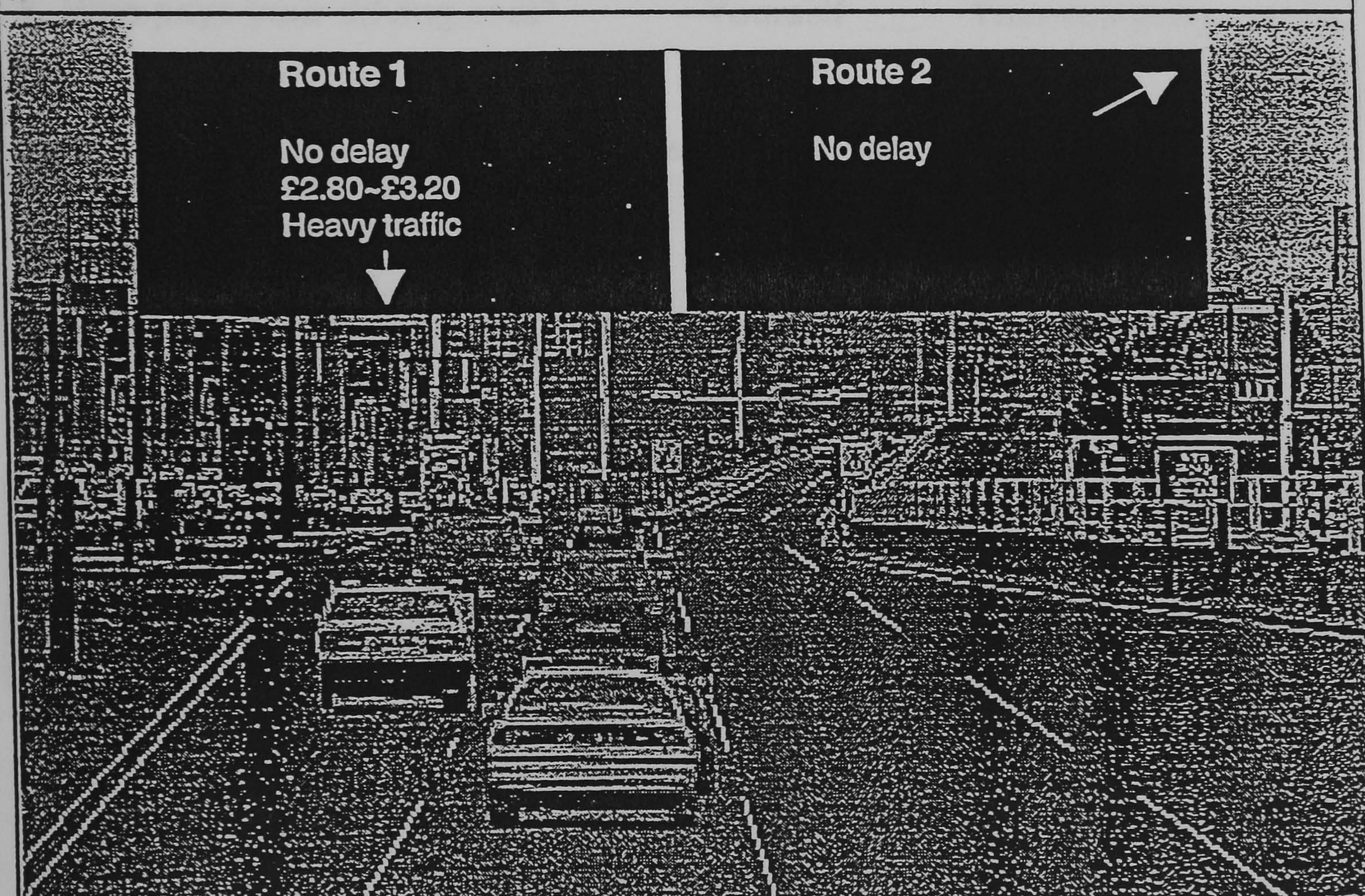
You can of course avoid paying the charge by choosing route 2.

d



	Distance(mile)	Travel time	Extra delay	Charge	Choice
Route 1	4	18~22	10	£0.80~£1.20	
Route 2	10	33~37	5	0	

d



	Distance(mile)	Travel time	Extra delay	Charge	Choice
Route 1	4	18~22	0	£2.80~£3.20	
Route 2	10	33~37	0	0	

Appendix 2:

An Example of the Revised Pilot Survey Questionnaire

PART 1

1. Are you : male? ___ female? ___

2. To which age group do you belong?

   under 24 ___ 25 to 34 ___ 35 to 54 ___ over 55 ___

3. Please indicate total annual income of your household? (voluntary question)

   under £20,000 ___ £20,000 to £40,000 ___ over £40,000 ___

4. Are you: Full time employed ___ Part time employed ___ Other ___

5. Are your work hours: Fixed ___ flexible/variable ___

6. When do you usually start work? _____:_____

7. How long do you normally spend driving for the journey to work every morning?

   ___ minutes

8. Who pays your driving cost? Yourself ___ Your company ___

9. Do you ever use traffic information systems? (please tick)

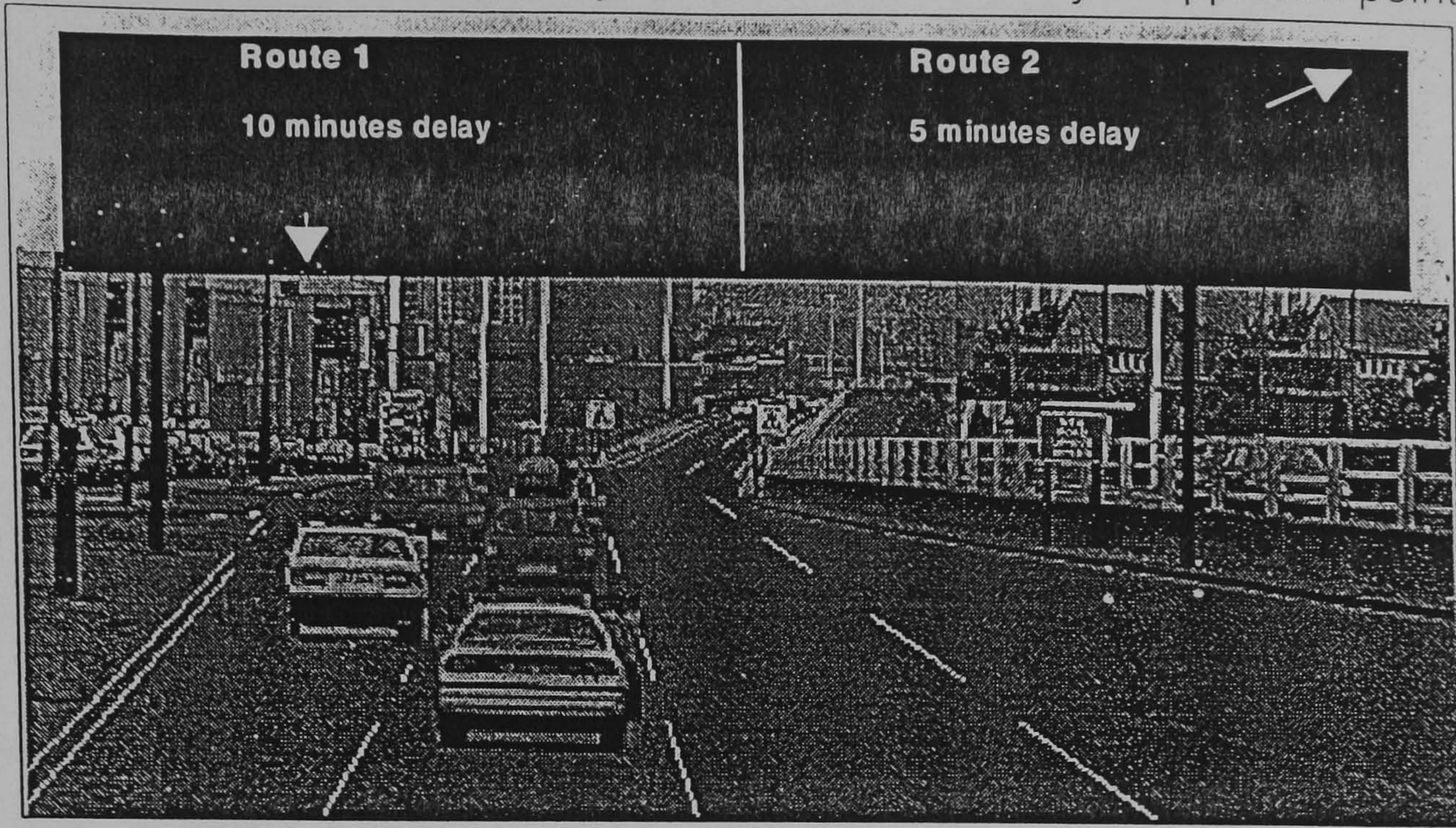
	Frequently	A little	Never
Roadside variable message signs			
Radio messages about traffic conditions			
In-vehicle guidance systems			

10. Did you find them useful? (please tick)

	Yes	Somewhat	No
Roadside variable message signs			
Radio messages about traffic conditions			
In-vehicle guidance systems			

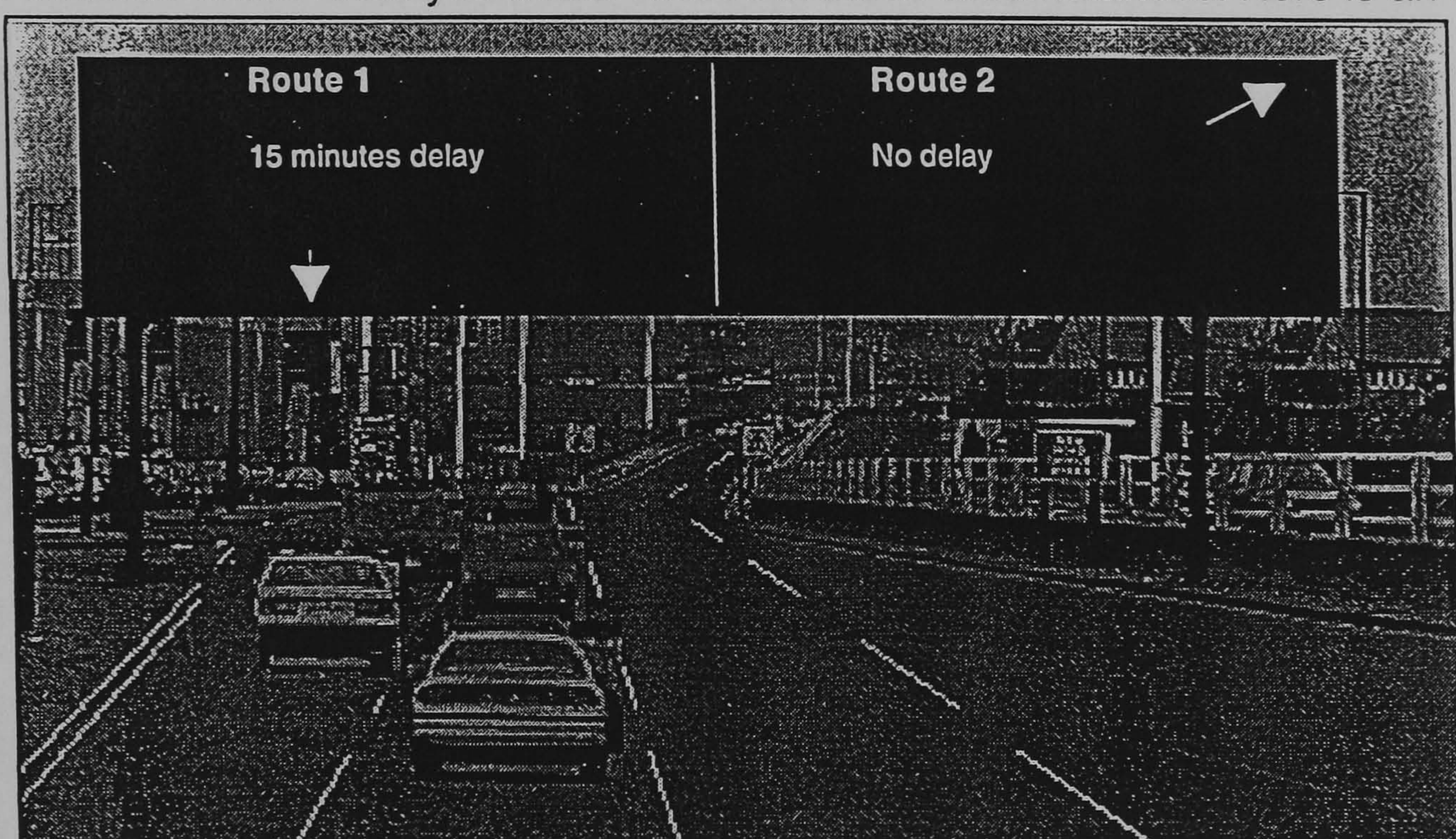
Section 1

When you pass point **A**, you get information from variable message signs about two routes. The picture below shows the view from your car windscreen as you approach point A.



The VMS sign indicates a **10 minutes delay in the city centre** and **5 minutes** delay on **route 2**. Note also that the picture shows a queue of traffic heading for the city centre.

We are going to show you a series of such photographs each with different VMS messages and local traffic conditions. Under each photograph we summarise the relevant information and ask you to indicate which route you would choose in those circumstances. Here is an example.

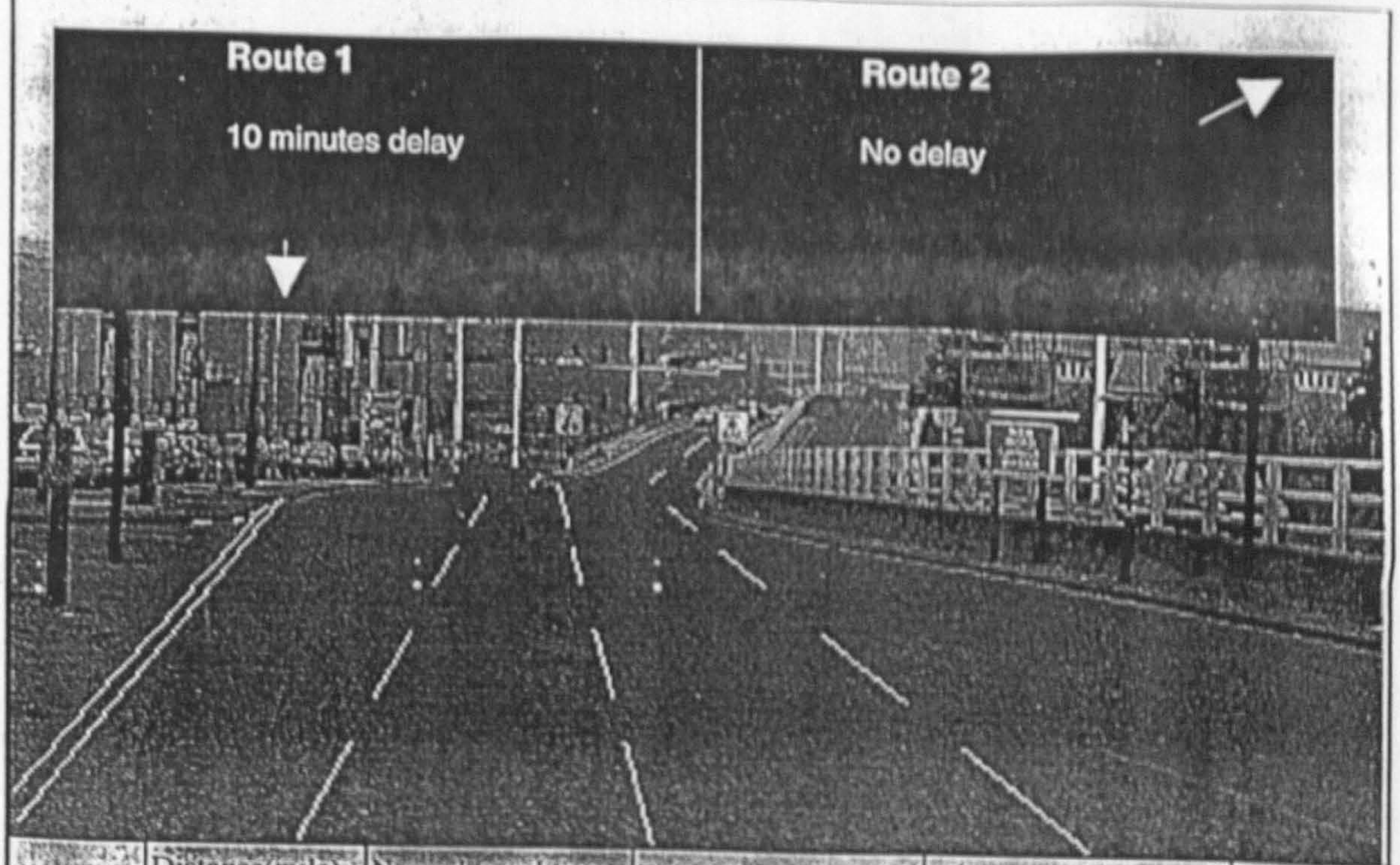


	Distance(mile)	Normal travel time	Extra delay expected	Queue for city centre	Choice
Route 1	4	23 - 27	15	Yes	X
Route 2	10	33 - 37	0		

This person chose route 1 : perhaps he thought that the lower distance(4miles) and the lower normal travel time(between 23 and 27 minutes) on route1 outweighed the delays mentioned on the VMS sign and the queue of traffic heading for the city centre.

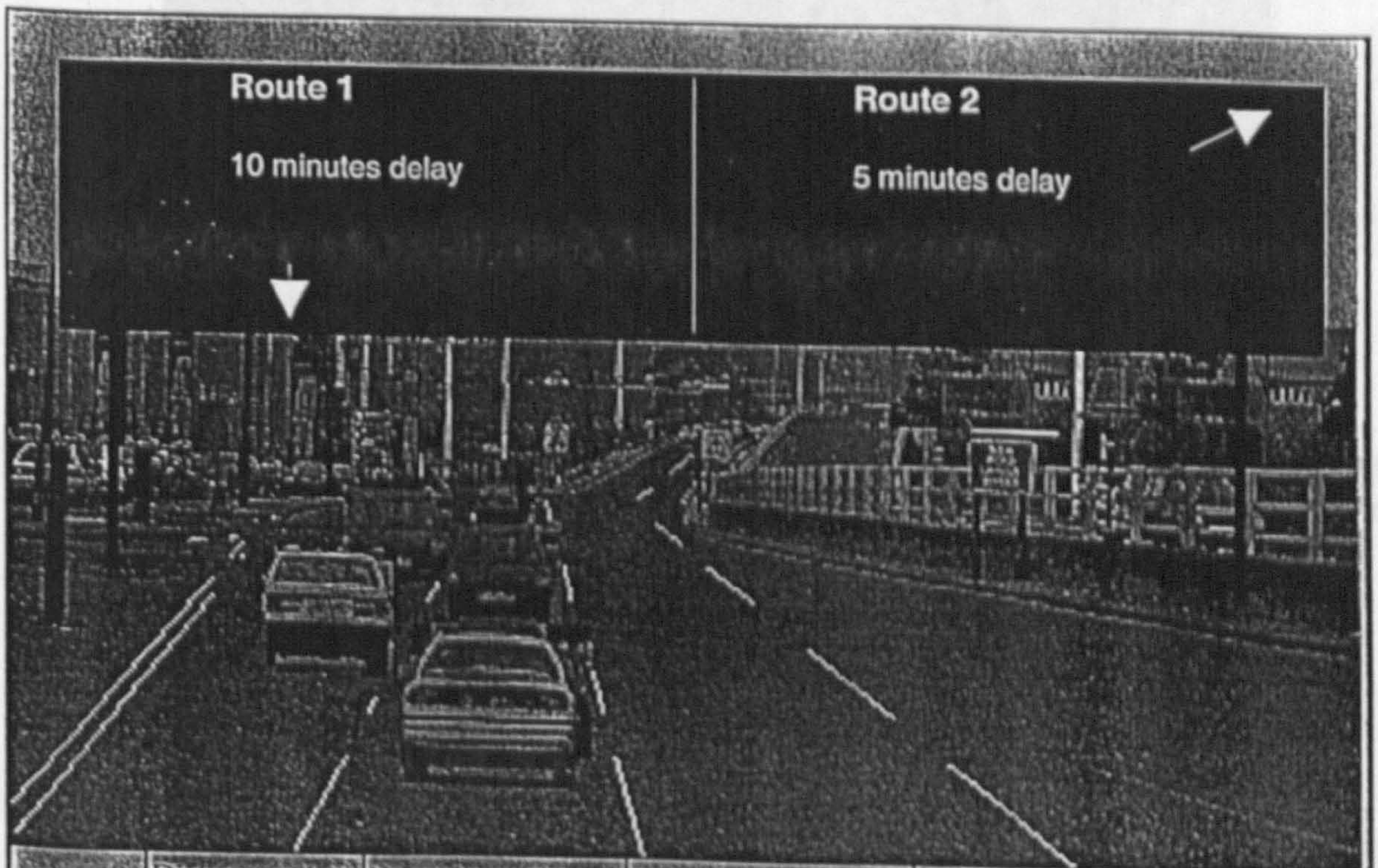
Please indicate your choice in each of the following situations

I



	Distance(mile)	Normal travel time	Extra delay expected	Queue for city centre	Choice
Route 1	4	23 - 27	10	No	
Route 2	10	33 - 37	0		

I



	Distance(mile)	Normal travel time	Extra delay expected	Queue for city centre	Choice
Route 1	4	23 - 27	10	Yes	
Route 2	10	33 - 37	5		

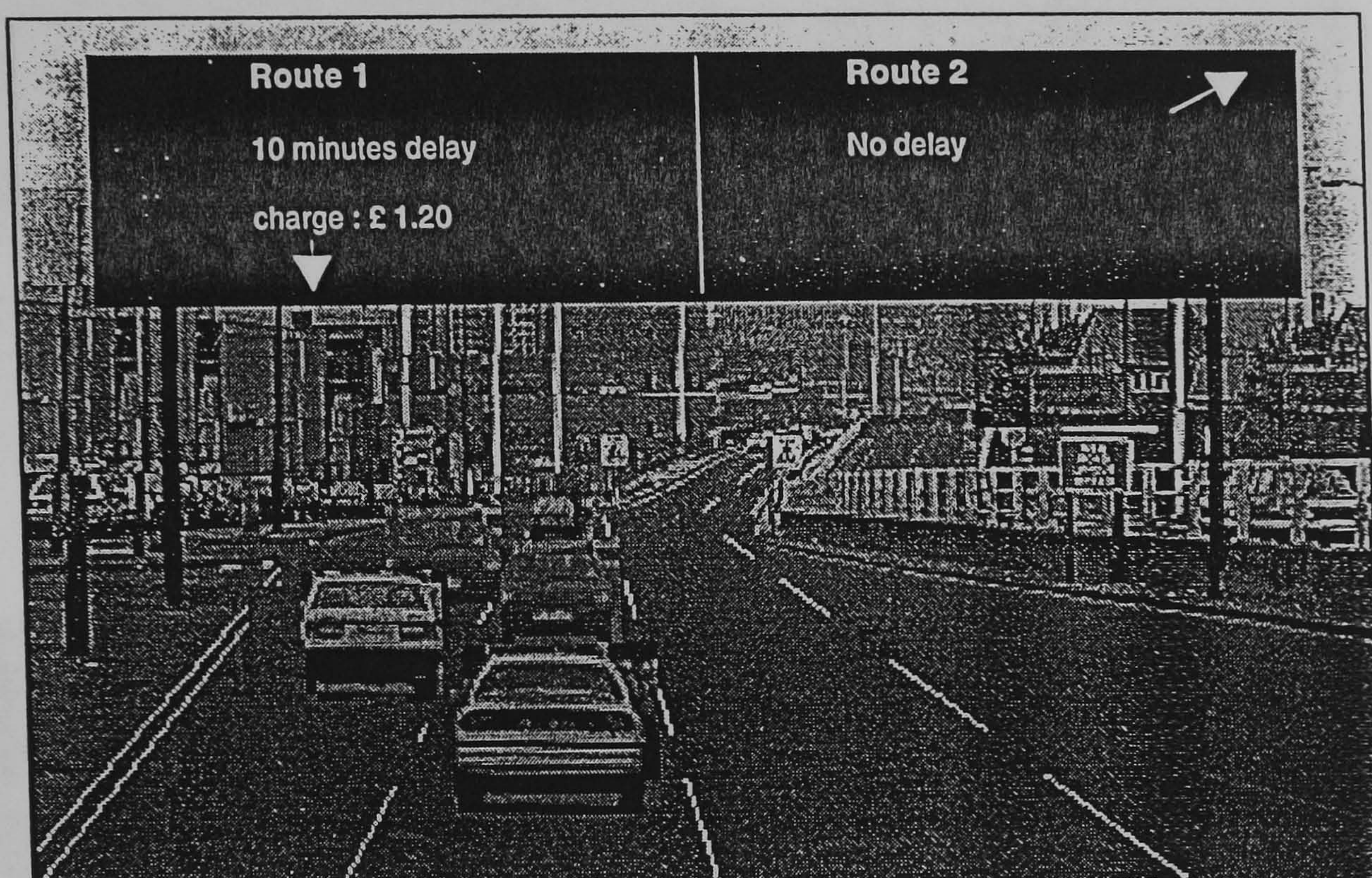
SECTION 2

Some local authorities are considering introducing charges for road use. We now want you to imagine that charges have been introduced for using route 1 and as a result some people have chosen not to drive through the city centre, so the normal travel time on route 1 has reduced to about 20 minutes.

The charge would be automatically deducted from the credit stored in a prepaid smart card in the vehicle while you are driving, so you need not stop to make the payment.

You can of course avoid paying the charge by choosing route 2.

We are going to show you a series of such photographs each with different VMS messages, a charge and local traffic conditions. We ask you to indicate which route you would choose in those circumstances. For example;

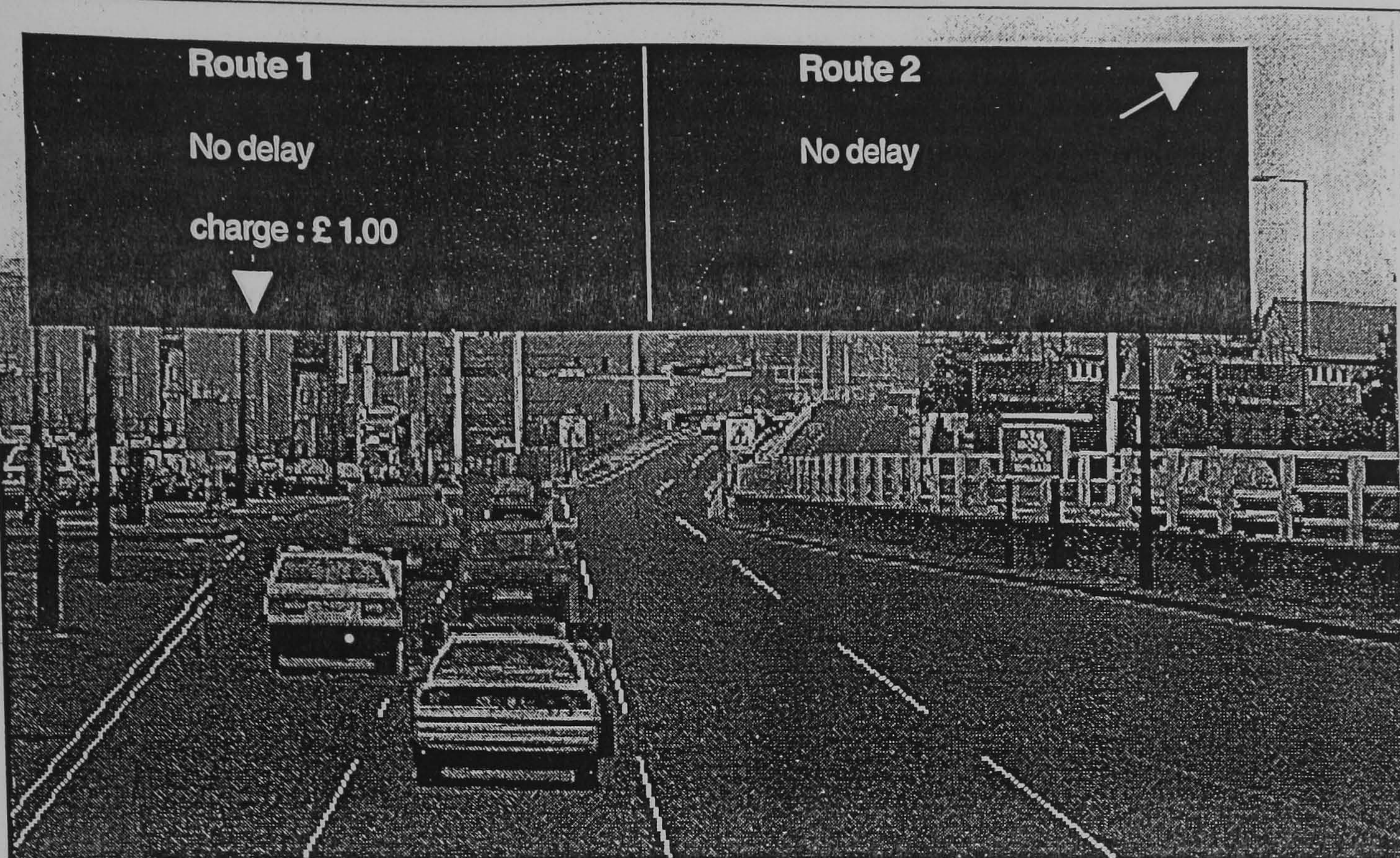


	Distance	Normal travel time	Extra delay expected	Queues for city centre	Charge	Choice
Route 1	4	18 - 22	10	Yes	£1.20	
Route 2	10	33 - 37	0			

The VMS sign indicates a charge of £ 1.20, as well as 10 minutes delay in the city centre and no delay on route 2. Note also that this photograph shows a queue of traffic heading for the city centre.

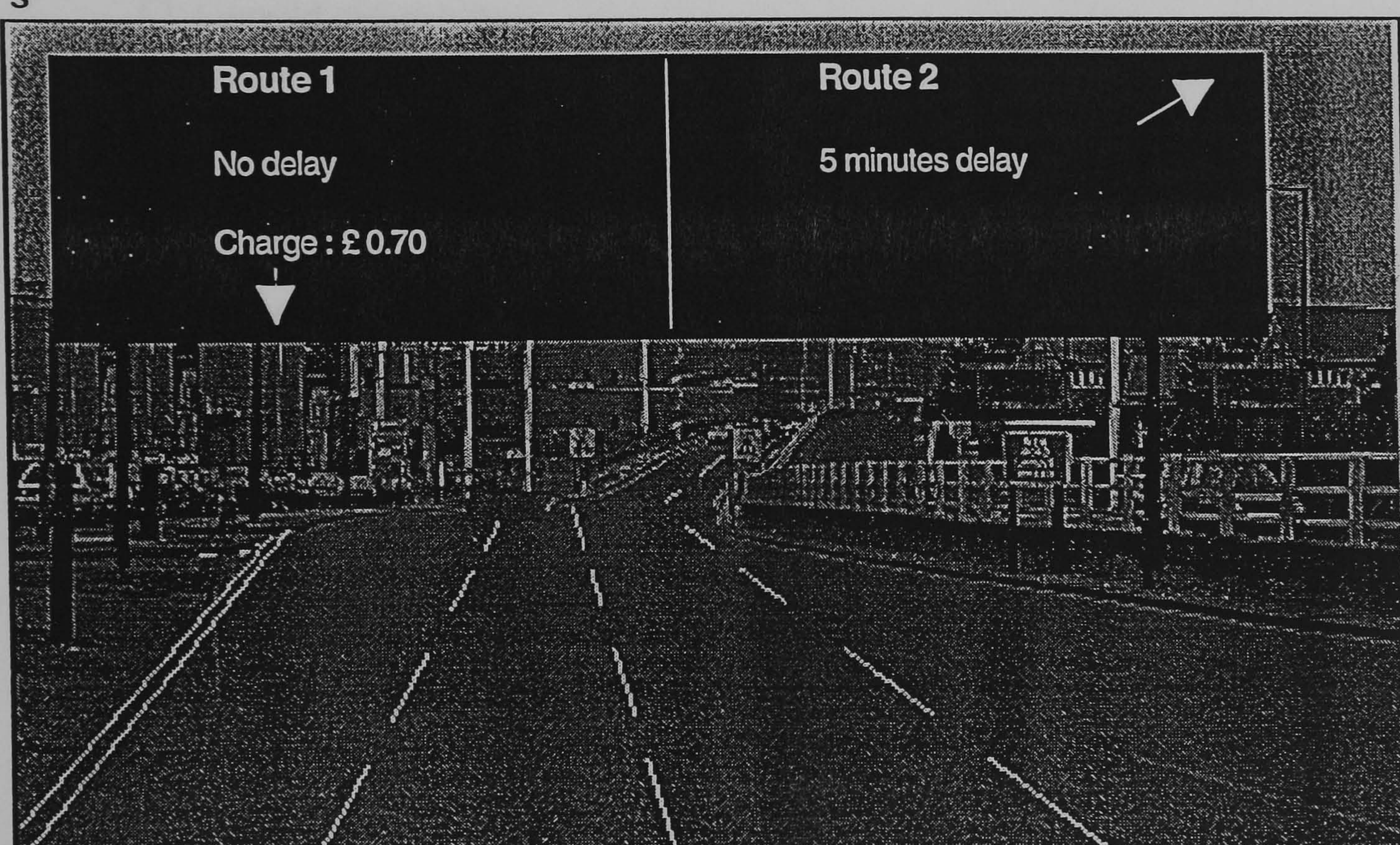
Please indicate your choice in each of the following situations

s



	Distance	Normal travel time	Extra delay expected	Queues for city centre	Charge	Choice
Route 1	4	18 - 22	0	Yes	£1.00	
Route 2	10	33 - 37	0			

s



	Distance	Normal travel time	Extra delay expected	Queues for city centre	Charge	Choice
Route 1	4	18 - 22	0	No	£0.70	
Route 2	10	33 - 37	5			

Part 3

Let's assume road pricing has been introduced for use of roads in Leeds city centre between 7:30 a.m. and 9:30 a.m.

1. If the charge per day was 50p, which of following options would you seriously consider ? (please rank them in order of importance)

   - ☐ I would pay the charge (£ 2.50 per 5 day week)
   - ☐ I would drive to the edge of the charge area, park and then walk or use public transport
   - ☐ I would travel before 7:30 am
   - ☐ I would travel after 9:30 pm
   - ☐ I would take a bus or train all the way
   - ☐ I would move jobs
   - ☐ Other (please specify) ______________________________

2. If the charge was £ 1 per day, which of following options would you seriously consider? (please rank them in order of importance)

   - ☐ I would pay the charge (£ 5 per 5 day week)
   - ☐ I would drive to the edge of the charge area, park and then walk or use public transport
   - ☐ I would travel before 7:30 am
   - ☐ I would travel after 9:30 pm
   - ☐ I would take a bus or train all the way
   - ☐ I would move jobs
   - ☐ Others (please specify) ______________________________

3. If the charge was £ 2 per day, which of following options would you seriously consider? (please rank them in order of importance)

   - ☐ I would pay the charge (£ 10 per 5 day week)
   - ☐ I would drive to the edge of the charge area, park and then walk or use public transport
   - ☐ I would travel before 7:30 am
   - ☐ I would travel after 9:30 pm
   - ☐ I would take a bus or train all the way
   - ☐ I would move jobs
   - ☐ Others (please specify) ______________________________

4. If you could avoid a £ 1 charge per day by travelling earlier, how much earlier would you be prepared to travel? _______ mins(max.)

Thank you very much for your assistance. Your time is very much appreciated.

Appendix 5:

An Example of the Third Pilot Survey and the Main Survey Questionnaire

ITS

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Direct line

Dear Sir/Madam,

One of my students is studying drivers' responses to information about traffic conditions and road-pricing. To help her in the study, I would very much appreciate it if you would complete and return this questionnaire by internal mail. The success of her study depends upon a high response rate!

The first part of the questionnaire asks general information about yourself and your travel. This helps us to determine whether our sample is representative of the general population. Then the second part asks how you would respond to each of a series of hypothetical driving situations.

If you have any queries or comments about this questionnaire, please do not hesitate to contact Ms Cho on 0113-233-6613. Thank you very much for your co-operation.

Yours faithfully

Peter Bonsall

Prof. Peter Bonsall

PART 1

1. Are you : male? ___ female? ____

2. To which age group do you belong?

   under 24 ___ 25 to 34 ___ 35 to 54 ___ over 55 ___

3. Please indicate total annual income of your household? (voluntary question)

   under £20,000 ___ £20,000 to £40,000 ___ over £40,000 ___

4. Are you: Full time employed ___ Part time employed ___ Other ___

5. Are your work hours: Fixed ___ flexible/variable ____

6. When do you usually start work? _____:______

7. How long do you normally spend driving for the journey to work every morning?

   ____ minutes

8. Who pays your driving cost? Yourself ___ Your company ___

9. Do you ever use traffic information systems? (please tick)

	Frequently	A little	Never
Roadside variable message signs			
Radio messages about traffic conditions			
In-vehicle guidance systems			

10. Did you find them useful? (please tick)

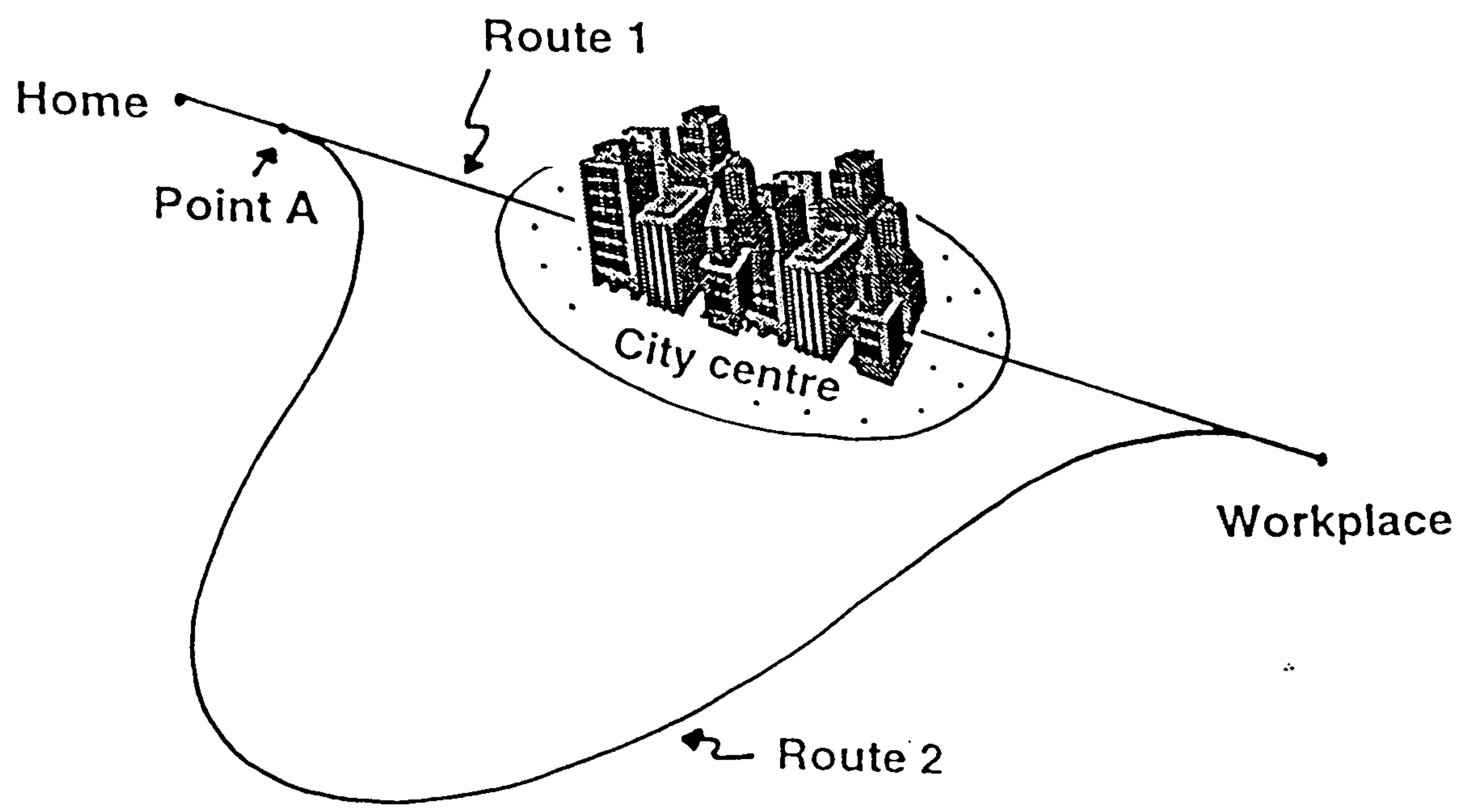
	Yes	Somewhat	No
Roadside variable message signs			
Radio messages about traffic conditions			
In-vehicle guidance systems			

PART 2

We would like to know how you would respond to each of a series of hypothetical travel choice situations.

Situation

The sketch below shows a journey from home to work. The workplace is the other side of the city centre.



Imagine that you are driving from home to work on a normal working day in the morning. When you pass point **A**, you have the choice of two routes to your workplace.

Route 1 is the shortest, 4 miles as the crow flies, and goes through the city centre. The normal travel time is about 25 minutes, of which about 10 minutes is spent in slow moving traffic during peak time.

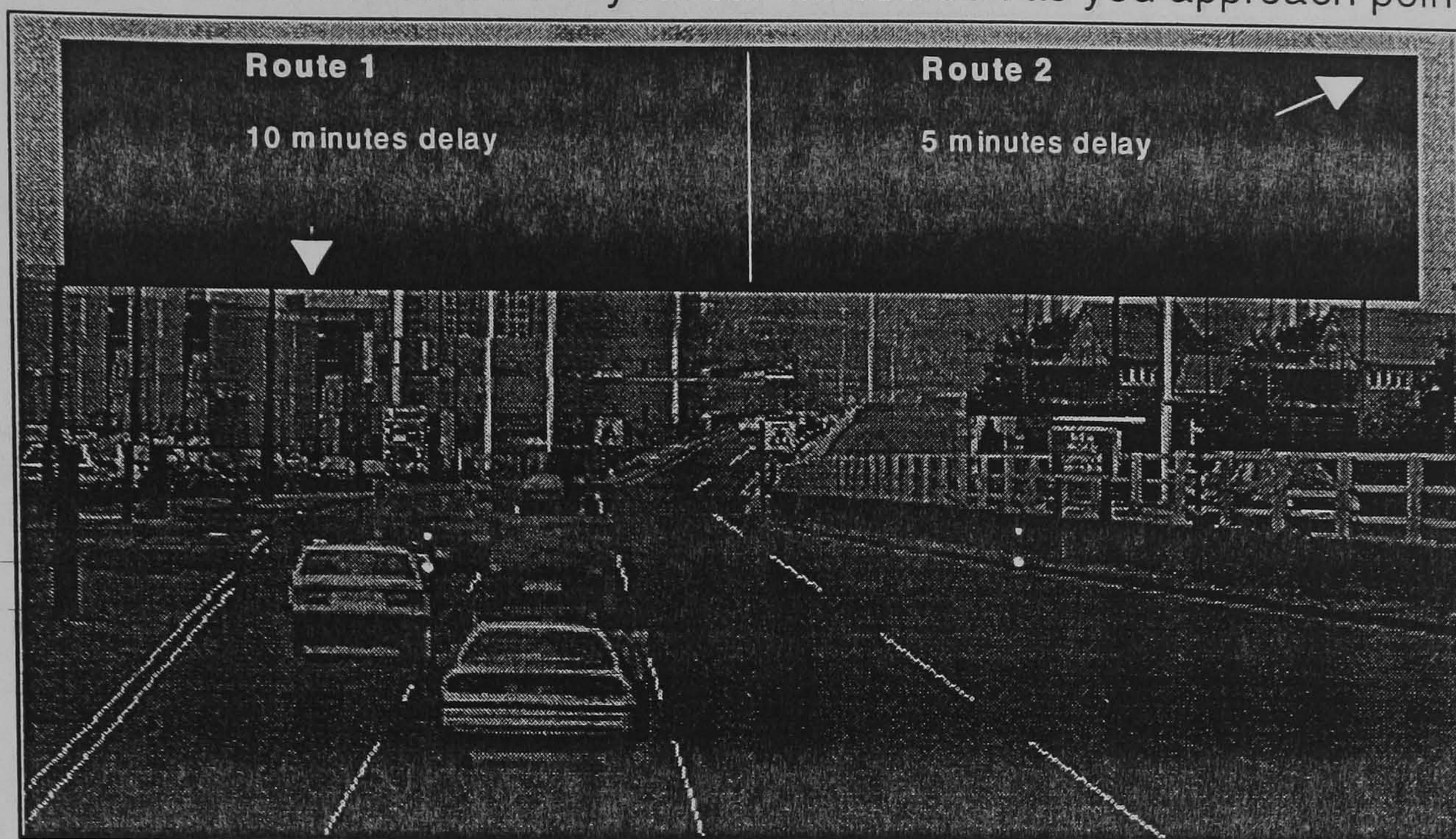
Route 2 is longer, 10 miles in total, but no delay is normally expected. The travel time is normally about 35 minutes.

What do you think the cost of petrol for these routes would be?

Route 1(4 miles) ________ p
Route 2(10 miles) ________ p

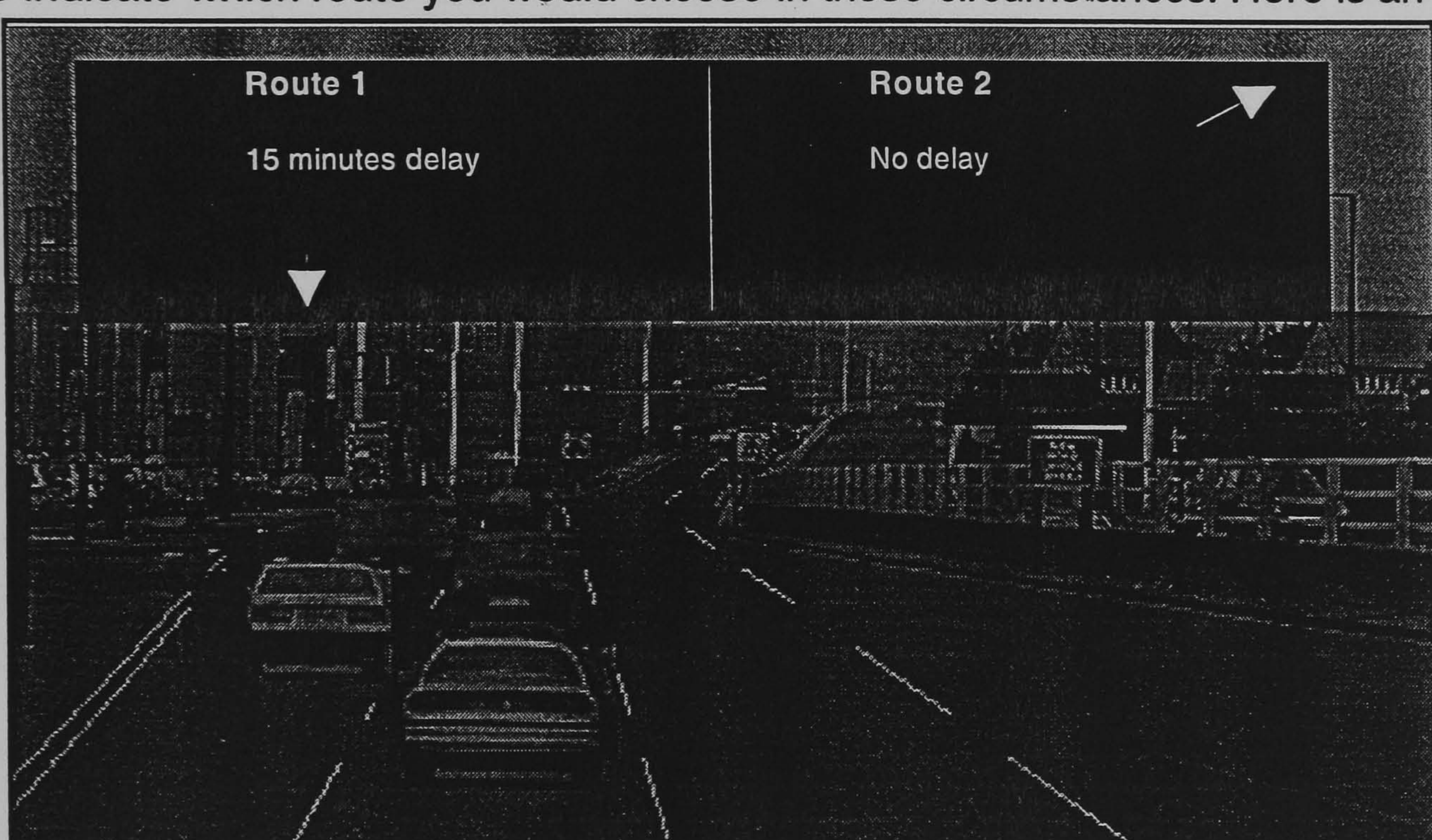
Section 1

When you pass point **A**, you get information from variable message signs about two routes. The picture below shows the view from your car windscreen as you approach point **A.**



The VMS sign indicates a **10 minutes delay in the city centre** and **5 minutes delay on route 2**. Note also that the picture shows a queue of traffic heading for the city centre.

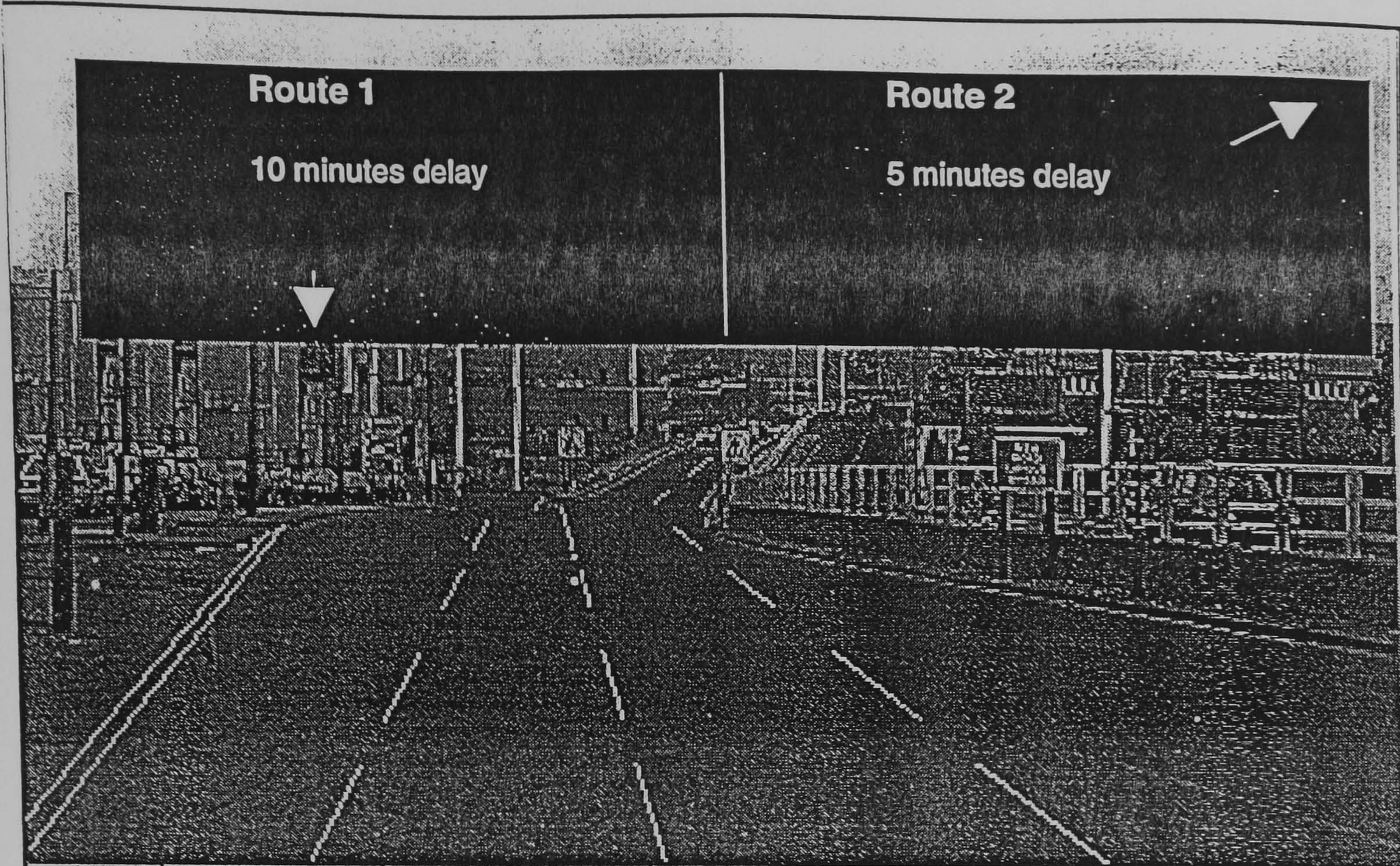
We are going to show you a series of such photographs each with different VMS messages and local traffic conditions. Under each photograph we summarise the relevant information and ask you to indicate which route you would choose in those circumstances. Here is an example.



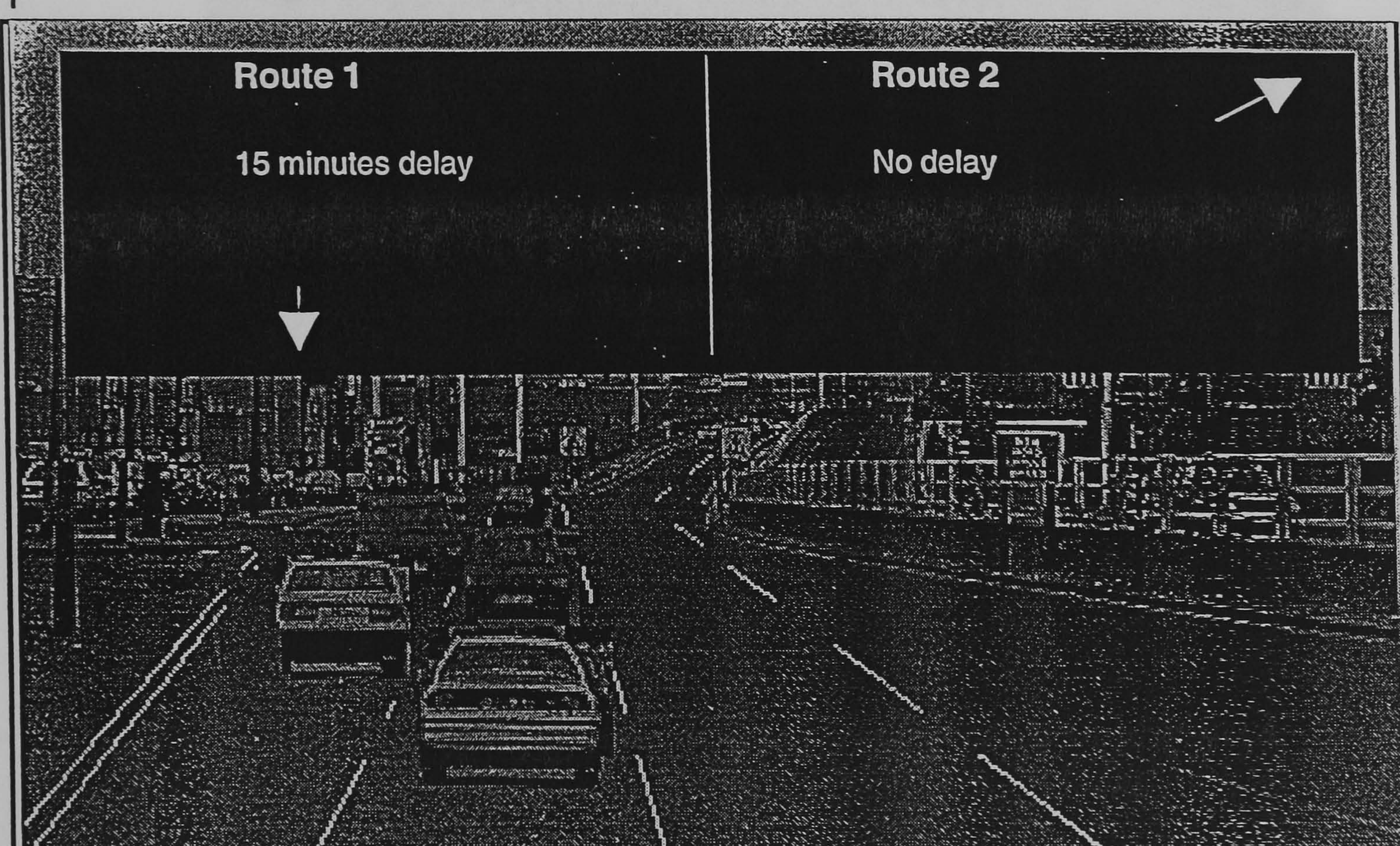
	Distance(mile)	Normal travel time	Extra delay expected	Queue for city centre	Choice
Route 1	4	23 - 27	15	Yes	
Route 2	10	33 - 37	0		

This person chose route 1 : perhaps he thought that the lower distance(4miles) and the lower normal travel time(between 23 and 27 minutes) on route1 outweighed the extra delay mentioned on the VMS sign and the queue of traffic heading for the city centre.

Please indicate your choice in each of the following situations



	Distance(mile)	Normal travel time	Extra delay expected	Queue for city centre	Choice
Route 1	4	23 - 27	10	No	
Route 2	10	33 - 37	5		



	Distance(mile)	Normal travel time	Extra delay expected	Queue for city centre	Choice
Route 1	4	23 - 27	15	Yes	
Route 2	10	33 - 37	0		

SECTION 2

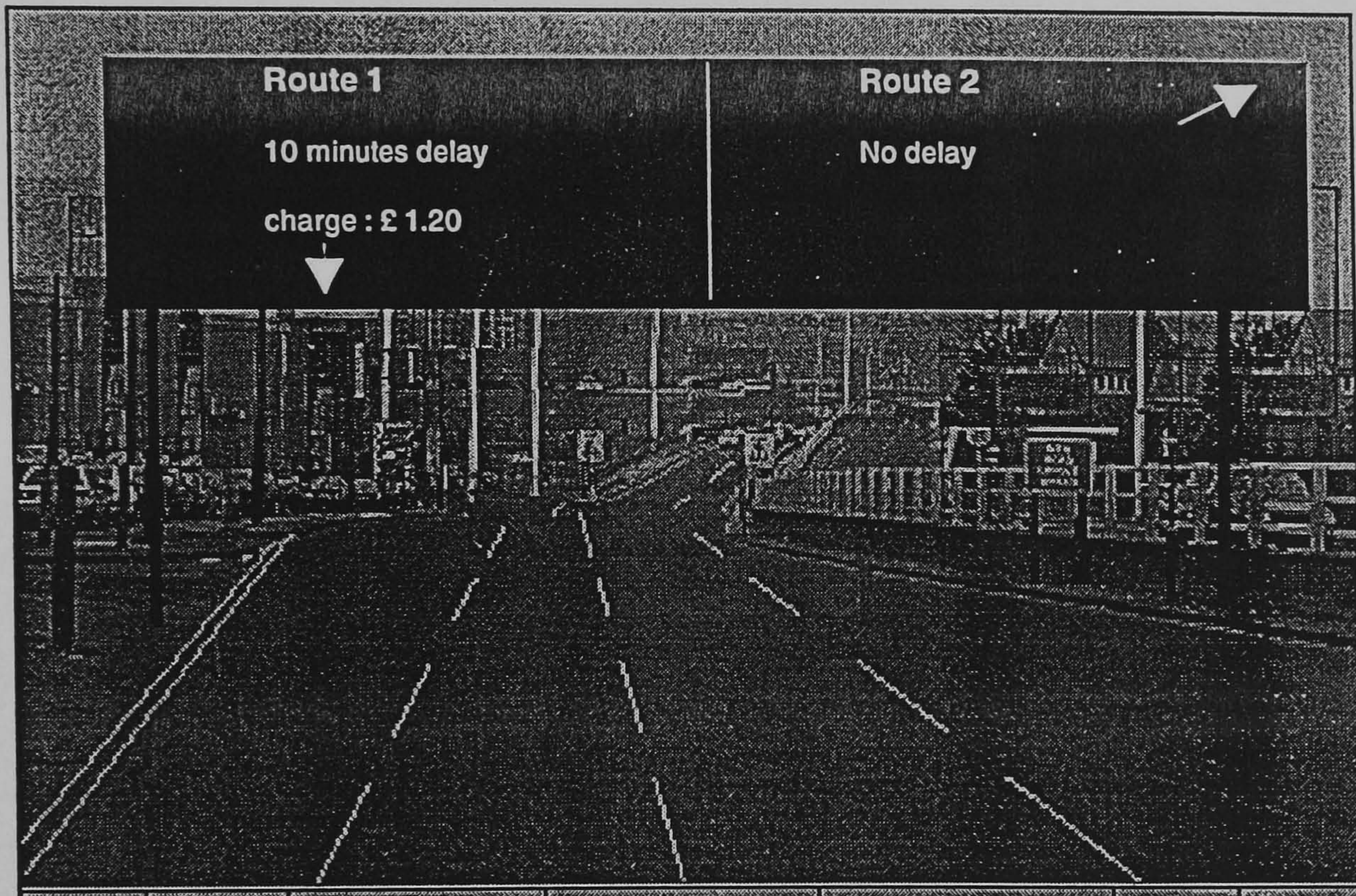
s

Some local authorities are considering introducing charges for road use. We now want you to imagine that charges have been introduced for using route 1 and as a result some people have chosen not to drive through the city centre, so the normal travel time on route 1 has reduced to about 20 minutes and the normal travel time on route2 has increased to about 40 minutes.

The charge would be automatically deducted from the credit stored in a prepaid smart card in the vehicle while you are driving, so you need not stop to make the payment.

You can of course avoid paying the charge by choosing route 2.

We are going to show you a series of photographs each with different VMS messages, a charge and local traffic conditions. We ask you to indicate which route you would choose in each situation. For example;

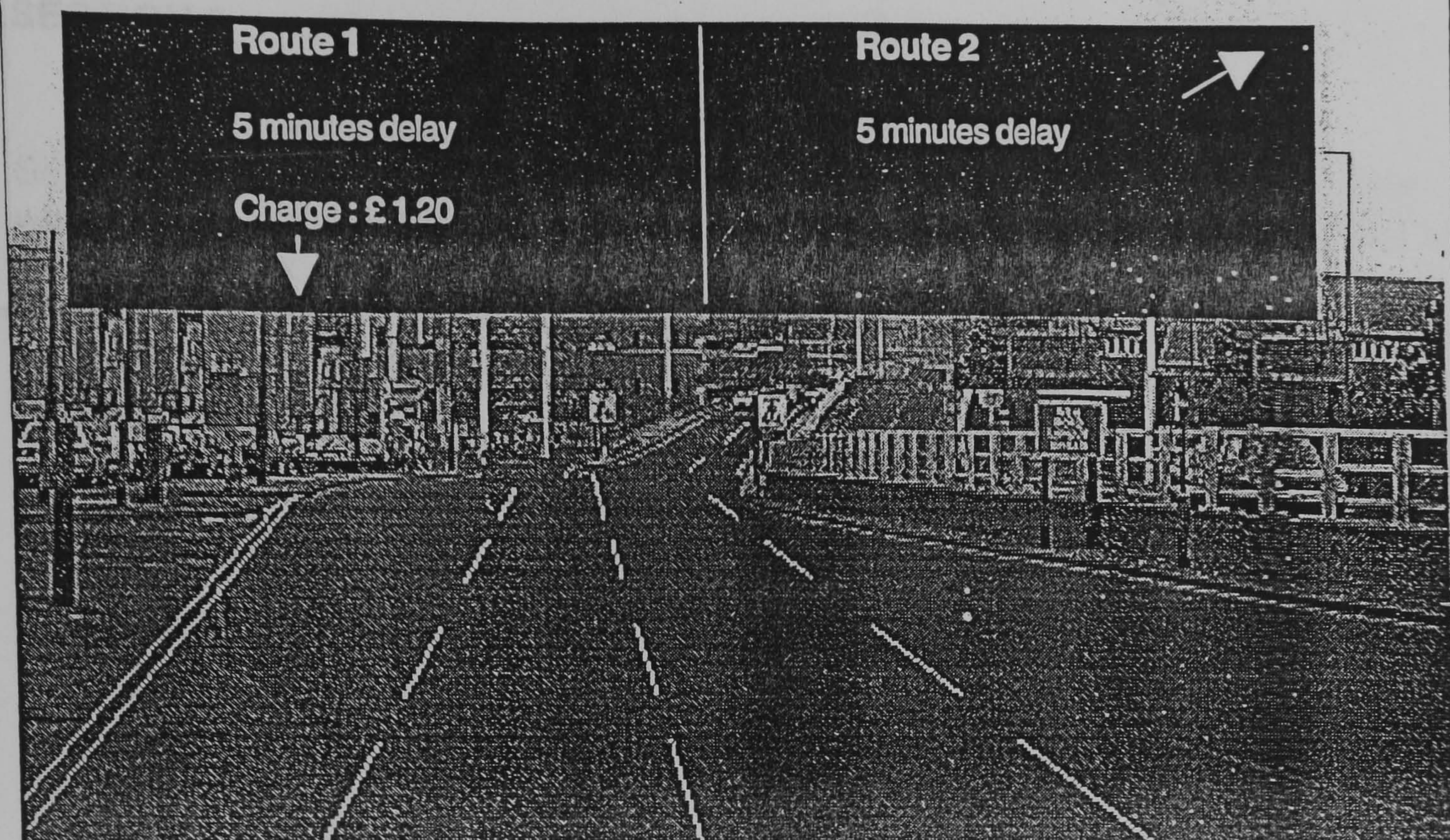


	Distance	Normal travel time	Extra delay expected	Queues for city centre	Charge	Choice
Route 1	4	18 - 22	10	No	£1.20	
Route 2	10	38 - 42	0			

The VMS sign indicates a charge of £ 1.20, as well as 10 minutes extra delay in the city centre and no delay on route 2.

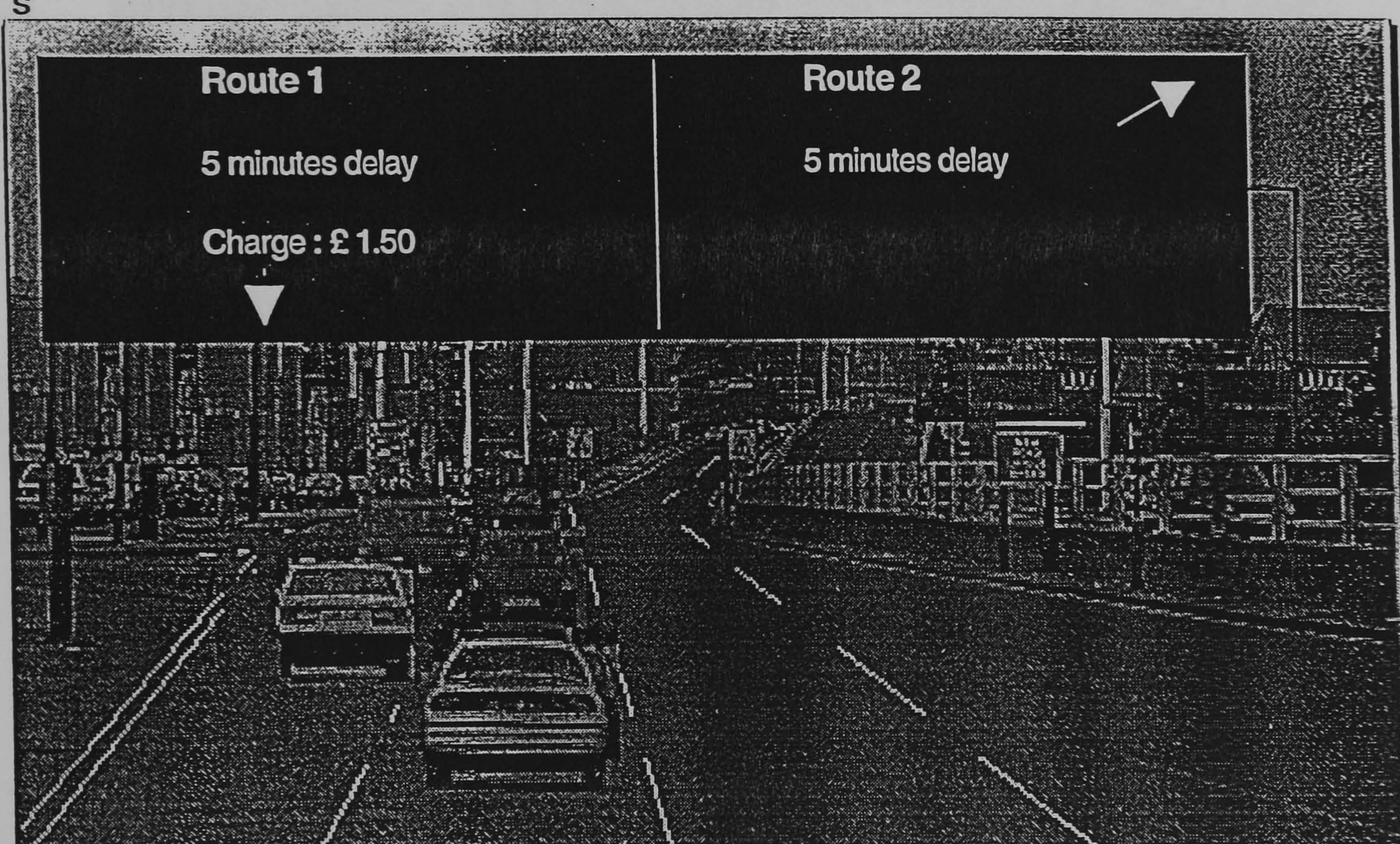
Please indicate your choice in each of the following situations

S



	Distance	Normal travel time	Extra delay expected	Queues for city centre	Charge	Choice
Route 1	4	18 - 22	5	No	£1.20	
Route 2	10	38 - 42	5			

S



	Distance	Normal travel time	Extra delay expected	Queues for city centre	Charge	Choice
Route 1	4	18 - 22	5	Yes	£1.50	
Route 2	10	38 - 42	5			

SECTION 2

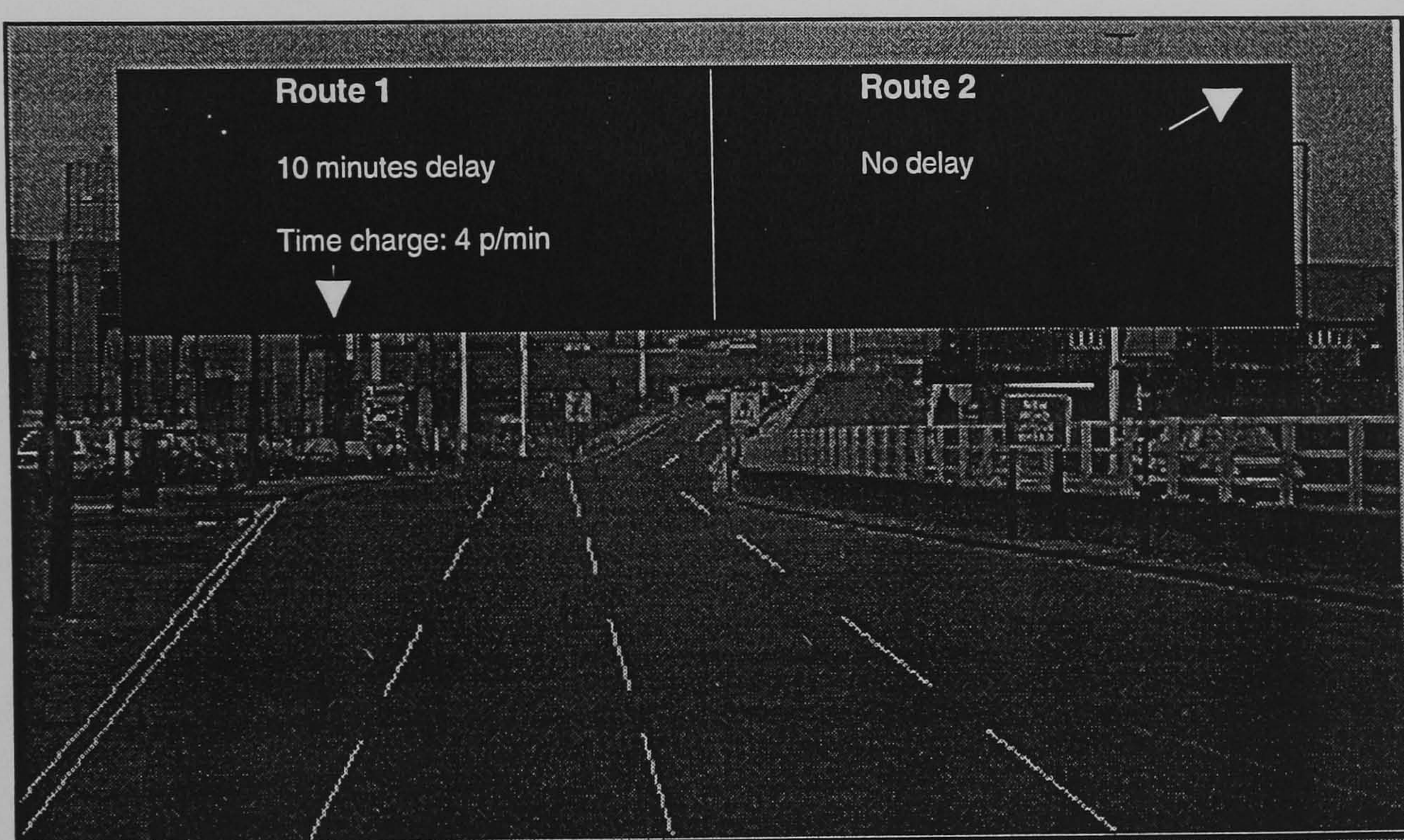
Some local authorities are considering introducing charges for road use. We now want you to imagine that charges have been introduced for using route 1 and as a result some people have chosen not to drive through the city centre, so the normal travel time on route 1 has reduced to about 20 minutes and the normal travel time on route2 has increased to about 40 minutes.

The charge payable is proportional to the time you spend on route 1. For example, if the rate is 10 pence per minute and a driver takes 12 minutes, then he will be charged £ 1.20.

The charge would be automatically deducted from the credit stored in a prepaid smart card in the vehicle while you are driving. You need not stop to make the payment.

You can of course avoid paying the charge by choosing route 2

We are going to show you a series of photographs each with different VMS messages, a charge and local traffic conditions. We ask you to indicate which route you would choose in each situation. For example;

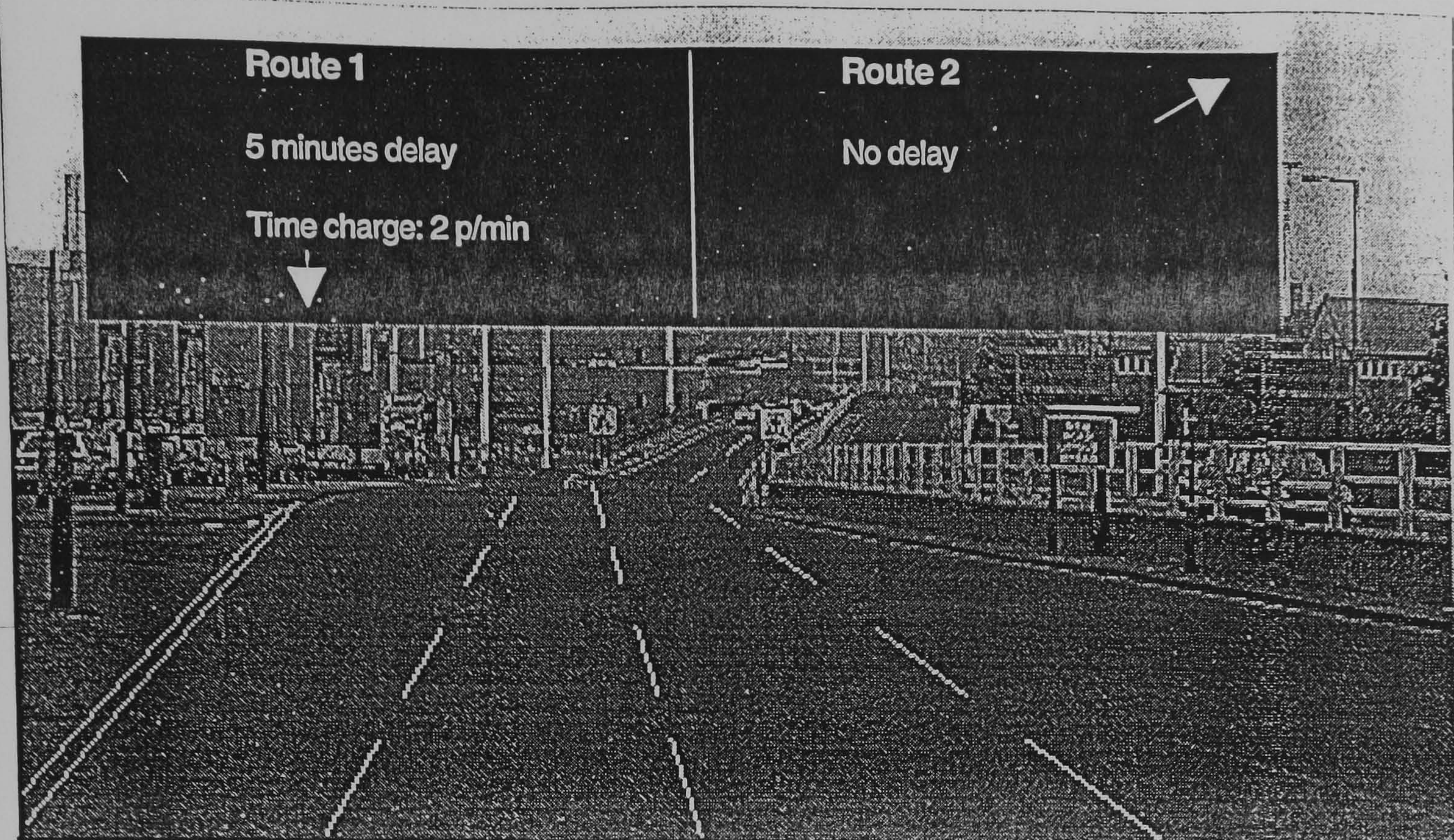


	Distance	Normal travel time	Extra delay expected	Queues for city centre	Charge	Choice
Route1	4	18 - 22	10	No	£2.25 - £2.55	
Route2	10	38 - 42	0			

The VMS sign indicates a charge rate of 4 pence per minute, as well as 10 minutes extra delay in the city centre and no delay on route 2. The charge quoted in the above box means that this driver would have to pay between £2.25 and £2.55 to use route 1.

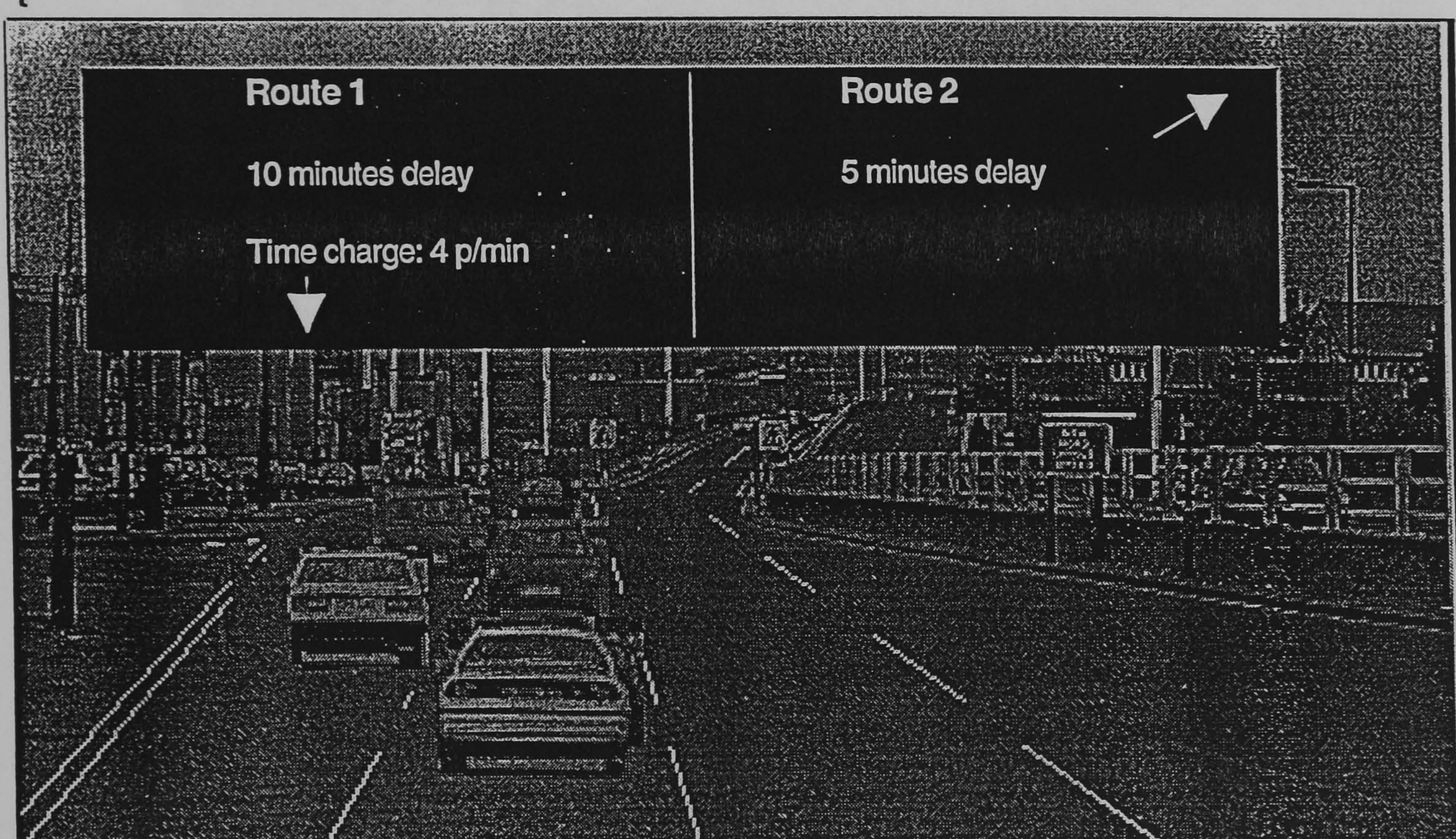
Please indicate your choice in each of the following situations

t



	Distance	Normal travel time	Extra delay expected	Queues for city centre	Charge	Choice
Route1	4	18 - 22	5	No	£0.45 - £0.55	
Route2	10	38 - 42	0			

t



	Distance	Normal travel time	Extra delay expected	Queues for city centre	Charge	Choice
Route1	4	18 - 22	10	Yes	£1.10 - £1.30	
Route2	10	38 - 42	5			

SECTION 2

d

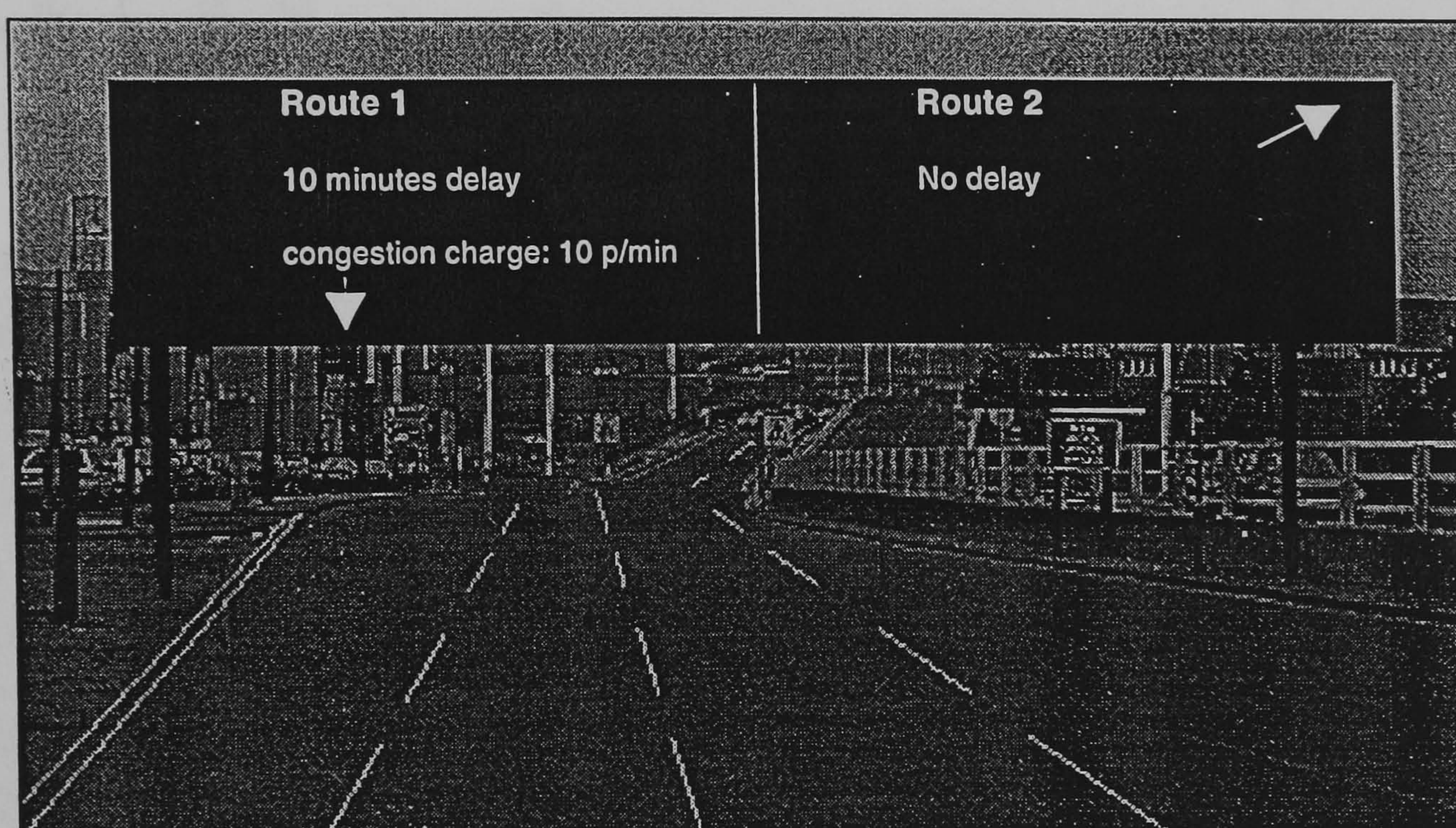
Some local authorities are considering introducing charges for road use. We now want you to imagine that charges have been introduced for using route 1 and as a result some people have chosen not to drive through the city centre, so the normal travel time on route 1 has reduced to about 20 minutes and the normal travel time on route2 has increased to about 40 minutes.

The charge is designed to reflect the current congestion pattern and so depends on the amount of time spent driving in slow moving traffic. For example, if a driver spends 12 minutes in slow moving traffic and the charge rate is 10 pence per minutes of delay, then he will be charged £ 1.20.

The charge would be automatically deducted from the credit stored in a prepaid smart card in the vehicle while you are driving. You need not stop to make the payment.

You can of course avoid paying the charge by choosing route 2.

We are going to show you a series of photographs each with different VMS messages, a charge and local traffic conditions. We ask you to indicate which route you would choose in each situation. For example;

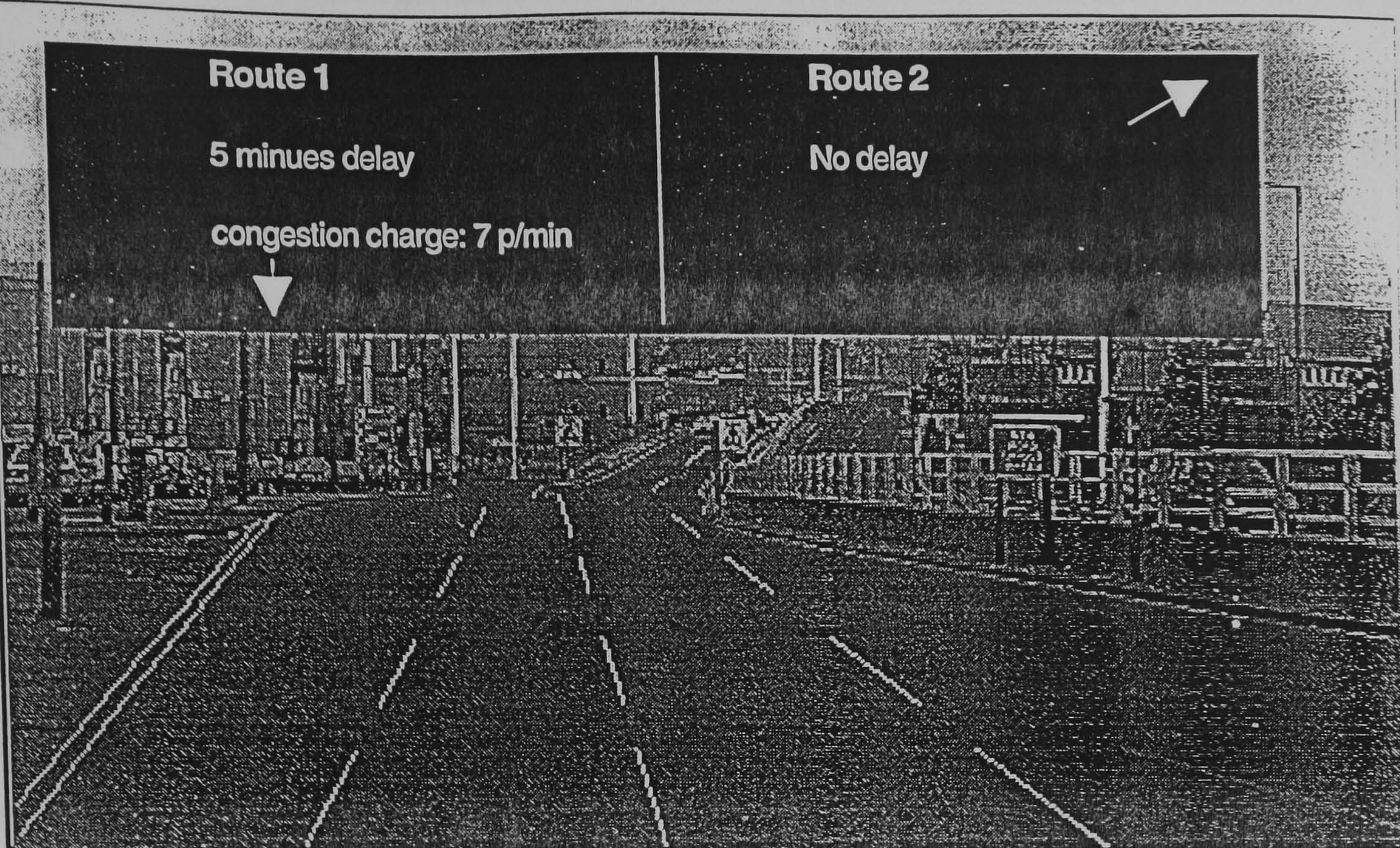


	Distance	Normal travel time	Extra delay expected	Queues for city centre	Charge	Choice
Route1	4	18 - 22	10	No	£1.20 - £1.80	
Route2	10	38 - 42	0			

The VMS sign indicates a charge rate of 10 pence per minute spent in slow moving traffic, as well as 10 minutes extra delay in the city centre and no delay on route 2. The charge quoted in the box means that this driver would have to pay between £1.20 and £1.80 to use route1.

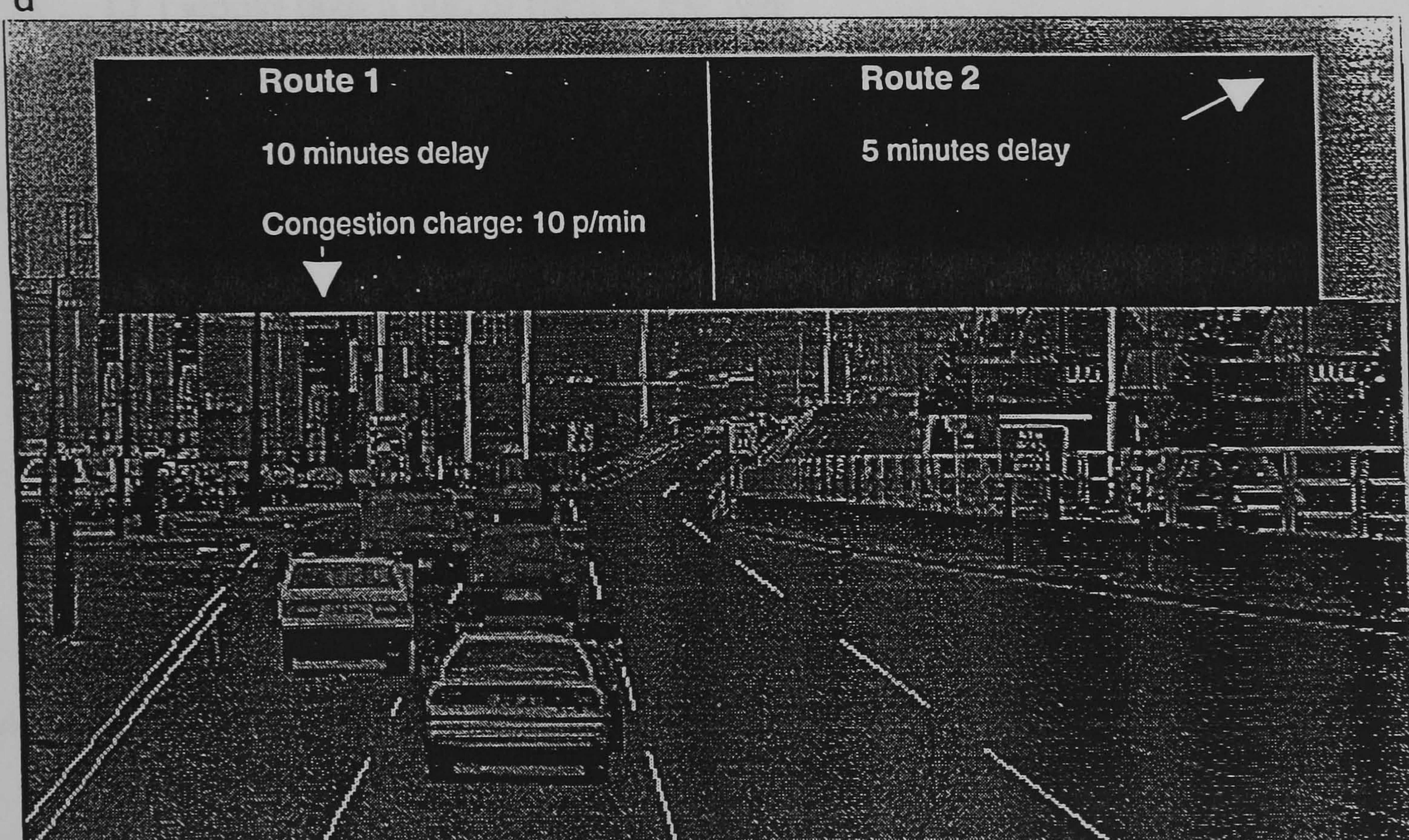
Please indicate your choice in each of the following situations

d



	Distance	Normal travel time	Extra delay expected	Queues for city centre	Charge	Choice
Route 1	4	18 - 22	5	No	£0.50 - £0.90	
Route 2	10	38 - 42	0			

d



	Distance	Normal travel time	Extra delay expected	Queues for city centre	Charge	Choice
Route 1	4	18 - 22	10	Yes	£1.20 - £1.80	
Route 2	10	38 - 42	5			

Part 3

Let's assume road pricing has been introduced for use of roads in Leeds city centre between 7:30 a.m. and 9:30 a.m.

1. If the charge per day was 50p, which of following options would you seriously consider ? (please rank them in order of importance)

   - ☐ I would pay the charge (£ 2.50 per 5 day week)
   - ☐ I would drive to the edge of the charge area, park and then walk or use public transport
   - ☐ I would travel before 7:30 am
   - ☐ I would travel after 9:30 pm
   - ☐ I would take a bus or train all the way
   - ☐ I would move jobs
   - ☐ Other (please specify) ______________________

2. If the charge was £ 1 per day, which of following options would you seriously consider? (please rank them in order of importance)

   - ☐ I would pay the charge (£ 5 per 5 day week)
   - ☐ I would drive to the edge of the charge area, park and then walk or use public transport
   - ☐ I would travel before 7:30 am
   - ☐ I would travel after 9:30 pm
   - ☐ I would take a bus or train all the way
   - ☐ I would move jobs
   - ☐ Others (please specify) ______________________

3. If the charge was £ 2 per day, which of following options would you seriously consider? (please rank them in order of importance)

   - ☐ I would pay the charge (£ 10 per 5 day week)
   - ☐ I would drive to the edge of the charge area, park and then walk or use public transport
   - ☐ I would travel before 7:30 am
   - ☐ I would travel after 9:30 pm
   - ☐ I would take a bus or train all the way
   - ☐ I would move jobs
   - ☐ Others (please specify) ______________________

4. If you could avoid a £ 1 charge per day by travelling earlier, how much earlier would you be prepared to travel? _______ mins(max.)

Thank you very much for your assistance. Your time is very much appreciated.

University of Leeds
Institute for Transport Studies

ITS

Dear Sir/Madam,

One of my students is studying drivers' responses to information about traffic conditions and road-pricing. To help her in the study, I would very much appreciate it if you would complete and return this questionnaire in the reply-paid envelope provided. The success of her study depends upon a high response rate!

The first part of the questionnaire asks general information about yourself and your travel. This helps us to determine whether our sample is representative of the general population. Then the second part asks how you would respond to each of a series of hypothetical driving situations.

If you have any queries or comments about this questionnaire, please do not hesitate to contact Ms Cho on 0113-233-6613. Thank you very much for your co-operation.

Yours faithfully

Prof. Peter Bonsall

PART 1

1. Are you : male? ___ female? ___

2. To which age group do you belong?

under 24 ___ 25 to 34 ___ 35 to 54 ___ over 55 ___

3. Please indicate total annual income of your household? (voluntary question)

under £20,000 ___ £20,000 to £40,000 ___ over £40,000 ___

4. Are you: Full time employed ___ Part time employed ___ Other ___

5. Do you ever use traffic information systems? (please tick)

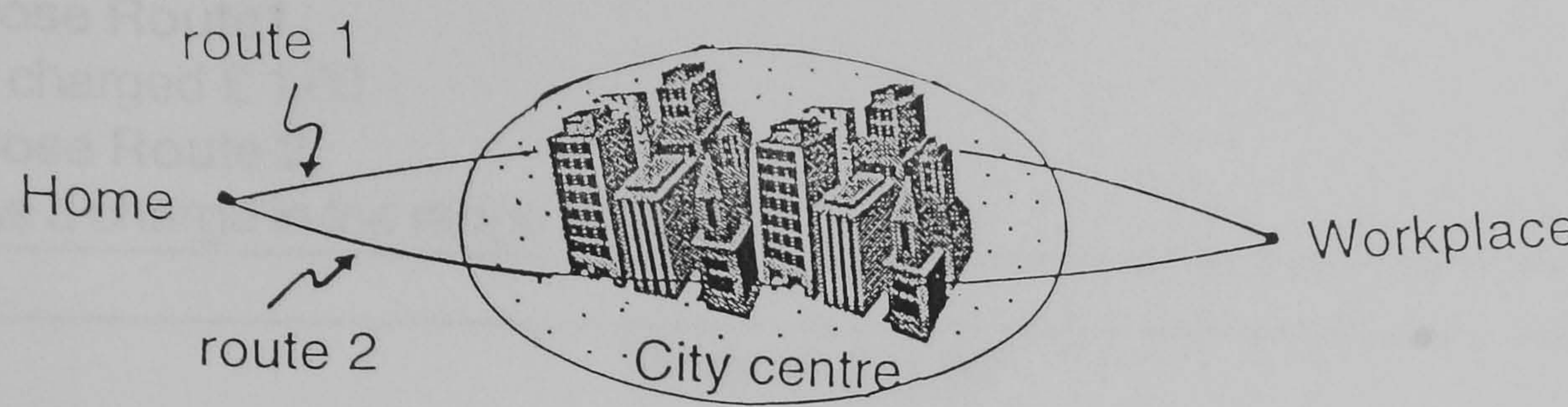
	Frequently	A little	Never
Roadside variable message signs			
Radio messages about traffic conditions			

10.Did you find them useful? (please tick)

	Yes	Somewhat	No
Roadside variable message signs			
Radio messages about traffic conditions			

PART 2

Imagine that you are driving from home to work on a normal working day in the morning. Your workplace is on the other side of the city centre and there are two possible routes to get there as shown below.



Both of the routes are about **4 miles** long, and go through the city centre. The normal travel time on each route is approximately **30 minutes**.

We want you to imagine that **charges** have been introduced for driving through the city. The charge payable is proportional to the time you spend on the streets. For example, if the rate is 10 pence per minute and you take 10 minutes, then you would be charged £ 1.00.

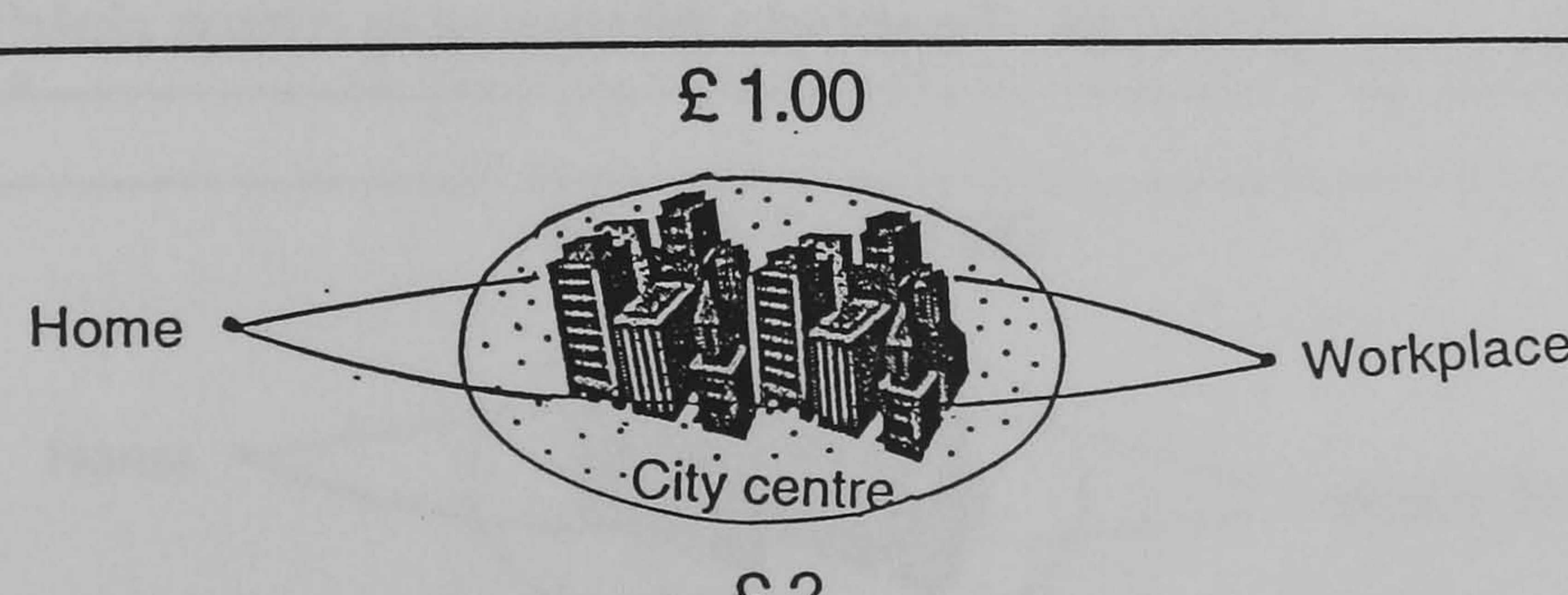
The charge would be automatically deducted from the credit stored in a prepaid smart card in the vehicle. This would happen while you were driving, so you wouldn't have to slow down or stop to make the payment.

Question 1

A traffic information system has been introduced on route 1 which provides an estimate of the charge and so helps drivers to decide which route to use.

If you choose Route1,
you will be charged £ 1.00

If you choose Route 2,
there will be a charge but you do not know how much it will be. The charge rate is 3 pence per minute and the normal travel time is about 30 minutes. But today's charge will depend on today's traffic conditions, so it may cheaper or more expensive.



Please indicate which route you would choose: Route 1 _____ or Route 2 _____

Question 2

An information system has now been installed for route 2 but it is not able to give accurate charge estimates because of the unpredictable traffic conditions on route 2 (it is only able to give rough estimates).

If you choose Route1,
you will be charged £ 1.00.
If you choose Route 2,
there will be a charge in the range shown.

a)

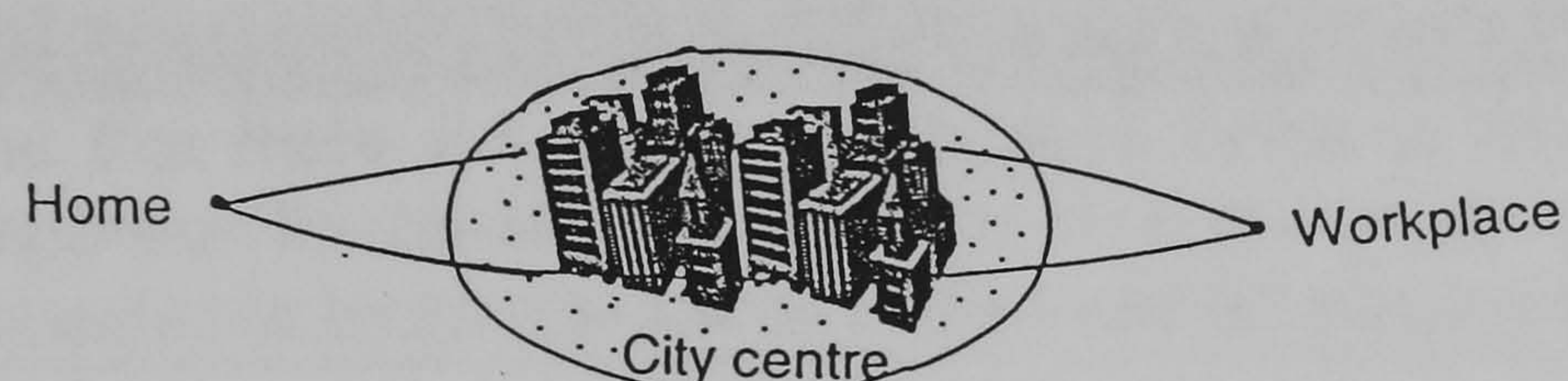
Route 1 : £ 1.00

Route 2: £ 0.90 - £ 1.10

Please indicate which route you would choose? Route 1 _____ or Route 2 _____

b)

Route 1 : £ 1.00

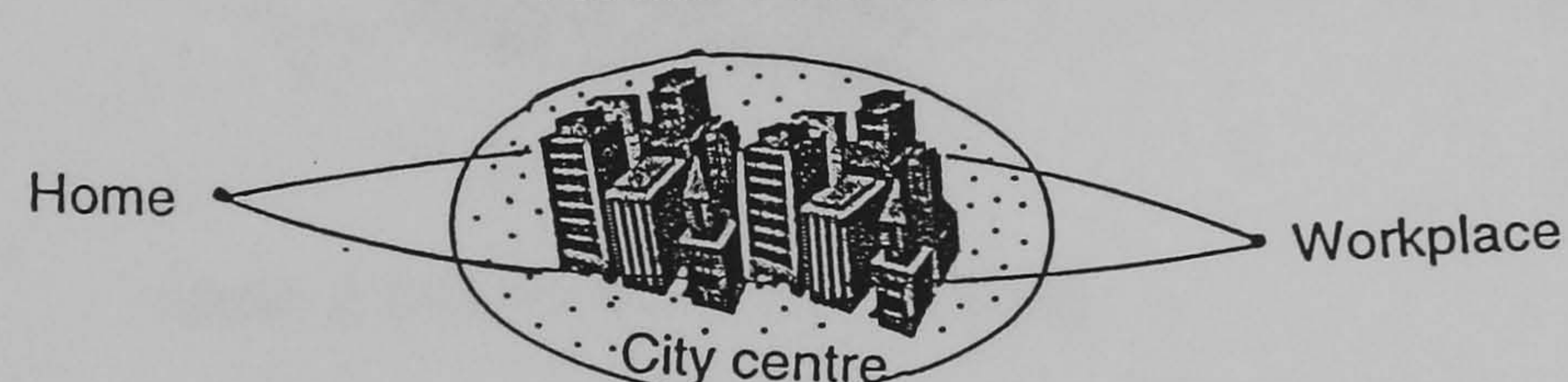


Route 2: £ 0.80 - £ 1.20

Please indicate which route you would choose? Route 1 _____ or Route 2 _____

c)

Route 1 : £ 1.00



Route 2: £ 0.70 - £ 1.30

Please indicate which route you would choose? Route 1 _____ or Route 2 _____

d)

Route 1 : £ 1.00

Route 2: £ 0.85 - £ 1.05

Please indicate which route you would choose? Route 1 _____ or Route 2 _____

e)

Route 1 : £ 1.00

Route 2 : £ 0.70 - £ 1.10

Please indicate which route you would choose? Route 1 _____ or Route 2 ____

f)

Route 1 : £ 1.00

Route 2: £ 0.80 - £1.40

Please indicate which route you would choose? Route 1 _____ or Route 2 _____

Question 3

Now please imagine that there is a charge on route 1 which is fixed(rather than depending on time spent on the streets) and that there is no charge on route 2. Today's journey times are expected to be 25 minutes on route 1 and 35 minutes on route 2.

route 1 (25 minutes, charge)

route 2 (35 minutes, no charge)

What would be the maximum charge that you would be prepared to pay to use route 1 today?

Max. Charge(approximate) £ __________

Thank you very much for your assistance. Your time is very much appreciated.

Appendix 5 :An Example of the Simulation Tests

Appendix 5-1:

An Example of a Program File to Create the Responses

```
      DOUBLE PRECISION E1,E2,RANDOM
      INTEGER T1(7), T2(7), CH(7), D51(7), D10(7), D0(7), D52(7),
     1HT(7)
      OPEN (UNIT=11,FILE='k:\home\hcho\ALEX\pilotD.ATT')
      OPEN (UNIT=12,FILE='k:\home\hcho\ALEX\PILOTD.DAT')
      OPEN (UNIT=13,FILE='k:\home\hcho\alex\piloterD.DAT')
      CALL DATE_TIME_SEED@
      ASCC=0.0
      VOT=-8.0
      VC=-1.0
      VD0=20.0
      VD5=-50.0
      VD10=-140.0
      VH=-100.0
      STDEV=180.0
      DENOM=1.28/STDEV
      DO 10 I=1,7
      READ (11,77) T1(I), T2(I), CH(I), D51(I), D10(I), D0(I),
     1D52(I), HT(I)
   77 FORMAT (8I8)
   10 CONTINUE
      DO 15 J=1,200
      DO 20 K=1,7
      E1=RANDOM()
      XXX1=E1
      E1=-DLOG(E1)
      E1=-DLOG(E1)
      E1=E1/DENOM
      E2=RANDOM()
      XXX2=E2
      E2=-DLOG(E2)
      E2=-DLOG(E2)
      E2=E2/DENOM
      UROUTE1= (VOT*T1(K))+(VC*CH(K))+(VD5*D51(K))+(VD10*D10(K)) +
     1(VH*HT(K))+E1
      UROUTE2= ASCC+(VOT*T2(K))+(VD0*D0(K))+(VD5*D52(K))+E2
      DUROUTE1=(UROUTE1-E1)
      DUROUTE2=(UROUTE2-E2)
      IF(UROUTE1.GE.UROUTE2) THEN
      IC=1
      ELSEIF(UROUTE1.LT.UROUTE2) THEN
      IC=2
      ENDIF
      WRITE (12,88) T1(K), T2(K), CH(K), D51(K), D10(K), D0(K),
     1D52(K), HT(K), IC
   88 FORMAT (9I8)
      WRITE (13,89) DUROUTE1,DUROUTE2,E1,E2
   89 FORMAT (2F18.2,2F9.2)
   20 CONTINUE
   15 CONTINUE
      STOP
      END
```

Appendix 5-2: An Example of Created Responses

20	40	70	1	0	1	0	0	2
20	40	150	0	1	0	1	1	2
20	40	120	1	0	1	0	1	2
20	40	105	0	1	0	1	0	1
20	40	100	1	0	0	1	0	1
20	40	120	1	0	0	1	1	2
20	40	105	0	1	1	0	0	2
20	40	70	1	0	1	0	0	1
20	40	150	0	1	0	1	1	2
20	40	120	1	0	1	0	1	2
20	40	105	0	1	0	1	0	1
20	40	100	1	0	0	1	0	2
20	40	120	1	0	0	1	1	2
20	40	105	0	1	1	0	0	2
20	40	70	1	0	1	0	0	2
20	40	150	0	1	0	1	1	2
20	40	120	1	0	1	0	1	2
20	40	105	0	1	0	1	0	1
20	40	100	1	0	0	1	0	1
20	40	120	1	0	0	1	1	2
20	40	105	0	1	1	0	0	2
20	40	70	1	0	1	0	0	1
20	40	150	0	1	0	1	1	2
20	40	120	1	0	1	0	1	1
20	40	105	0	1	0	1	0	2
20	40	100	1	0	0	1	0	2
20	40	120	1	0	0	1	1	2
20	40	105	0	1	1	0	0	1
20	40	70	1	0	1	0	0	1
20	40	150	0	1	0	1	1	2
20	40	120	1	0	1	0	1	1
20	40	105	0	1	0	1	0	1
20	40	100	1	0	0	1	0	1
20	40	120	1	0	0	1	1	2
20	40	105	0	1	1	0	0	2
20	40	70	1	0	1	0	0	2
20	40	150	0	1	0	1	1	2
20	40	120	1	0	1	0	1	1
20	40	105	0	1	0	1	0	1
20	40	100	1	0	0	1	0	2
20	40	120	1	0	0	1	1	2
20	40	105	0	1	1	0	0	2
20	40	70	1	0	1	0	0	1
20	40	150	0	1	0	1	1	2
20	40	120	1	0	1	0	1	2
20	40	105	0	1	0	1	0	2
20	40	100	1	0	0	1	0	1
20	40	120	1	0	0	1	1	2
20	40	105	0	1	1	0	0	2
20	40	70	1	0	1	0	0	1
20	40	150	0	1	0	1	1	2
20	40	120	1	0	1	0	1	1
20	40	105	0	1	0	1	0	2
20	40	100	1	0	0	1	0	1
20	40	120	1	0	0	1	1	1
20	40	105	0	1	1	0	0	2
20	40	70	1	0	1	0	0	1
20	40	150	0	1	0	1	1	1
20	40	120	1	0	1	0	1	2
20	40	105	0	1	0	1	0	2
20	40	100	1	0	0	1	0	1

Appendix 5-3:

An Example of Model Estimation Results Using Simulated Responses

```
Hague Consulting Group                                                        Page
ALOGIT Version 3F/2 (635)                                       14:52:35 on  3 Mar 9

 Test for simulation WITH pilot2.dat : time-based charging with average values

Last input data item in transformations or utilities      9


   4 transformation codes; maximum 5000


 PREPARE transformations
 CHOICE     = Data0009

 INFORMATION: DATA input set by user from    9 to    9


 Maximum Iterations 10
 Convergence criterion is  .10E-01  Option 3

 INFORMATION: No explicit specification - base file read with default format


 Report of user selections

    0 Observations rejected because item 2012 = 1.00


 DATA INPUT COMPLETED

   from data file : a:\pilotd.dat

 Total observations read from file     :  1400

 Observations rejected by user tests   :     0

 Observations rejected automatically   :     0

 Observations accepted for processing :  1400

 Sum of weights of observations :         1400.00


 SPECIFICATION OF MODEL and DATA STATISTICS


 Alternative   1: chosen  563.0 of available 1400.0 observations

 Coefficient      vot     +    vc      +    vd5     +    vd10    +     vh
 Number (Con)     1 (F)        2 (F)       10 (F)       11 (F)       12 (F)
 Start Value      .0000        .0000        .0000        .0000        .0000

 Data Item     *Data0001   *Data0003   *Data0004   *Data0005   *Data0008
 % Non-Zero      100.0        100.0        57.1         42.9         42.9
 Mean (N-Z)      20.00       110.00        1.00         1.00         1.00
 C. of V. %         .0         20.5          .0           .0           .0
```

Test for simulation WITH pilot2.dat : time-based charging with average valu

Convergence achieved after 3 iterations

Analysis is based on 1400 observations

Likelihood with Zero Coefficients = -970.4061

Likelihood with Constants only = -943.4193

Initial Likelihood = -970.4061

Final value of Likelihood = -895.3955

"Rho-Squared" w.r.t. Zero = .0773

"Rho-Squared" w.r.t. Constants = .0509

ESTIMATES OBTAINED AT ITERATION 3

Likelihood = -895.3955

	vot	vc	vd5	vd10	vh
Estimate	-.4898E-01	-.5262E-02	-.4618	-1.260	-.6647
Std. Error	.374E-01	.826E-02	.148	.203	.325
"T" Ratio	-1.3	-.6	-3.1	-6.2	-2.0

Correlation of Estimates (multiplied by 1000)

		1	2	10	11
vc	2	988			
vd5	10	676	610		
vd10	11	-320	-433	282	
vh	12	-885	-930	-514	494

Convergence (option 3) value is .8414E-02

Normal finish after 0 mins. 13.1 secs.

Test for simulation WITH pilot2.dat : time-based charging with average values

Alternative 2: chosen 837.0 of available 1400.0 observations

Coefficient	vot	+	vd5
Number (Con)	1 (F)		10 (F)
Start Value	.0000		.0000

Data Item	*Data0002	*Data0007
% Non-Zero	100.0	57.1
Mean (N-Z)	40.00	1.00
C. of V. %	.0	.0

RANGES OF INDEPENDENT VARIABLES

Variable		vot	vc	vd5	vd10	vh
Chsn	Min	20.00	.00	.00	.00	.00
	Max	40.00	150.00	1.00	1.00	1.00
Diff	Min	-20.00	-150.00	-1.00	-1.00	-1.00
	Max	20.00	150.00	1.00	1.00	1.00

Data preparation completed

Linear ("Quick") algorithm being used

Appendix 6: Prospect Theory

1 Evaluation

Following the editing phase, the decision maker is assumed to evaluate each of the edited prospects, and to choose the prospect of highest value. The overall value of an edited prospect, denoted V, is expressed in terms of two scales, π and v.

The first scale, π associates with each probability p, a decision weight $\pi(p)$, which reflects the impact of p on the over-all value of the prospect. The second scale, v, assigns to each outcome x a number $v(x)$, which reflects the subjective value of that outcome. Outcomes are defined relative to a reference point, which is the zero point of the value scale. Hence, v measures the value of deviations from that reference point, i.e., gains and loses.

In Prospect Theory, the evaluation of strictly positive and strictly negative prospects follows a different rule from which applies to the regular prospect. If outcomes of prospects are all positive, i.e., if $x, y > 0$ and $p + q = 1$, the prospect is strictly positive; otherwise, it is strictly negative. A prospect is regular if it is neither strictly positive nor strictly negative.

If$(x, p; y, q)$ is a regular prospect (i.e., either $p+q<1,\ or\ x \geq 0 \geq y$ or $x \leq 0 \leq y$), then

$$V(x, p; y, q) = \pi(p)v(x) + \pi(q)v(y) \qquad \textbf{(1)}$$

where, x, y are the expected outcome of prospects and p, q are their probabilities. For the evaluation of strictly positive and strictly negative prospects, in the editing phase, such prospects are segregated into two components: the riskless component, which is certain to be obtained or paid and the risky component, i.e., the additional gain or loss which is actually at risk.

if $p+q=1$ and either $x>y>0\ or\ x<y<0$, then

$$V(x, p; y, q) = v(y) + \pi(p)[v(x) - v(y)] \qquad \textbf{(2)}$$

That is, the value of strictly positive or strictly negative prospect equals the value of the riskless component plus the value-difference between the outcomes, multiplied by the weight associated with the more extreme outcome. For example, $V(400,\ 0.25;\ 100,\ 0.75) = V(100) + \pi(0.25)\ [v(400) - v(100)]$. The important feature of equation **(2)** is that the decision weight (π) is applied only to the value difference $v(x)$-$v(y)$, which represents the risky component of the prospect but not to $v(y)$, which represents the riskless component. Note that the right-hand side of equation **(2)** equals to the righ-hand side of equation **(1)** if $\pi(p)+\pi(1-p)=1$.

2 Value Function

The essential assumption of Prospect Theory is that the carriers of value are changes in wealth or welfare, rather than final states, i.e., the evaluation of changes or differences rather than to the evaluation of absolute magnitudes.

Therefore, value function represents the reference point, and the magnitude of the change (positive or negative) from the reference point. The difference in value between a gain of 100 and a gain of 200 appears to be greater than the difference between a gain of 1,100 and a gain of 1,200 and this also applies to the domain of loss. Thus it was hypothesized that the value function for changes of wealth is normally concave above the reference point ($v''(x) < 0$, for $x > 0$) and often convex below it ($v''(x) > 0$, for $x < 0$). That is, the marginal value of both gains and losses generally decreases with their magnitude. The preference in both of riskless context and risky context are consistent with the hypothesis that the value function is concave for gains and convex for losses.

A prominent characteristic of attitudes to changes of outcomes is that losses seem to be more important than gains to people. The loss appears to be even more greater than the gain, even associated with the same amount of money. Thus, the value function for losses is steeper than the value function for gains.

Figure1 shows the value function which satisfies these properties. The proposed S-shaped value function is steepest at the reference point.

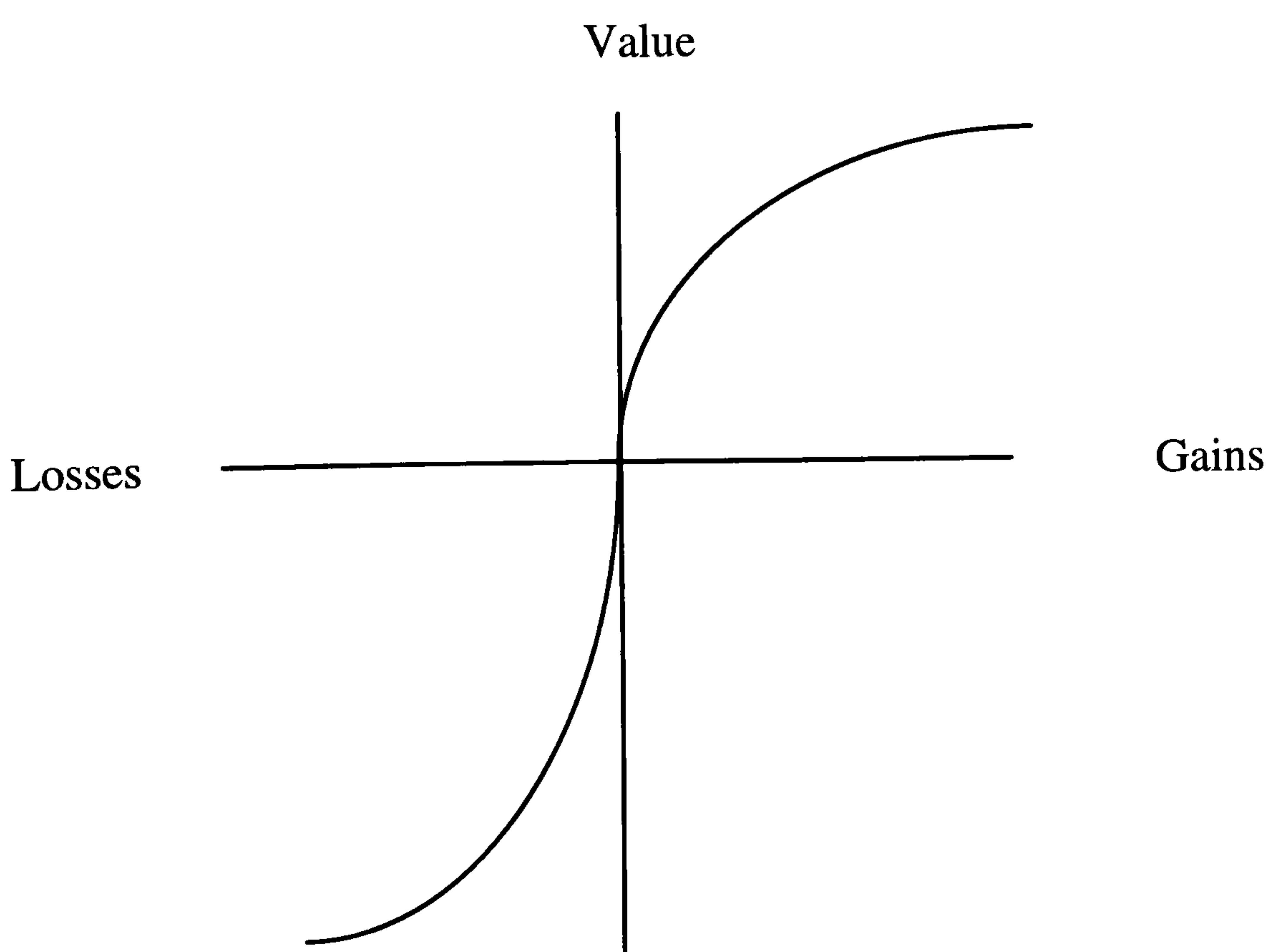


Figure1 A hypothetical value function

Even though the present theory can be applied to derive the value function from preferences between prospects, the actual scaling is considerably more complicated than in Utility Theory, because of the introduction of decision weights.

3 The Weighting Function

In Prospect Theory, the value of each outcome is multiplied by a decision weight. Decision weights (π) are inferred from choices between prospects. Decision weights(π) measure the impact of events on the desirability of prospects, and not merely the perceived likelihood of these events (i.e. probabilities).

1. The weighting function π relates decision weights to stated probabilities. π is an increasing function of p, with $\pi(0)= 0$ and $\pi(1)=1$ i.e. outcomes which depend on an impossible event are ignored, and the scale is normalized. So $\pi(p)$ is the ratio of the weight associated with the probability p to the weight associated with the certain event.

2. Most people choose the prospect that offers the larger gain, if winning is possible but not probable. For small value of p, π is a subadditive function of p, i.e., p (i.e. $p(rp) > rp(p)$ for $(0 < r < 1)$.

3. Very small probabilities are generally overweighed, that is, $\pi(p) > p$.

   Evidence shows that preferences are generally less sensitive to variations of probability than the expectation principle would dictate. This property was called "subcertainty". $\pi(p)+\pi(1-p)<1$ for $0 < p < 1$. Thus, subcertainty captures an essential element of people's attitudes to uncertain events, namely that the sum of the weights associated with complementary events is typically less than the weight associated with the certain event.

4. For a fixed ratio of probabilities, the ratio of the corresponding decision weights is closer to unity when the probabilities are low than when they are high. This property of π, called subproportionality, imposes considerable constraints on the shape of π : it holds if and only if log π is a convex function of log p. Subproportionality: $\frac{\pi(pq)}{\pi(p)} \leq \frac{\pi(pqr)}{\pi(pr)}$ for $0 < p , q, r \leq 1$

Figure 2 presents a hypothetical weighting function which satisfies overweighting and subadditivity for small values of p, as well as subcertainty and subproportionality. These properties lead to that π is relatively shallow in the open interval and changes suddenly near the end-points where $\pi(0) = 0$ and $\pi(1) = 1$. The simplification of prospects in the editing phase can lead the individual to discard events of extremely low probability and to treat events of extremely high probability as if they were certain. Because people are limited in their ability to comprehend an evaluate extreme probabilities, highly unlikely events are either ignored or overweighed, and the difference between high probability and certainty is either neglected or exaggerated.

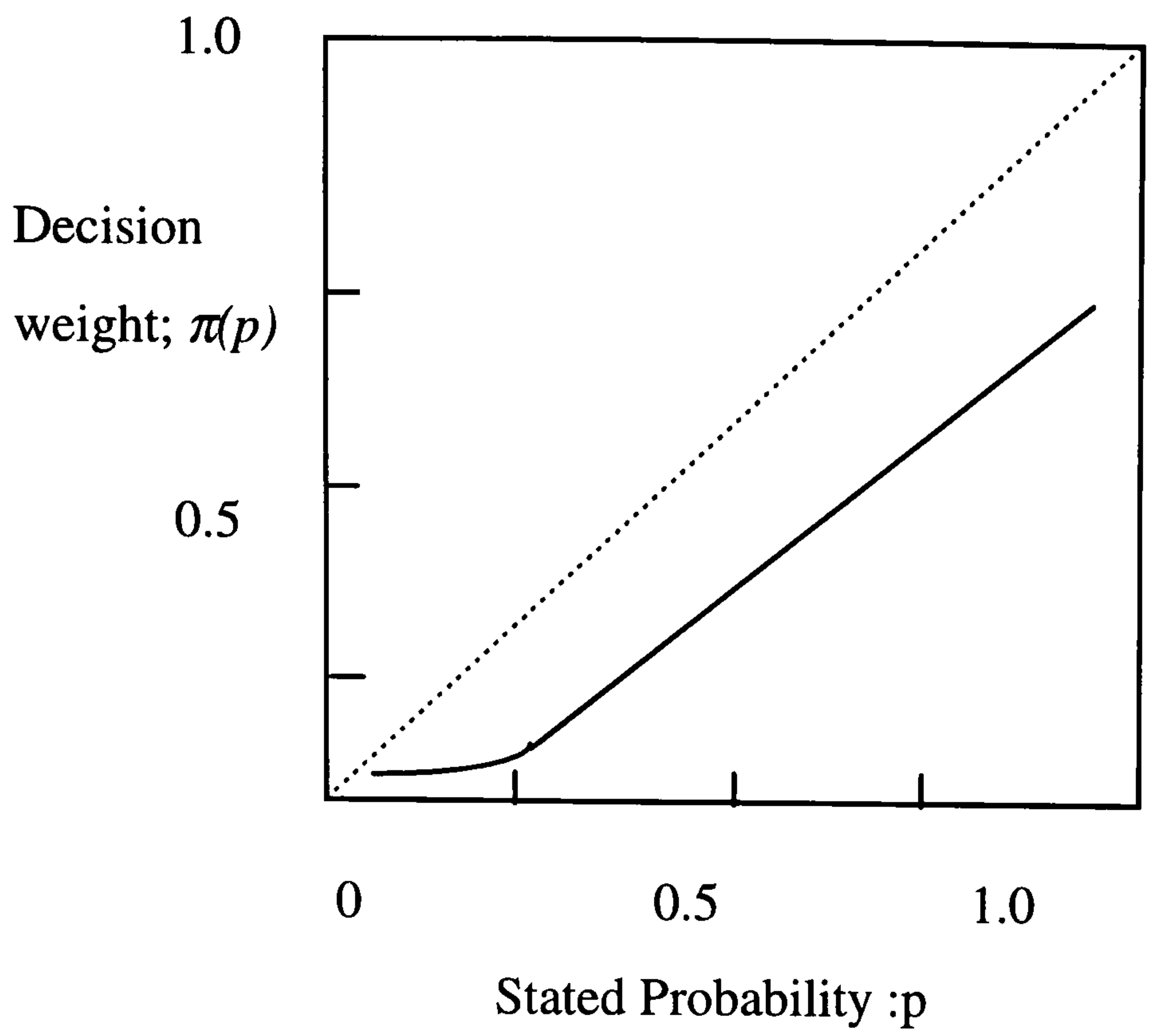


Figure 2 The Weighting Fuction

4 Summary

Prospect Theory, proposed by Kahneman and Tversky(1979), has a made a substantial contribution by offering a framework from which to understand well-documented violations of Utility Theory. While there are many similarities, Prospect Theory differs from Utility Theory in the following ways.

1. Prospect theory defines a value function which deviates from the reference point, it is generally concave for gains and convex for loss and is steeper for losses than for gains.

2. Instead of the objective probabilities used in Utility Theory, Prospect Theory introduced decision weights, $\pi(p_i)$, that reflect the impact of outcomes on the prospect's attractiveness. It was suggested that low probabilities are generally overweighed and high ones underweighed.

3. Prospect theory treats choice situations involving strictly positive or negative outcomes differently than those involving zero and /or both positive and negative. In the former case, the sure gain or loss is factored out.

4. Prospect Theory proposes an editing phase prior to the evaluation of the choice situations. Various editing operations are suggested in order to simplify choice.

5. Finally, the value function in Prospect Theory measures the subjective value of outcomes relative to some reference point that may vary as a function of problem presentation. The emphasis is on changes in wealth, not on final states as in Utility Theory.
6. To summarize the features of the value function in Prospect Theory, the value function is defined on deviations from the reference point; generally concave for gains and commonly convex for losses; and steeper for losses than for gains.