AN EVALUATION
OF THE IMPLICATIONS OF IMPOSING SPEED LIMITS ON MAJOR ROADS

by

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Abstract

The effectiveness of speed limits has been the subject of considerable debate over the years. In most cases in the past, speed limits have been changed because of a single factor (e.g. improving the safety of road traffic or saving energy). In this thesis an attempt has been made to evaluate the consequences of changing a speed limit using cost-benefit analysis which formed the principle objective of this study. The scope was confined to motorways and similar high-quality roads operating under free-flow traffic conditions where speed limits were believed to be most effective. To achieve the main goal, the effect of the speed limit on the mean speed of traffic was investigated which was the second objective of the study. The third objective was to find the effect of the speed of traffic, and especially the mean speed of traffic, on the frequency and severity of personal injury accidents. There was a need to investigate these two relationships as the literature was not consistent on these relationships.

A hypothesis was proposed to achieve the second objective. This was tested by defining criteria that had to be met for each of the data collection sites and measuring the speed of vehicles. There were 11 sites in Tyne & Wear, England and 14 sites in the State of Bahrain. A statistical analysis was applied to the data collected. It was found, from both sets of data, that speed limits had a positive effect on the mean speed and the eighty-fifth percentile speed of traffic. Linear and non-linear (multiplicative) models were developed for each set of data. In addition to the speed limit, the trip length and the length of the section were shown to affect significantly the mean speed of traffic. The amount of change in the mean speed of traffic varied between the models tested but, generally, for every 4 to 5 km/h change in the speed limit the mean speed of traffic changed by, about, 1 km/h.

In a similar way, a hypothesis was proposed to pursue the third objective. Criteria were established for the selection of suitable data collection sites and for the types of accidents. 9 sites were selected in Tyne & Wear and 10 sites in the State of Bahrain. Data was drawn from a 5 year set of accident records in Tyne and Wear and a four year set in the State of Bahrain. A statistical analysis was applied to the data. The set of data from Tyne & Wear revealed no significant relationship between the mean speed of traffic and the frequency of accidents but the speed differentials affected the frequency of the personal injury accidents. The data from Bahrain showed that both the mean speed of traffic and the speed differentials of vehicles affected the frequency of the personal injury accidents. No significant relationships were found between the speed of vehicles and the severity of the personal injury accidents.

The principle objective of the study was achieved by applying cost-benefit analysis to the consequences of changing the speed limit for a hypothetical typical section of road. The components of cost were the cost of travel-time, the vehicle operating cost, and the cost of accidents. No monetary values were assigned to the environmental effects so it was not possible to include them in the cost-benefit analysis but they were acknowledged. Any changes in air pollution and noise annoyance due to a change in the mean speed of traffic following a change in a speed limit were likely to be small and were not considered in the study. The significance of the uncertainty in the frequency and severity of personal injury accidents in relation to the mean speed of traffic was studied using 'break-even analysis'. Generally, it was believed that lowering the speed limit on motorways and similar high-quality roads would produce negative benefits, even if the frequency and severity of personal injury accidents decreased within expected ranges. Increasing the speed limits would produce positive economic benefits but the conclusion was less firm than the previous case. Sensitivity analysis was applied to the variables used in the cost-benefit analysis. It was found that the net benefits were most sensitive to the estimation of the effect of the speed limits on the mean speed of traffic, the initial mean speed of traffic in the base year of the assessment, the travel-time cost, the changes in the frequency of the personal injury accidents, and changes in the number of fatal injury casualties per average personal injury accident as the speed limit varied (i.e. in descending order for most speed limits). The ranking of these variables differed as the speed limit was changed.

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To
My Wife
&
Fajer,
Noor,
&
Duha

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Chapter One

Introduction

1.1 Background

Speed limits were first introduced to improve safety on roads by restricting the excessive speed of vehicles which was thought to be the main cause of accidents (Harkey et al., 1990). Since that time, in most parts of the world, traffic safety has been the dominating factor in determining posted speed limits on roads (Department of Transport, 1967), (Newby, 1970), (Cooper, 1972), (Lenz, 1975), (Egede Larssen, 1975). During the energy crisis which started in late 1973, the speed limit was used as a means to reduce the speed of traffic in order to cut down the fuel consumption of vehicles (Salter, 1974), (Fiander, 1974).

There are two types of speed limits. The first type is known as a 'reasonable' speed limit, where the drivers decide an appropriate speed according to the road conditions. The second type is the 'absolute' speed limit (i.e. the speed limit considered in this study), where drivers are restricted to an absolute speed limit. There might be different speed limits according to the environment, type of vehicles and the lighting conditions. Also, there are maximum and minimum speed limits on some roads (O'Flaherty, 1986), (Spitz, 1984), (Fiander, 1974).

1.2 The Problem Statement

If a posted speed limit was to be changed, the assumption would be that the main consequence would be a variation in the speed of road traffic which would lead to changes in other factors related to that variation in speed. These changes would vary in their absolute amount and direction. It would be difficult to evaluate the overall changes in this situation as each element of the change would be in different units. If these different types of change were converted to a common unit or a uniform scale (i.e. monetary values), the comparison could be more objective and the relative importance of each component could be revealed. This concept has been discussed in similar studies (European Conference of Ministers of Transport, 1977). The consequences associated with changing speed limits could be expected changes in: the speed of traffic, the frequency and severity of accidents, the travel time of road users, the fuel consumption of vehicles, the non-fuel element of vehicle operating cost , the emitted pollutants of vehicles, the noise produced by vehicles, the ease of driving, the restriction of drivers freedom, and the motor industry.

1.3 The Anticipated Consequences of Changing Speed Limits

If speed limits were changed, the following most important consequences would be anticipated:

(i) Speed of Traffic

As mentioned above, a change in the speed of traffic would be likely to be the main consequence of changing the speed limit; all other related effects would be associated to that change in the speed of traffic.

(ii) Safety of Road Traffic

One of the major effects of changes in the speed of traffic is road safety and, therefore, the most related consequence to the imposition of speed limits. Road safety forms a major element in road traffic cost.

(iii) Travel Time

The travel time cost is another principle component of road traffic cost (Hall et al., 1970) and is directly related to changes in the speed of traffic and speed limits.

(iv) Vehicle Operating Cost (VOC)

VOC is another vital element of road traffic cost. It consists of a fuel and a non-fuel element. Its relationship, especially the fuel element, with speed limits and the speed of traffic was a major issue during and after the energy crisis in 1973.

(v) Vehicle Emission Pollutants

A pollutant is defined as "a material which is present at a level higher than is normally found" (Case, 1982) so water vapour (H_2O) and carbon dioxide (CO_2), which are the main product of emissions, are not considered to be pollutants because they are not poisonous and are present in the atmosphere but a pollutant like carbon dioxide could degrade the atmosphere due to the time taken for its physical or chemical removal from the atmosphere which contributes to the "green house" effect (Department of Transport U.K., 1993b). Evaporation losses from the fuel tank and carburettor, dust from rubber tyre wear, brake-linings and clutch-plates, and losses from the crank case accounted for a significant proportion of hydrocarbons (HC) which are emitted from motor vehicles. In the internal combustion engine, if oxidation was completed, only carbon dioxide would be produced which is not considered to be a pollutant. Actually, oxidation is never completed and, therefore, organic compounds are produced. Petrol contains 'Anti-Knock' agents which contain lead and lead compounds like oxides of nitrogen (NO_x) which are formed in the engine. Exhaust gas consists of: carbon dioxide, water vapour and unburnt petrol which are not considered to be pollutants, and organic compounds produced from petrol, carbon monoxide (CO), oxides of nitrogen, lead compounds, and carbon particles (smoke,soot) which are considered to be pollutants. Some of these products might react together to form secondary effects (e.g. in Los Angeles: the oxides of nitrogen and the hydrocarbons reacted with bright sunlight and the special topography to form what was known as "Smog"- i.e. a combination of fog and smoke). Diesel engines have a lower concentration of pollutants than petrol engines (Hickman and Colwill, 1982).

It is difficult to distinguish between the effects of air pollution from different sources but, generally, it is believed that road traffic was responsible for 90 per cent of carbon monoxide, 46 per cent of the hydrocarbons, 51 per cent of the oxides of nitrogen and an added 19 per cent of carbon dioxide in the atmosphere (Department of Transport U.K., 1993b) but air pollution from road traffic has, mainly, a temporary effect on road-users and tunnel ventilation systems (Hickman et al., 1982).

It was reported that the lead and carbon monoxide levels were not at a dangerous level but recommended that it should not increase (Department of the Environment U.K., 1974),(Dockerty and Bayley, 1970) but the carbon monoxide levels could have affected drivers who had some disabilities (Sherwood and Bowers, 1970).

As the speed of the traffic increases the emission rate, carbon monoxide and hydrocarbons would decrease (i.e. more emissions happen when the engine is idling) where other pollutant concentrations would increase (see Figure 1.1). Concentrations of most emissions reduce within 100 metres of the road (Colwill and Hickman, 1981),(Colwill et al., 1985), (Joyce et al., 1975), (Colwill, 1980), (Joumard, 1990). The rate of emissions of road traffic pollutants depend on several factors such as: traffic volume, traffic speed, traffic composition and engine mode (Hickman and Colwill, 1982).

The air pollution caused by road traffic could be reduced by several methods such as: engine modifications (e.g smaller engines & vehicles), reduction of pollutants in exhaust gases, reduction of evaporative losses, reduction of smoke, use of alternative fuels, use of alternative methods of propulsion (e.g. electrically propelled vehicle), tougher directives, and by improving traffic flow (Hickman and Colwill, 1982).

Models have been developed to predict the pollutants emitted by road traffic such as:

(i) **Pollution Concentration from Road Traffic** (TRRL Method) (Hickman and Colwill, 1982), (Hickman et al., 1979)

The method was based on a theory explained by a differential equation based on Gaussian-type dispersion which depended on the following variables: time, position of receptor relative to source (in three-dimension), wind speed components (in three dimensions), coefficients of turbulent diffusions, contribution from different types of vehicles and changes caused by chemical reactions. A more simplified equation has been produced where more variables were assumed to be independent of each other. The pollutant concentration in the new form was of exponential form depending, primarily, on the emission rate of vehicles. Formulae have been developed to estimate the variables mentioned above.

For the sake of simplicity, it was assumed that petrol-engines and diesel-engines emitted the same amount of carbon monoxide (i.e. diesel-engines emitted less gaseous pollutants than petrol-engines) and the speed of vehicles represented the mode of the engine;

(ii) **graphical screening method**: which was used to locate sites which needed more attention and study (Waterfield and Hickman, 1982). Carbon monoxide is a good indicator to other pollutant concentrations like lead, the oxides of nitrogen and hydrocarbons (e.g. methane, polynuclear) which could be predicted using conversion equations (Hickman and Waterfield, 1984). It was recommended by the developer of this method to use the model in comparative cases because of their approximation;

(iii) **prediction of the lead level emitted by vehicles based on empirical data** (Colwill and Hickman, 1981); and

(iv) **other models** were developed in U.S.A. like AIRPOL-4 (developed by Virginia Highway & Transportation Research Council), CALAIR (developed by California Division of Highways), and HIWAY (U.S. Environmental Protection Agency Models)

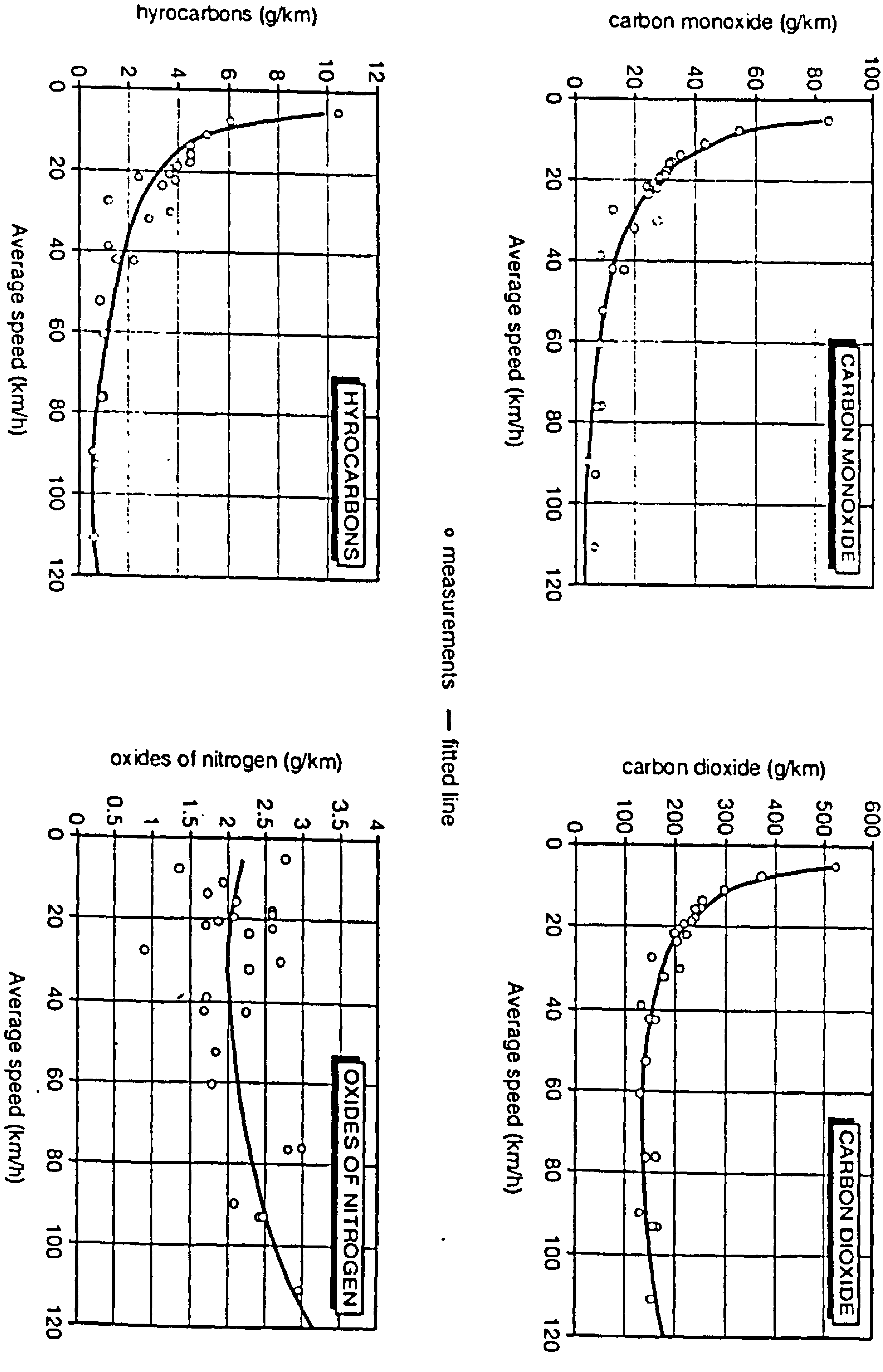
(Carpenter and Clemena, 1976). The examination of these models revealed that the most suitable one of them was the CALAIR. The current versions of these models were not available. The models were of a sophisticated nature serving the purpose of predicting the exact absolute concentration of air pollution in a specific area.

It was difficult to include the effect of air pollution caused by road traffic in any cost-benefit evaluation without the assignment of appropriate monetary values (Colwill, 1980),(Colwill and Hickman, 1981),(Margason and Corcoran, 1978). The attempts to associate a monetary value to the subjective opinions of people failed in producing consistent relationships (Roseman, 1978).

As illustrated, pollutants emitted by road traffic can be quantified and predicted, with reasonable accuracy. As it can been seen from Figure 1.1, not all pollutants increased with the increase in the speed of road traffic which suggested there were counter effects of pollutants emitted when the mean speed of traffic was changed. Also, there were, relatively, small changes in the emitted pollutants of vehicles corresponding to changes in the speed of road traffic at 'high' speeds (e.g. 100 km/h) which was within the scope of this study. So the overall change in the emitted pollutants of road traffic would not be expected to be significant if the speed limit was changed. Until now, no reliable monetary values have been assigned to the cost of these pollutants.

Figure 1.1: Speed-Related Emission Factors for CO, CO_2,NO_x, and HC

Source: Department of Transport U.K. (1993b)



(vi) Traffic Noise

The factors that affect the noise levels on roads are: traffic volume, traffic composition, distance from kerbside to centre of flow, traffic speed (Mackie and Griffin, 1977), (Joyce et al., 1975), (Nelson and Piner, 1977), and the meteorological conditions (Nelson and Godfrey, 1974).

The source of the noise coming from vehicles differs according to the vehicle type and the speed of the vehicle. At high speeds, the noise by tyres, especially, from heavy vehicles, was the predominant source of noise. Tyre noise depended on vehicle speed and the gear which was engaged, the tyre tread pattern, the road surface texture and the weather conditions (Underwood, 1973), (Harland, 1970). During non-free-flow the predominant source of noise would be the engine, the exhaust system, and the transmission (Department of Transport U.K., 1993b). The condition of the vehicle, whether it is accelerating or going steady, affects the noise generated (Harland, 1970). The orientation of buildings affects noise propagation (Bullen and Frick, 1979).

Usually, the noise level is measured in decibels, dB(A), units which is a dimensional unit derived from the logarithm of the ratio of the pressure fluctuations due to the passage of sound wave and a small reference pressure 2×10^{-5} Pascals (Department of Transport U.K., 1993b). Usually, the traffic noise index is expressed by L_{10}(i.e. the level of noise exceeded for 10 per cent of the time) (Hothersall and Salter, 1977).

The noise level increases with an increase in the speed of traffic (Salter, 1985) (see Figure 1.2 and Table 1.1). The correction of noise level for the mean speed of traffic is:

$$C_1 = 33\log(V+40+\frac{500}{V}) + 10\log(1+\frac{5p}{V}) - 68.8\ dB(A)$$

C_1= correction of mean speed;

V= mean speed of traffic (km/h); and

p= percentage of heavy vehicles.

(Department of Environment U.K., 1975)

Figure 1.2: Correction for the Noise Level for Mean Traffic Speed and Heavy Vehicle Content

Source: Salter (1985)

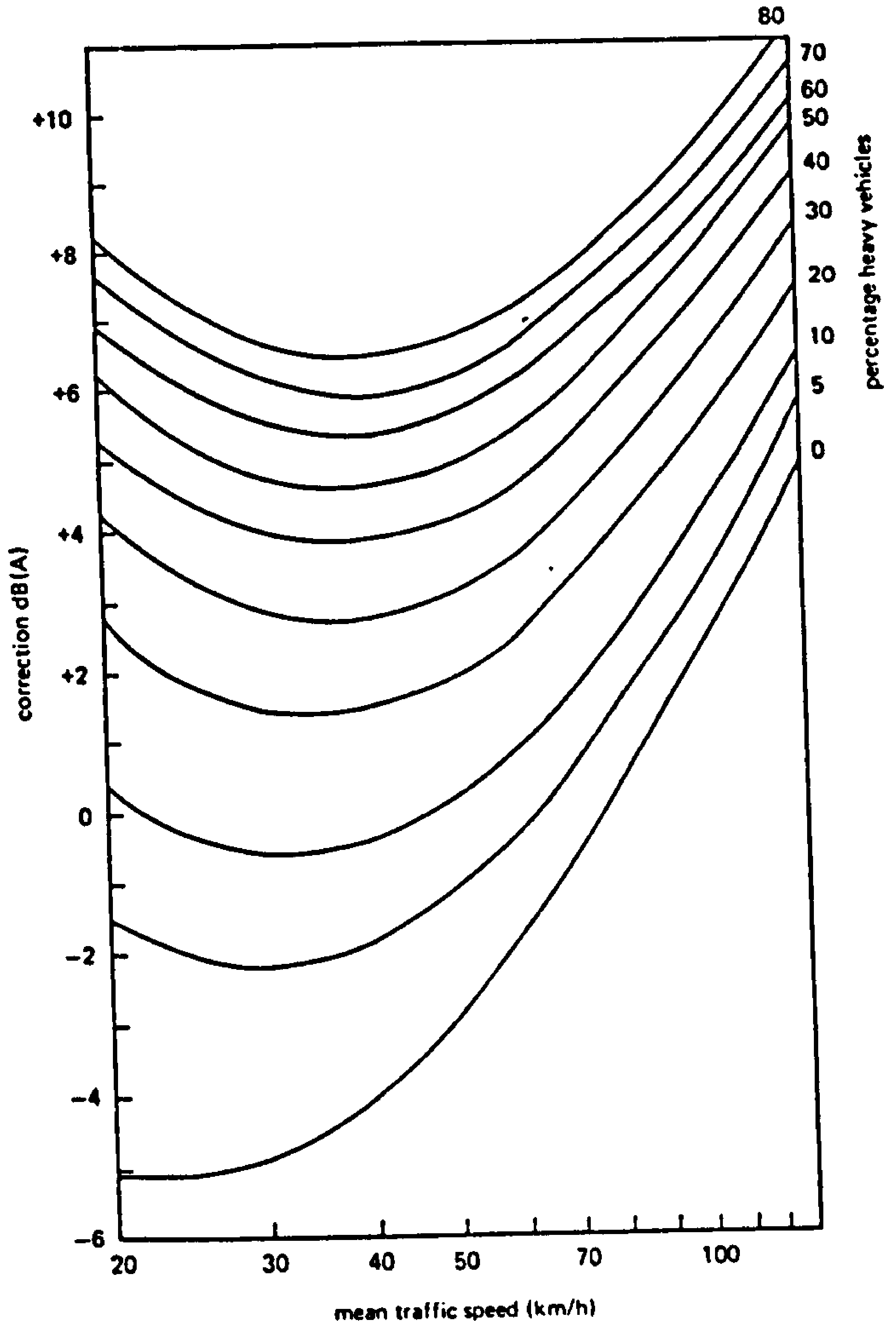


Table 1.1: Noise Level Corrections for Different Mean Speeds of Traffic *

Speed (km/h)	Noise level correction dB(A)
80	3.81
90	4.57
100	5.31
110	6.04
120	6.73
130	7.41

* heavy vehicle content was assumed to be 18% (national average for motorways) (Department of Transport U.K., 1993a)

After examining several noise prediction models such as the DoE (Department of Environment U.K.), Burgess (Uni. of N.S.W., Australia), DPH (Department of Public Health, South Australia), Delany (National Physics Laboratory, U.K.), Ontario (Ministry of Transportation and Communication, Ontario), and NSBR (National Swedish Building Research), it was found that the DoE method was the most suitable in terms of prediction accuracy and practicality (Brown, 1978).

Double glazed windows and the construction of barriers are used as a means of reducing the effect of vehicle noise in residential places. A combination of both solutions were found to be slightly cheaper (Davies and Dawson, 1980). The noise could be lowered by enforcing stricter noise emission standards for the vehicles and, at the same time, planning houses and roads in a way to minimise the effect of the noise (Nelson, 1980) and/or by diverting the heavy vehicles to routes further away from the public (Bauchan, 1980). In Belgium, porous asphalt surfaces have been used to decrease the level of noise emitted by vehicles on wet roads (Permanent International Association of Road Congress, 1987).

It was found that it was hard to put monetary values on the nuisance caused by traffic noise which makes any cost-benefit analysis much more difficult (Watkins, 1980). When the TRL Environmental Simulator was used to help 70 subjects to evaluate 'before' and 'after' cases, the subjects were not able to put consistent monetary values on the disturbance encountered (Roseman, 1980). There have been attempts to use more than one method to assess the monetary value of noise (Silvani, 1979). It was suggested that the method might be used nationally, but the monetary values could be a reflection of the local situation. Other methods have been tried to evaluate the monetary valuation of noise (Plowden and Sinnott, 1977) such as: putting machines that emitted noise in houses and evaluating the amount of money that made this arrangement acceptable to the residents, insulating the house, or receiving a cash compensation. The responses differed widely.

Many models have been developed to predict the noise caused by road traffic. If the speed limit was to be changed, the noise of road traffic would alter. Due to the logarithmic nature of noise indices, small changes would be expected at 'high' speeds, as was the case in air pollution models and as was illustrated in Figure 1.2 and Table 1.1. No successful research has been conducted in evaluating the monetary values of noise nuisance. For this reason the consequent effect of noise when a speed limit was changed could not be included in the cost-benefit analysis.

(vii) Effects on Employment in the Motor Vehicle Industry

The motor vehicle industry could be affected by lowering speed limits in two ways: firstly, certain models of cars were bought, only, for their ability of achieving 'very' high speeds on roads. If a speed limit was imposed or lowered, the demand for that type of car would drop. This argument was opposed by what happened in U.S.A., when a fifty-five mile/h speed limit was imposed. The motor industry concentrated their advertising on aspects of the vehicles other than their speed so their sales were not affected very much. Secondly, lower speed limits might lead to less wear and tear, safer roads, and, therefore, fewer repairs and fewer replacement of vehicles. The moral standards would rule out such argument (i.e. exposing road users to higher safety risks for the sake of higher profits in motor industry) (European Conference of Ministers of Transport, 1977).

The uncertainty in the effect of changing speed limits on the motor vehicle industry prevented it from being included in the final evaluation.

(viii) Effects on Ease of Driving

Driver stress is defined as "the adverse mental and physiological effects experienced by a driver traversing a road network". Frustration is a component of driver stress (Department of Transport U.K., 1993b). If speed limits were imposed or lowered, the effect on the ease of driving could be anticipated for two reasons:

(a) a reduction in the stress of 'reasonable' drivers overtaken by the 'very' fast drivers; and

(b) it would make the judgement of gaps and headways easier and more accurate (European Conference of Ministers of Transport, 1977). On the other hand the ease of driving could be affected differently by generating frustration in the driver by restricting his/her choice of the desired speed (Department of Transport U.K., 1993b). The ease of driving has not, yet, been understood thoroughly. It was hard to include this consequence in the final assessment.

(ix) Restrictions of Personal Freedom

It would be most likely that the personal choice of road users would be restricted if the speed limit was imposed or lowered but, again, it is, well, accepted in liberal societies that the principle that the freedom of the individual must stop where it interfere with other people's interests (European Conference of Ministers of Transport, 1977).

Such an effect would be difficult to quantify and measure, not the least, assign monetary value to it.

1.4 Objective and Scope

As discussed previously, in most cases, the decision for imposing the speed limit depended on a single factor. There is a need to conduct a comprehensive study which takes into consideration most of the significant consequences of imposing speed limits. The consequences should be brought to a common base in order to be able to evaluate them objectively. The effect of changes in the speed limit on the mean speed of traffic and the frequency and severity of personal injury accidents needed more investigation as the conclusions of the literature was not consistent. This formed the basis of the thesis.

The first objective of this study was to assess the economic consequences of changing posted speed limits on roads using cost-benefit analysis (discussed in Chapter Four, Five, and Six). Only the consequences that could be quantified and assigned a monetary value would be considered. The relationships established between the various components of total cost and the mean speed of traffic and their monetary values both of which are published by the Department of Transport have been used in this study. To achieve the main objective (i.e. the first objective), the relationship between speed limits and the speed of traffic was reviewed and investigated, which was the second objective of this study (discussed in Chapter Two). The third objective was to review and test the relationship between the speed of road traffic and the frequency and severity of personal injury accidents (discussed in Chapter Three). The scope of the study will be confined to the links and times of the day when the speed limit was likely to be most effective: for example high quality links (i.e. sections of roads free from geometric elements that might influence the speed of traffic) and during free-flow traffic conditions.

1.5 A Brief on the Proposed Methodology

The effectiveness and the implications of the introduction of speed limits have been contested since speed limits were first introduced (Indiana University, 1970). To establish the consequences of changing speed limits, the relationship between speed limits and the speed of traffic had to be explored which formed one of the objectives of this study. A methodology was suggested which set criteria for selecting the location, the time, the level of traffic flow, the condition of the environment and, also, the analysis method. Similar data was collected in Tyne & Wear, England and the State of Bahrain to compare the results from different countries and cultures. A major aspect of the study was to investigate the effect of speed limits and the speed of road traffic on road accidents. In many cases the sole reason for imposing or changing speed limits was safety. Even though, safety is one of the major implications for changing speed limits and, at the same time, the most emotive as far as the public are concerned, the literature on this affiliation was not conclusive (Leeming, 1969), (Munden, 1966), (Johnson et al., 1981). More research was needed in this field which was the third goal of the study. A plan was suggested to examine the affiliation between the speed of traffic and road traffic accidents. Criteria were established to select accident data relating to a prescribed link classification that fulfilled the main objective and scope of the study. A method of analysis was proposed to explore the relationship between the speed of traffic and the frequency and severity of personal injury accidents . The data were collected from Tyne & Wear and the State of Bahrain to compare the two trends. Other significant characteristics that would be affected by the change in the speed of traffic were reviewed such as: travel time and the operating costs of vehicles. The link between these components and the speed of traffic were well established in the literature (Department of Transport U.K., 1982). Other consequences that could not be quantified and/or evaluated in monetary terms were acknowledged but were not included in the final economic assessment. An economic assessment was designed using the cost-benefit analysis method and the relationships and the official values published by The Department of Transport U.K. which was the main objective of the study. An economic appraisal of the changes in speed limits was carried out to determine the present value of the net benefits of such changes. The sensitivity analysis technique was used to evaluate the sensitivity of the net present value of the total cost and the net benefits derived from changing the speed limit to the following variables and assumptions used in the cost-benefit analysis: the components of the total cost, the effect of the speed limits on the mean speed of traffic, the discount rate value, the initial daily traffic flow in the base year, the initial mean speed of traffic in the base year, the growth of traffic, the growth of the speed of traffic, the growth of traffic flow with a corresponding assumed reduction in the speed of traffic, the frequency of personal injury accidents, the severity of personal injury accidents, the economic growth, and traffic composition. The sensitivity ratio for each of these variables was determined in order to be able to compare their effects. The uncertainty of accident benefits was dealt with within the net benefit analysis using 'break-even' analysis.

1.6 The Thesis Layout

The thesis structure follows a logical track which satisfies the main objective of the study. The second chapter discusses the second objective of the study which was the effect of the speed limit on the speed of traffic, describes the methodology that was carried out to test the effect, and presents the results obtained. The third chapter examines the relationship between the speed of traffic and the frequency and severity of accidents by analysing the data collected from the sites, which formed the third objective of the study. The fourth chapter reviews the cost-benefit analysis method using the method adopted by The Department of Transport U.K. The fifth chapter illustrates the total and the elemental costs of road traffic operation at different mean speeds and the net benefit of the total and elemental costs resulting from changes in the mean speed of traffic relating to the base case. The net present value of the benefits that would follow changes in speed limits was determined (which was the principle objective of this study). The possible effect of the uncertainty of the cost of accidents on the net present value of the net benefits was explored. The sixth chapter examines the sensitivity of the net present value of the total cost and the net benefits at various speed limits to each of the components of the total cost, other variables that were used in the calculation, and the assumptions used in determining the economics of changing speed limits. The final chapter summarises the overall findings, and states conclusions and recommendations.

Chapter Two

The Effect of Speed Limits on the Speed of Traffic

2.1 Introduction

Speed limits were first introduced as a safety measure when it was realised that excessive speeds could be a source of accidents on roads (Harkey et al.,1990). The level of success of this measure has been debated since that time, as there were many different opinions on this matter. Some researchers claimed that speed limits had no effect on the speed of vehicles which implied, that they had no effect on the accident rate, whereas others claimed quite the opposite view (Indiana University, 1970). These widely differing views suggested the need for research which forms the main objective of this study. This chapter investigates the relationship, if any, between speed limits imposed on highway links with a high level of service and either the mean speed of traffic or the eighty-fifth percentile speed of traffic. A hypothesis was formulated. A methodology was proposed to test this hypothesis and was applied in the County of Tyne & Wear, England, and the State of Bahrain.

There appears to be clear evidence that speed limits affect the speed of traffic on such road links, even though the influence is not great. The results of this part of the study have been used as part of the input data to the final economic assessment model.

2.2 Literature Review

2.2.1 Speed Limits: A Historical Background

Newby (1970) reported that since 1930 the average speed of motor vehicles in the United Kingdom (U.K.) decreased every time a speed limit was imposed on an unrestricted highway or the speed limit was lowered. When a speed limit of 70 mile/h was imposed on motorways and all-purpose roads in December 1965, the mean speed of the vehicles dropped slightly (i.e. between 1 to 3 mile/h) and the number of drivers exceeding 70 mile/h reduced from 30 per cent to 10 per cent (Department of Transport U.K., 1967). During the energy crisis in 1973/74, the maximum speed limit was reduced from 70 mile/h to 50 mile/h. The mean speed of traffic dropped by 10 mile/h (Salter, 1974); other reports reinforced this observation (Duncan et al., 1977, Eaton and Burrow, 1975, and Webb, 1980). Jarvis (1983) and Summers (1985) noticed that advisory signs were effective in reducing the speed of traffic within maintenance zones. It was revealed by Lee and Forni (1991) that the mean speed of traffic, observed at different locations under free flow conditions, reduced as the speed limits decreased, even though there were no significant relationships found between the two variables. In a recent study by Finch et al. (1994), they found, after reviewing some cases of imposing speed limits in different countries, that the change in mean speed of traffic was, roughly, a quarter of the change in the speed limit. In Ireland, the mean speed of traffic always dropped when different national maximum speed limits were introduced on the road network (Newby, 1970). The first maximum speed limit to be imposed on a road network was in 1901 in the United States of America (U.S.A). More recently, the maximum speed limit was reduced to 55 mile/h throughout the USA due to the energy crisis in 1973. The mean speed of vehicles together with the eighty-fifth percentile speed decreased but remained higher than the speed limit that was imposed. However the speed distribution of the traffic had more uniform shape (ITE Metropolitan Section of New York and New Jersey, 1977), (ITE Technical Council Committee 4M-2, 1977), (ITE, 1987), (Fiander, 1974). The effect of the change in the speed limit tended to erode as public concern for the energy crisis faded (Meddleton and Kenyon, 1981). In 1987, the Maximum National Speed Limit (MNSL) was raised from 55 mile/h to 65 mile/h. Some states adopted the new speed limit on all the routes, some others imposed it on a number of selective routes, whereas the rest of the states did not change the speed limit. The mean speed of traffic increased (i.e. by about 3 per cent), the eighty-fifth percentile speed increased and the violations of the speed limit, surprisingly increased as well. This increase was observed in the states that raised the speed limit on all the routes and also in the states that raised it on selective routes only. No significant change was observed in the speed of traffic on the routes of the states that did not raise the speed limit (McKnight and Klein, 1990), (Hall and Pendleton, 1990), (McKnight et. al, 1989).

In a study to evaluate the speed zoning criteria (Harkey et al., 1990), it was observed that the mean speed and the eighty-fifth percentile speed of the traffic tended to increase as speed limits increased and, in most cases, were higher than the speed limits. An experiment was conducted in California to find the effect of the speed limits on drivers' behaviour. Speed limits were increased at some sites, lowered at some others, and the rest were kept unchanged as control sites (Spitz, 1984). It was concluded that there was no significant evidence that the speed of traffic was influenced by the change in the speed limit and that drivers would choose their speed according to their perception of the environment around them. This view was shared by Garber and Gadiraju (1991) who added that the difference between the speed limit and the design speed of the road affected the variance of speed. Others suggest that the speed limits were observed more on rural roads than urban roads (Ogawa et al., 1962). In Austria, an observation was carried out to measure the variations in the speed of vehicles entering a speed limit zone travelling from an unrestricted zone. It was noticed that the drivers reduced their speeds as they were entering the speed limit zone (Bhalla et al. ,1970). The Traffic Safety Committee (1965) in Sweden found that the speed limits had an effect on the mean speed of traffic. Newly et al. (1986) concluded that, generally in Europe, the speed of vehicles increased as the speed limits were raised. The same conclusion was reported by most of the European countries (OECD, 1972). In Australia, Thompson and Fry (1980) carried out a survey of the speed of vehicles on rural and urban roads. They observed that the mean speed of vehicles was not related to the speed limits. In most countries, it was found that the speed of the vehicles always decreased when speed limits were imposed (O'Flaherty, 1986).

2.2.2 Speed Limit Criteria

There are two types of speed limit. The first type can be considered to be a 'reasonable' speed limit, where the drivers decide the appropriate speed according to the road conditions. The second type is an 'absolute ' speed limit, where drivers are restricted to a numerical speed limit. There might be different speed limits according to the environment, the type of vehicles and the lighting conditions. There are maximum and minimum speed limits on some roads (O'Flaherty, 1986). Usually, the eighty-fifth percentile speed has been taken to be the main guideline for selecting the level of a speed limit (Spitz, 1984), (Indiana University, 1970) providing it has not exceeded the design speed of the road (ITE, 1987). Other criteria have been used to determine the speed limit such as the 10 mile/h pace, the average test run speed, the accident experience, the roadway characteristics and the roadside development (Fiander, 1974). It was concluded that the selection of the speed limit had to be chosen at a realistic level in order not to lose the respect of drivers for traffic signs.

This conclusion was supported by another study (McGee et al., 1988). Other criteria have been suggested such as the cost function method which was developed by Oppenlander who defined the 'suitable' speed limit to be the one which produced the least total cost and Taylor's theory of speed distribution skewness which defined the most suitable speed limit to be the one which produced the least skewness in the speed distribution and the least accident rate. Both these two approaches would need more research before adopting them was considered (Indiana University, 1970).

2.2.3 Factors Affecting the Speed of Traffic

There are many factors which affect the operating speed of vehicles on roads such as; the geometric features of the road (i.e. horizontal and vertical alignment), the lane width, the shoulder width (McLean, 1981), the uniformity of the standard of the link, the weather, the road surface, the functional classification of the road, the number of lanes, the lane position, the median type, the access control, the design speed of the road, the pedestrian activity, the land use activities, the trip purpose, the trip distance, the trip destination, the sex of the driver, the passengers, the arrival time, the frequency of road use, the traffic flow, the density of traffic (Cremer and Fleischmann, 1987), (Cremer, 1978), the vehicle type, the age of the vehicle, the light conditions, and the day of the week (Jackson and Morton, 1991), (Shepperd, 1971), (Galin, 1981), (O'Flaherty and Coombe, 1971), (Ackroyd and Bettison, 1970), (Mclean, 1980), (Indiana University, 1970). The perception of the drivers of the safety level (Hauer, 1970), the economics of travelling, and the capacity of the link (Tebly, 1978) affected their choice of speed.

2.2.4 The Drivers Appreciation of Speed Limits

It was revealed that the position of the sign posts affected the driver's knowledge of the speed limit (Hogg, 1977). Drivers were in favour of the speed limit (O'Flaherty, 1986) despite this fact but they were not satisfied with the existing restrictions. It was noticed, also, that the degree of violations was relevant to the level of the speed limit. Other surveys showed that drivers thought the speed limit was only a guideline (Mostyn and Shepperd, 1980), most of them knew the speed limit on the road they were travelling on (Cameron, 1980), and less than half of them knew the speed limit on other fast main roads (Department of Transport U.K., 1967).

2.2.5 Speed Limit Enforcement

Police presence has been shown to reduce the speed of vehicles for a distance of up to five kilometres beyond the observation point (Armour, 1984a) (Muden, 1966) which reduced the number speed of violaters by 70 per cent with the reduction lasting for up to a two day period (Armour, 1984b). A safety poster has been used to reduce the speed of vehicles at some locations on roads. A 'before' and 'after' study of the speed of vehicles at those sites revealed that there was no significant overall effect on the speeds, even though speeds reduced at some sites (Department of Transport U.K., 1992). The same conclusion was produced by Jarvis and Hoban (1988) who suggested that speed limits based on rational decisions were more likely to be observed by drivers and to be enforced by the police. Another means of enforcing speed limits was the 'self-policing' method which consisted of introducing rumble bars, bar markings (i.e. which alert drivers to the change in roads conditions), and road humps (i.e. which force vehicles to reduce their speed). Fiander (1974) suggested that a high level of speed enforcement was needed for speed limits to be effective.

2.3 The Hypothesis

If the speed limit had an effect on the speed of vehicles, this effect would vary depending on the traffic, environment, and geometric conditions on the roads. It was perceived that if these conditions could be controlled the speed of vehicles would reflect the effect of the speed limit. Further, if the speed of vehicles was observed under prescribed conditions on similar sections of different roads with different speed limits, the variations in the speed of traffic, if there were any, could be assumed to be due to the effect of the speed limit. A model could be constructed that would be able to predict the effect of speed limits on the speed of traffic. A methodology was proposed and was carried out to test this hypothesis.

2.4 Criteria Set for Selecting Data Collection Sites

The following criteria needed to be fulfilled in order to collect speed data that would enable the hypothesis to be tested. The criteria of selection served two purposes:

(i) to minimise (or eliminate) the influence of conditions other than the speed limit on the speed of the vehicles; and

(ii) to select sections of different roads of similar characteristics (i.e. to have consistency in the site characteristics).

2.4.1 Geometric Alignment

Lee and Forni (1991) found that the bendiness and the junctions were among the most significant variables that affected the speed of vehicles. These variables were avoided in the sites that were chosen. The sites had the following characteristics:

(i) horizontal curves of less than four degrees to decrease the effect of the horizontal alignment on the speed of vehicles;

(ii) gradients less than 3 per cent to diminish the effect of the vertical alignment on the speed of vehicles;

(iii) no at-grade intersections such as restricted access, to prevent the effect of crossing and/or merging traffic on the speed of vehicles;

(iv) reasonable length of section (i.e. more than 1.5 km so the vehicles could attain their desired speed);

(v) observation points at locations where vehicles had reached a stable operating speed away from acceleration, deceleration ,merging or diverging traffic zones;

(vi) dual-carriageways with more than one lane in each direction so vehicles would have freedom to manoeuvre;

(vii) good pavement surface conditions;

(viii) no bus-stops or pedestrian crossings; and

(ix) low land use activity to minimise the influence of the environment

(see Figures 2.1a and 2.1b and Appendix I: Tables 2.1a and 2.1b).

2.4.2 Traffic and Weather Conditions

In order to have a free-flow condition, the traffic flow should not influence the drivers' freedom to manoeuvre. In this study, free-flow traffic was defined as traffic flow at the 'Level Of Service' (LOS) A or B. These levels of services were chosen because LOS B is the last LOS where drivers have an unrestricted choice to manoeuvre "...Drivers, however, do not find it difficult to make such manoeuvres [make lane changes..]..." (Garber and Lester, 1988). The concept was used, usually, for freeway roads. It was assumed that free-flow criteria could be applied to a section of a road fulfilling the criteria of this study, even though, the road, commonly, was classified at a lower level than a freeway. All the measurements were taken during the Summer season and observations that happened during extreme weather conditions (e.g. heavy fog , heavy rain) were excluded.

The service flow at LOS_B was determined for each site and compared to the actual hourly flow using the following equation:

$$SF_i = MSF_i (N) (f_w) (f_{HV}) (f_p)$$

SF_i= service flow rate under prevailing traffic and roadway condition for the level of service $_i$ (veh/h)

MSF_i= maximum service flow rate per lane for level of service i under ideal conditions in passenger cars per hour, per lane (pc/h/lane)

f_w= adjustment factor for the effect of restricted lane widths and/or lateral clearance

f_{HV}= adjustment factor for the combined effect of trucks, buses, and recreational vehicles in the traffic stream which equals

$$f_{HV} = \frac{1}{1+P_T(E_T-1)+P_B(E_B-1)+P_R(E_R-1)}$$

where

P_T,P_B,P_R = proportion of trucks, buses, and recreational vehicles (RVs), respectively, in the traffic stream

E_T,E_B,E_R= PCEs for trucks, buses, and Rvs, respectively

f_p= adjustment factor for the effect of driver population (1.0 for weekdays and commuter, others 0.75-0.90 depending on engineering judgement)

N= number of lanes in one direction

(All the equations and tables, used to extract the correction factors, were taken from (National Research Council, 1980) and (National Research Council, 1985))

Hourly traffic flows that were less than the Service Flow for LOS_B were considered to be operating under free-flow conditions; all other flows were excluded from further analysis (Tables 2.1a and 2.1b).

Figure 2.1a: A Plan of the Location of the Sites and their Coded Names (Tyne & Wear)

(1) EA1: A1(M) road in Durham County, near CLS_Carrville.
(2) E19: A19 trunk road in Durham County, near Hawthorn.
(3) E167: A167 trunk road in Durham County, South of Picktree.
(4) EHW: Felling By-Pass in Gateshead, west of Heworth roudabout.
(5) EJR: John Reid road in South Tyneside, south of B1298.
(6) EGHN: A167 in Gateshead, north of Mobile garage.
(7) EGHS: A167 in Gateshead, south of Mobile garage.
(8) EGN: Great North road in Newcastle, south of Brunton Lane.
(9) E194: A194 in south Tyneside, western approach.
(10) ELN: The Links in North Tyneside, south of Westly Avenue.
(11) EOC: Felling By-Pass in Gateshead, near Orchid Crescent.

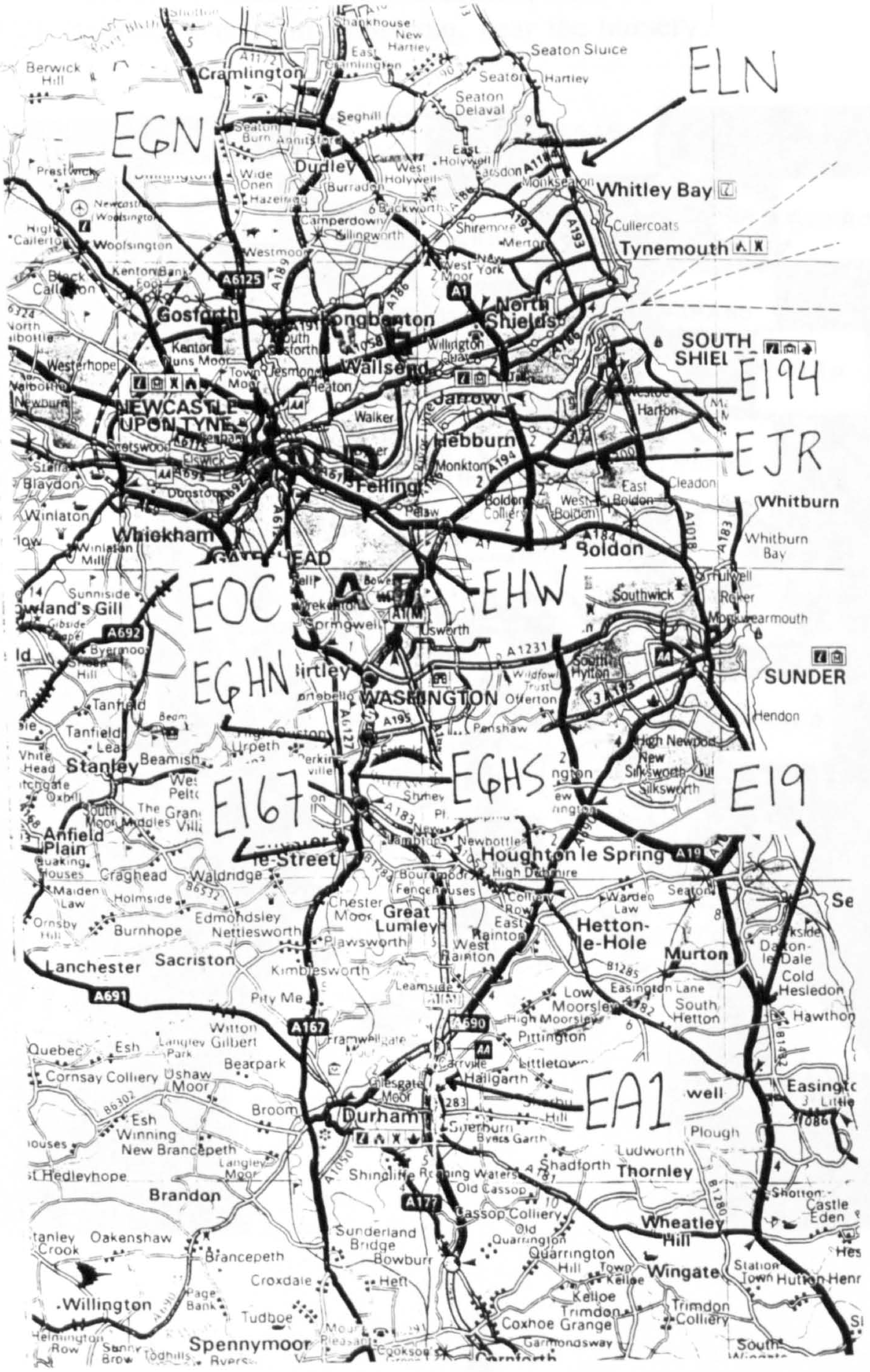


Figure 2.1b: A Plan of the Location of the Sites and their Coded Names (Bahrain)

(1) BKH100: Khalifa Bin Salman Highway in Sanabis, near the exhibition centre.
(2) BSA100: Salman Highway in Riffa, near the Ministry of Interior.
(3) BMU100: AlMu'askar Highway in Riffa, near Awali roundabout.
(4) BMJ100: Majles AlTa'wan Highway in Sitra, near the oil refinery.
(5) BFA80: AlFateh Highway in Manama, near the Amiri Palace.
(6) BHA80: Sheikh Hamad Causeway in Muharraq, near the touring company.
(7) BKH80: Khalifa AlKabeer Highway in Muharraq, near the falcon monument.
(8) BGH80: AlGhous Highway in Muharraq, near the A'mina girls' school.
(9) BIS80: Isa Bin Salman Highway in Manama, near the port.
(10) BBU70: Buday'a Highway in Budaya'a, near the fire brigade station.
(11) BSA70: Salman Highway in Adari, near Adari spring.
(12) BSE70: AlSehla Avenue in AlSehla, near the brick factory.
(13) BKU50: Kuwait Avenue in Um-AlHassam, near the science centre.
(14) BSA50: Salman Avenue in Muharraq, near the nursery.

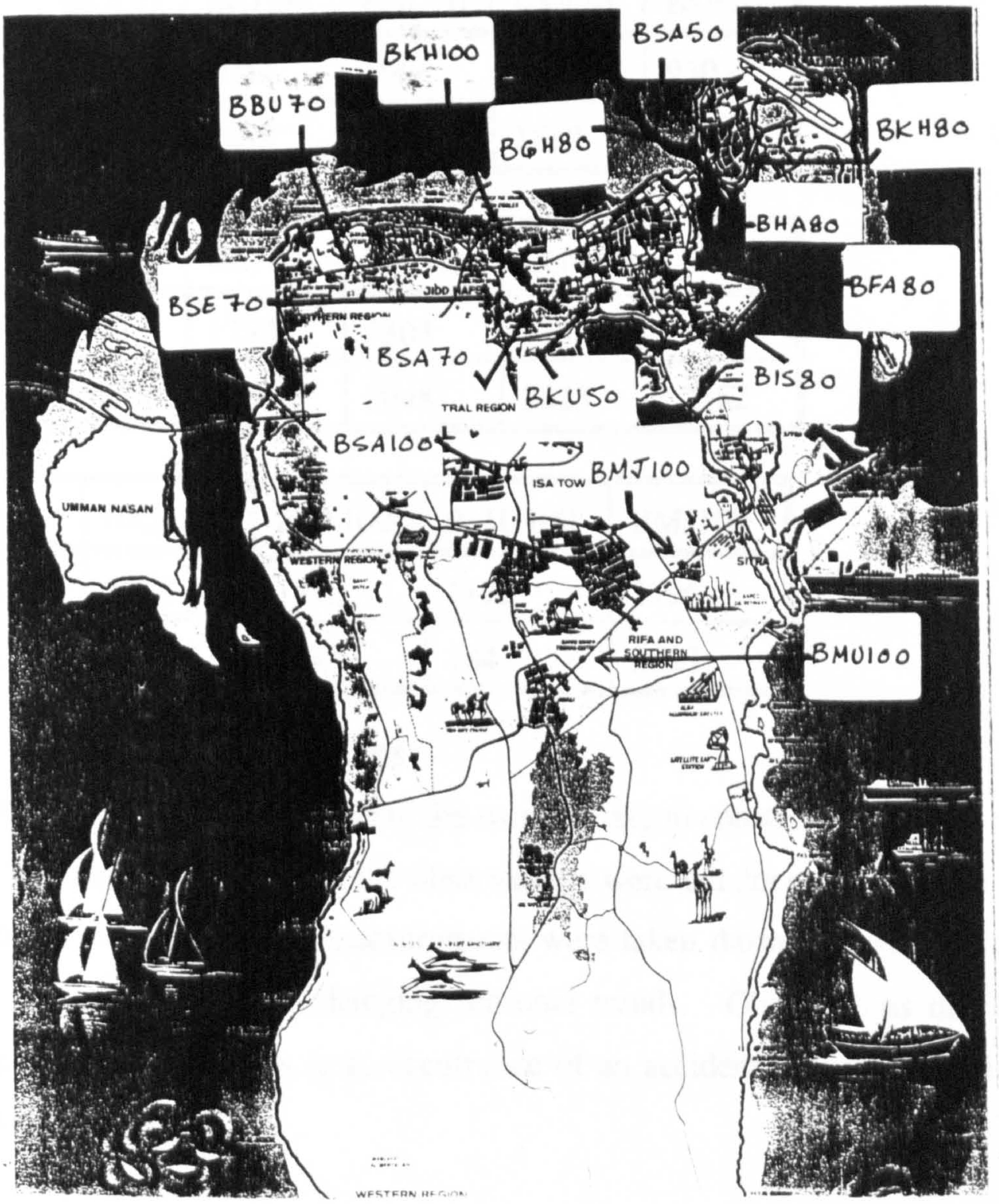


Table 2.1a: Maximum Service Flow (MSF) (veh/h) for LOS_A and LOS_B (Tyne & Wear)

Site	EA167	EA1	EA19	EGHN	EGHS	EJR
LOS_A	1060	1064	1069	1053	1053	1080
LOS_B	1666	1672	1680	1655	1655	1697

Site	ELN	EGN	EA194	EHW	EOC
LOS_A	1032	1067	1090	1056	1056
LOS_B	1621	1676	1713	1659	1659

Table 2.1b: Maximum Service Flow (MSF) (veh/h) for LOS_A and LOS_B (Bahrain)

Site	BSA50	BKU50	BBU70	BSA70	BSE70
LOS_A	998	1054	1066	998	930
LOS_B	1568	1658	1675	1568	1461

Site	BFA80	BKH80	BHA80	BGH80	BIS80
LOS_A	1643	1758	1303	1796	1643
LOS_B	2582	2763	2048	2823	2582

Site	BKH100	BSA100	BMU100	BMJ100
LOS_A	1834	1222	1172	1796
LOS_B	2883	1921	1841	2823

2.4.3 Time of the Observations

The observations took place during the working day to constrain the trip purpose mix for all the sites. At all sites, the observations were conducted during the light and dark hours of the day. All measurements were taken during the summer season to avoid any influence from changing seasonal trends. Observations that happened during extreme influences (e.g. occurrence of an accident) were excluded from the analysis.

2.5 The Equipment

2.5.1 The Automatic Speed Recorder

A survey was carried out to find a speed measurement device suitable for the purpose of this study. It was found that the GK Instrument Series 5000 with 13 speed bins was the most suitable, and it was used in both Bahrain and Tyne and Wear.

The automatic speed recorder used pneumatic sensors across the road. An air pulse was generated as the front axle tyres crossed the first tube which started an internal clock which was stopped when the second air pulse was sent as the first axle tyres crossed the second tube. It has an algorithm to distinguish different axle configurations. The speed was determined from the time taken to travel between the two sensors and the fixed distance between them (GK Instruments, 1990). On some other sites (70 mile/h sites in Tyne and Wear), the GK 6000 instrument was used which used magnetic detection loops. The automatic speed recorder produced an output which consisted of the time and date for each interval, number of vehicles, and the frequency in each of the 13 speed bins (see Appendix I, Exhibit 2.1).

The Installation Procedure

Two pneumatic tubes were clamped to the top of the pavement at the specified distance apart and connected to the recorder. The free-end of the sensors were fitted with a plug with an air hole to avoid double-counting. The recorder then was chained to a piece of road furniture (e.g. traffic sign post). The instrument had to be adjusted for the following settings: medium speed band, band width, tube configuration, distance between tubes, time-out distances, and units of measurements. The same procedure was used with the 6000 GK instrument except, that permanent magnetic detection loops were used instead. When the observation ended, the recorder was linked to a personal computer which was already loaded with the proper software (i.e. Vehicle Identification System Analysis VISA) and the data was retrieved and passed into a computer (GK Instruments, 1991).

2.5.2 The Radar Speed Meter

The radar speed meter (MUNIQUIP) was used to calibrate the GK instrument. It emitted radio waves which were reflected back to the instrument when they meet an object. If the object was moving there was a time lag between the emitted and reflected waves which was proportional to the speed of the object. This phenomena is known as the Doppler effect (TRIBAR Industries, 1989).

The Speed Detecting Procedure

The radar speed meter was calibrated using a frequency fork pre-calibrated at 60 mile/h. The spot speeds of about 30 vehicles at each of the Tyne and Wear sites were measured by both types of equipment. The GK instrument had a facility for displaying the spot speed of each vehicle crossing the tubes or the inductive loops while the radar speed meter was pointed directly to the vehicle to minimise any cosine error (Salter, 1985).

2.5.3 Calibration Analysis of The Automatic Speed Recorder

For the Tyne and Wear sites where the automatic GK speed recorder was calibrated against the radar, a two-tail t-test was run to test the null hypothesis which was: there was no difference between the mean of the readings of the two sets of equipment at a confidence level of 95 per cent (Table 2.2 and Figure 2.2).

Figure 2.2: The Calibration of the Automatic Speed Recorder Using the Radar Speed Meter

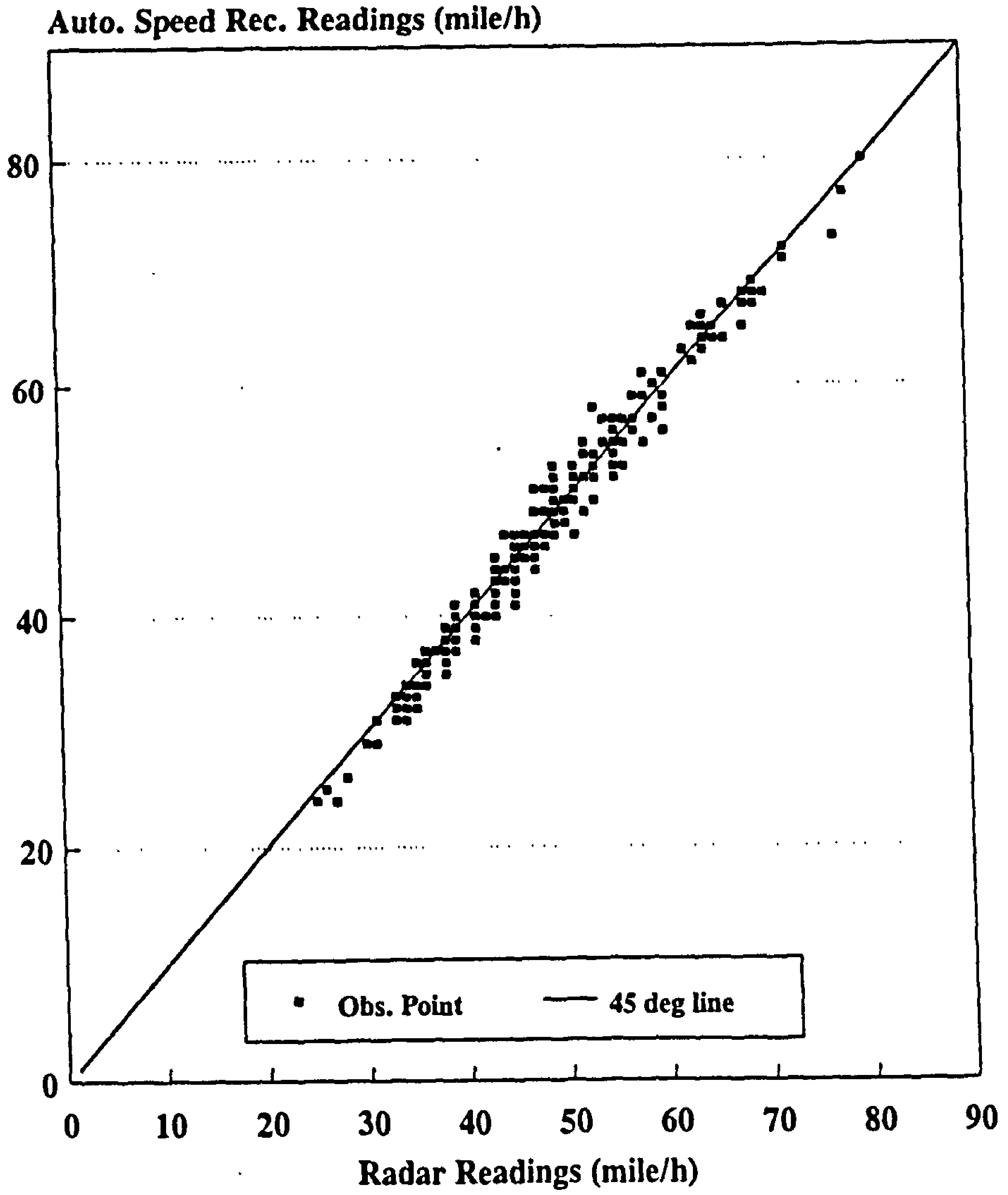


Table 2.2: The T-Test Results from the Comparison between the Radar Speed Meter and the Automatic Speed Recorder Readings

Equipment	Mean of the readings (mile/h)	Standard deviation of the readings (mile/h)
Radar	45.6	10.7
Automatic speed recorder	46.0	10.3

T value= -0.51, p= 0.61 (significant at 95% confidence level (i.e. cannot reject that the mean of values are equal)), Degree of Freedom= 612

2.6 The Validation of Free-Flow Traffic Criteria and the Significance of Daily Variations in the Speed of Traffic

2.6.1 Introduction

(Most of the statistical procedures have been taken from (Bajpai et. al, 1978), (Bluman, 1992), and (Draper and Smith, 1980)).

(The statistical package used was MINITAB Release 8.0 with the help of the guide book (Joiner et. al., 1985) and LOTUS 1-2-3R Spreadsheet, release 2.1)

In this study, it has been assumed that free-flow traffic conditions were related to LOS_A and LOS_B. To test this claim, the relationship between the hourly traffic flow and the hourly mean speed of traffic was tested. Other variables that could have affected the speed of traffic were included in order to identify their effects such as lighting conditions and seasonal trends. Multiple regression analysis was used with coded dummy variables to test the assumptions. The data was collected for more than one day. To examine the similarity of the observations of various days, data were grouped according to their day of observation and were included in the multiple regression analysis.

2.6.2 Estimation of the Hourly Mean of the Speed Distribution of Vehicles

The average speed was determined using the following equation:

$$\mu=\frac{\Sigma f_i\, md_i}{\Sigma f_i}$$

where
μ= hourly mean speed
f_i= frequency for the ith speed class
md_i= mid-value speed for the ith speed class

2.6.3 Validation of the Significance of Daily Variations of Traffic

In the multiple regression equation, where the hourly mean speed was considered to be the dependent variable, independent dummy variables were coded according to the day of observation in which the hourly mean speed was observed at (X_{d1}, X_{d2},X_{d3},...). The first day of observation was considered as the reference day; for example, it was coded as 0,0,0. To account for the effect of traffic flow fluctuation during the days of observation, independent variables were introduced describing the day of observation and the hourly flow (X_{df1}, X_{df2}, X_{df3},...) (i.e. the interaction effect of the day of observation and the hourly flow at that day).

2.6.4 The Validation of the Free-Flow Criteria

To test the free-flow criteria, the influence of the hourly observed flow on the hourly mean speed of traffic was investigated. In the regression analysis equation, where the hourly mean speed was the dependent variable, the hourly traffic flow (X_1) was the independent variable. Forms other than the linear relationship were tested (i.e. X_2 the square power, X_3 the square root). The free-flow traffic hours, according to the definition, were represented as coded dummy variables (X_f:0,1). The hourly flow during free-flow traffic hours was represented in the form of interaction variable (X_{ff}). If there had been variations in the hourly mean speed, it could have been due to variables other than the hourly flow. To test this hypothesis other variables were included like: lighting conditions (light/dark hours, as a coded dummy variable, X_4:0,1), hours of the day (in the absolute form X_7), hourly trends (cosine X_5 and sine X_6 trends).

2.6.5 The Multiple Regression Analysis

All the variables were gathered in a single multiple regression analysis equation to assess their effect collectively on the hourly mean speed of traffic. The variables with statistically significant coefficients were considered to have an effect on the hourly mean speed of the traffic.

The multiple regression had the following form:

$$\begin{gathered} Y=\beta_0+\beta_1 X_1+\beta_2 X_2+\beta_3 X_3+\beta_4 X_4+\beta_5 X_5+ \\ \beta_6 X_6+\beta_7 X_7+ \\ [\beta_{d1} X_{d1}+\beta_{d2} X_{d2}+\beta_{d3} X_{d3}+\ldots]+ \\ [\beta_{df1} X_{df1}+\beta_{df2} X_{df2}+\beta_{df3} X_{df3}+\ldots]+ \\ [\beta_f X_f]+[\beta_{ff} X_{ff}] \end{gathered}$$

where
Y= the hourly mean speed of traffic (the dependent variable)
X_1= hourly traffic flow (veh/h)
X_2= the square power of hourly traffic flow(X_1^2)
X_3= the square root of hourly traffic flow($\sqrt{X_1}$)

X_4= dummy variable for the lighting condition of the hour (e.g. 0 for dark and 1 for light)
X_5= cosine trend (cosine ($2\pi t/24$) where t= hour of the day)
X_6= sine trend (sine ($2\pi t/24$) where t= hour of the day)
X_7= hour of the day
[X_{d1}, X_{d2}, X_{d3},...]= dummy variables representing observation days (d1= day2, d2=day3, d3=day4,...etc.) where applicable
[X_{df1}, X_{df2}, X_{df3},...]= interaction effects (e.g. $X_{df1}=X_{d1}*X_1$,$X_{df2}=X_{d2}*X_1$...) where applicable
[X_f]= a dummy variable representing free-flow traffic hours (i.e. less than or equal LOS_B traffic flow)
[X_{ff}]= interaction effects of the free-flow conditions (e.g. $X_{ff}=X_f*X_1$)
β_0 = constant
β_1, β_2, β_3, ... = coefficients of regression
(Tables 2.3a and 2.3b and Figures 2.3a and 2.3b)

2.7 The Model Describing the Effect of the Speed Limit on the Speed of Traffic

2.7.1 Determination of the Typical Speed Characteristics of the Sites

The mean speed of traffic at a site was determined by calculating the arithmetic mean of the mean speeds of the free-flow traffic for a typical day (the typical day was determined in Section 2.7). The cumulative speed distribution was determined for each site (see Figures 2.4a and 2.4b) together with the standard deviation, the fiftieth percentiles (i.e. the median speed), the eighty-fifth percentile and the proportion of drivers exceeding the speed limit (see Tables 2.4a and 2.4b, and Figures 2.5a and 2.5b).

2.7.2 The Input Data for the Analysis of the Effect of Speed Limits

The dependent variable was the speed of traffic which was represented by the mean and the eighty-fifth percentile speed of traffic. The variables that could have influenced the speed of traffic were considered to be: the speed limit (i.e. which is the principle objective of this part of the study), the proportion of heavy vehicles, the number of lanes (i.e. where applicable), the length of the section under observation (see Table 2.5), and the trip length (see Table 2.6) (i.e. the values based on the engineering judgement of the local highway authorities and some limited traffic data). The values which were used represented typical days (see Tables 2.7a and 2.7b).

Table 2.3a: The Results of the Multiple Regression Analysis (Tyne & Wear)

Site	E167N	E167S	EA1N	EA1S	E19N
X_1					0.04
X_2		0.38			
X_3					-0.75
X_4	3.00	1.46			3.04
X_d	X_{d1} to X_{d3}	X_{d1} to X_{d3}	X_{d1}-2.58 X_{d2}	X_{d1}-3.08	X_{d1}-X_{d2} X_{d3}1.48 X_{d4}
X_{df}	X_{df1} to X_{df3}	X_{df1} to X_{df3}	X_{df1} X_{df2}	X_{df1}	X_{df1} to X_{df4}
X_7		-0.11			
X_5	1.96	1.53	3.66		
X_6	1.22				
X_f	NA*				
X_{ff}	NA*				
R^2	34.5	28.0	74.2	55.1	53.6

where
X_1= hourly traffic flow (veh/h)
X_2= the square power of hourly traffic flow(X_1^2)
X_3= the square root of hourly traffic flow($X_1^{.5}$)
X_4= dummy variable for the lighting condition of the hour (e.g. 0 for dark and 1 for light)
X_5= cosine trend (i.e. cosine ($2\pi t/24$) where t= hour of the day)
X_6= sine trend (i.e. sine ($2\pi t/24$) where t= hour of the day)
X_7= hour of the day
[X_{d1}, X_{d2}, X_{d3},...]= dummy variables representing observation days (d1= day2, d2=day3, d3=day4,...etc.) where applicable
[X_{df1}, X_{df2}, X_{df3},...]= interaction effects (e.g. $X_{df1}=X_{d1}*X_1$,$X_{df2}=X_{d2}*X_1$,...) where applicable
[X_f]= a dummy variable representing free-flow traffic hours (i.e. less than or equal LOS_B traffic flow)
[X_{ff}]= interaction effects of the free-flow conditions (e.g. $X_{ff}=X_f*X_1$)
β_0 = constant
β_1, β_2, β_3, ... = coefficients of regression
* NA: not applicable (free-flow traffic)

Table 2.3a: (continued)

Site	E19S	EGN	ELN	E194	EJR	EHW	EGHSA
X_1			-0.08			-0.05	
X_2				-2.51			
X_3			1.58	-2.28		1.04	
X_4	2.87			3.06			.68
X_d	X_{d1}-3.00 X_{d2} X_{d3} 2.06 X_{d4} 3.30 X_{d5}	X_{d1} 2.43 X_{d2} 2.00 X_{d3} 1.94	X_{d1} 1.67	X_{d1} to X_{d4}	X_{d1}-X_{d2} X_{d3} 1.88 X_{d4} 1.17 X_{d5}		X_{d1} to X_{d10}
X_{df}	X_{df1} to X_{df5}	X_{df1} to X_{df3}	X_{df1}	X_{df1} to X_{df4}	X_{df1} to X_{df5}		X_{df1} to X_{df10}
X_7	-0.10		-0.20	0.24			-0.09
X_5	1.88		1.68				0.49
X_6	-1.68					1.89	-0.37
X_f		NA*	NA*	NA*	NA*		NA*
X_{ff}		NA*	NA*	NA*	NA*		NA*
R^2	80.3	36.5	62.7	47.49	15.9	70.9	33.5

where
X_1= hourly traffic flow (veh/h)
X_2= the square power of hourly traffic flow(X_1^2)
X_3= the square root of hourly traffic flow($X_1^{.5}$)
X_4= dummy variable for the lighting condition of the hour (e.g. 0 for dark and 1 for light)
X_5= cosine trend (i.e. cosine ($2\pi t/24$) where t= hour of the day)
X_6= sine trend (i.e sine ($2\pi t/24$) where t= hour of the day)
X_7= hour of the day
[X_{d1}, X_{d2}, X_{d3},...]= dummy variables representing observation days (d1= day2, d2=day3, d3=day4,...etc.) where applicable
[X_{df1}, X_{df2}, X_{df3},...]= interaction effects (e.g. $X_{df1}=X_{d1}*X_1$,$X_{df2}=X_{d2}*X_1$,...) where applicable
[X_f]= a dummy variable representing free-flow traffic hours (i.e. less than or equal LOS_B traffic flow)
[X_{ff}]= interaction effects of the free-flow conditions (e.g. $X_{ff}=X_f*X_1$)
β_0 = constant
β_1, β_2, β_3, ... = coefficients of regression
* NA: not applicable (free-flow traffic)

Table 2.3a: (continued)

Site	EHW	EOC	EGHNB	EGHSB	EGHNA	EGHSA
X_1	-.05			0.10		
X_2						
X_3	1.04			-2.76		
X_4				3.40		0.68
X_d			X_{d1} to X_{d3}	X_{d1} -6.0 X_{d2} X_{d3} -3.58 X_{d4} -4.75	X_{d1} to X_{d9}	X_{d1} to X_{d10}
X_{df}			X_{df1} to X_{df3}	X_{df1} 0.01 X_{df2}-X_{df3} X_{df4} 0.01	X_{df1} to X_{df9}	X_{df1} to X_{df10}
X_7					-0.09	-0.09
X_5						0.49
X_6	1.89					-0.37
X_f			NA*	NA*	NA*	NA*
X_{ff}			NA*	NA*	NA*	NA*
R^2	70.9	91.7	43.2	44.3	43.3	33.5

where

X_1= hourly traffic flow (veh/h)

X_2= the square power of hourly traffic flow(X_1^2)

X_3= the square root of hourly traffic flow($X_1^{.5}$)

X_4= dummy variable for the lighting condition of the hour (e.g. 0 for dark and 1 for light)

X_5= cosine trend (i.e. cosine ($2\pi t/24$) where t= hour of the day)

X_6= sine trend (i.e. sine ($2\pi t/24$) where t= hour of the day)

X_7= hour of the day

[X_{d1}, X_{d2}, X_{d3},...]= dummy variables representing observation days (d1= day2, d2=day3, d3=day4,...etc.) where applicable

[X_{df1}, X_{df2}, X_{df3},...]= interaction effects (e.g. $X_{df1}=X_{d1}*X_1$,$X_{df2}=X_{d2}*X_1$,...) where applicable

[X_f]= a dummy variable representing free-flow traffic hours (i.e. less than or equal LOS_B traffic flow)

[X_{ff}]= interaction effects of the free-flow conditions (e.g. $X_{ff}=X_f*X_1$)

β_0 = constant

β_1, β_2, β_3, ... = coefficients of regression

* NA: not applicable (free-flow traffic)

Table 2.3b: The Results of the Multiple Regression Analysis (Bahrain)

Site	BKH100	BSA100	BMU100	BMJ100	BFA80
X_1				-0.11	
X_2				-2.09	
X_3					
X_4	-9.12	-9.40		-5.02	-4.67
X_d	NA+	NA+	NA+	NA+	X_{d1}
X_{df}	NA+	NA+	NA+	NA+	X_{df1}
X_7					
X_5	9.49	6.54		4.50	
X_6			-4.55		
X_f	NA*	NA*	NA*	NA*	
X_{ff}	NA*	NA*	NA*	NA*	
R^2	41.5	49.9	20.0	37.9	43.6

Table 2.3b: (continued)

Sites Varb	BHA80	BIS80	BKH80	BGH80	BBU70
X_1					
X_2					1.87
X_3					
X_4		-4.84	-4.42	-3.56	
X_d	X_{d1}-X_{d2}	X_{d1}	X_{d1} -6.96	Xd1 2.51	NA
X_{df}	X_{df1}-X_{df2}	X_{df1}	X_{df1} 0.01	X_{df1} -0.01	NA+
X_7	-0.15			-0.17	
X_5					
X_6				-2.02	
X_f		3.20	NA*	NA*	NA*
X_{ff}		-1.70	NA*	NA*	NA*
R^2	57.7	27.2	39.5	44.7	25.3

NA*: free-flow traffic

NA+: not applicable (there was one day of observation, only)

Table 2.3b: (continued)

Site	BSA70	BSE70	BKU50	BSA50
X_1			-0.07	
X_2			1.15	
X_3				
X_4	-7.00		-2.07	
X_d			X_{d1} 3.38 X_{d2}-X_{d5}	X_{d1} to X_{d5}
X_{df}			X_{df1}-X_{df4} X_{df5} -0.01	X_{df1} to X_{df5}
X_7				
X_5				
X_6				-1.34
X_f	NA*	NA*	NA*	NA*
X_{ff}	NA*	NA*	NA*	NA*
R^2		41.8	34.5	5.1

where

X_1= hourly traffic flow (veh/h)

X_2= the square power of hourly traffic flow(X_1^2)

X_3= the square root of hourly traffic flow($X_1^{.5}$)

X_4= dummy variable for the lighting condition of the hour (e.g. 0 for dark and 1 for light)

X_5= cosine trend (i.e. cosine ($2\pi t/24$) where t= hour of the day)

X_6= sine trend (i.e. sine ($2\pi t/24$) where t= hour of the day)

X_7= hour of the day

[X_{d1}, X_{d2}, X_{d3},...]= dummy variables representing observation days (d1= day2, d2=day3, d3=day4,...etc.) where applicable

[X_{df1}, X_{df2}, X_{df3},...]= interaction effects (e.g. $X_{df1}=X_{d1}*X_1$,$X_{df2}=X_{d2}*X_1$,...) where applicable

[X_f]= a dummy variable representing free-flow traffic hours (i.e. less than or equal LOS_B traffic flow)

[X_{ff}]= interaction effects of the free-flow conditions (e.g. $X_{ff}=X_f*X_1$)

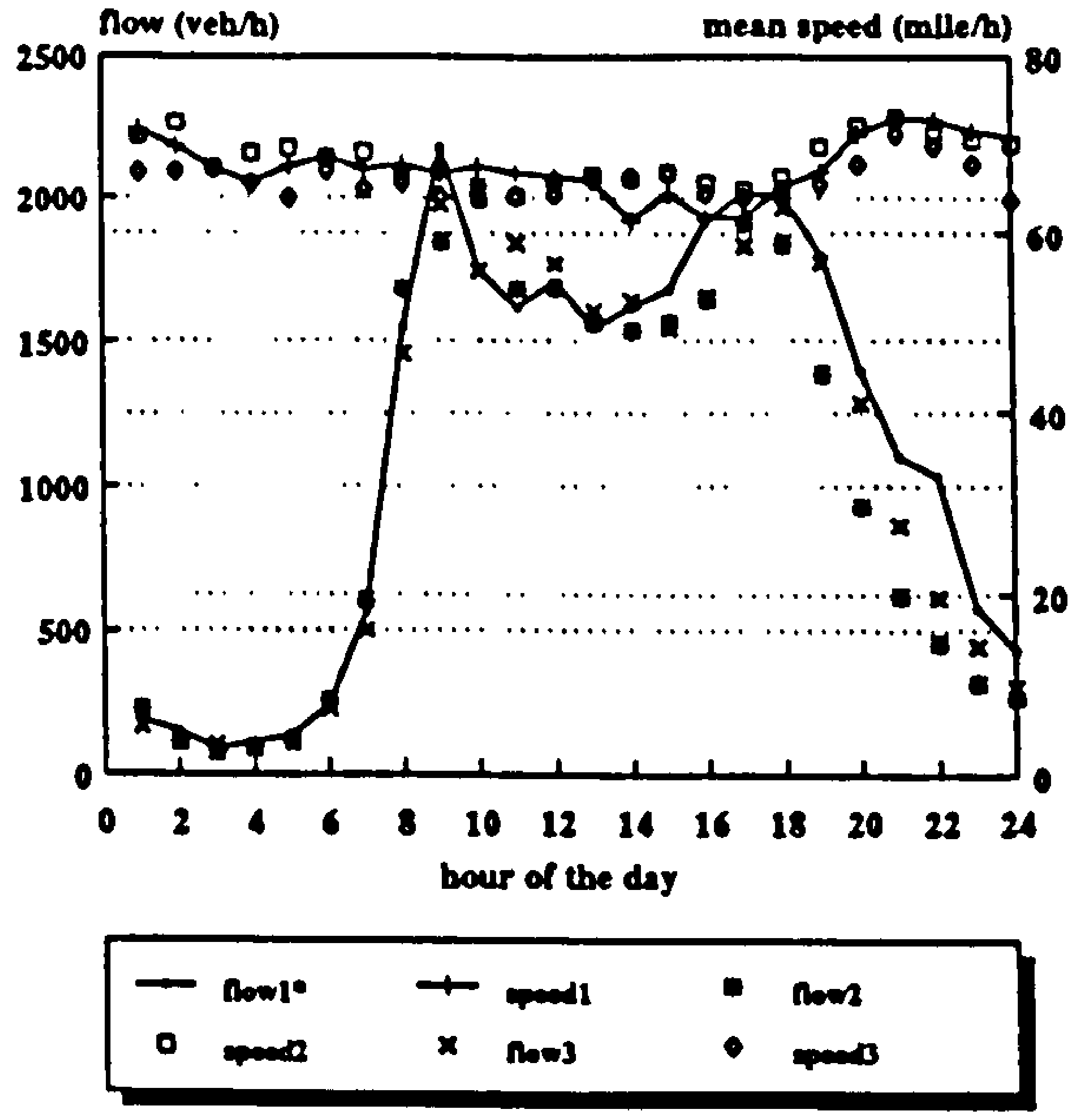
β_0 = constant

β_1, β_2, β_3, ... = coefficients of regression

* NA: not applicable (free-flow traffic)

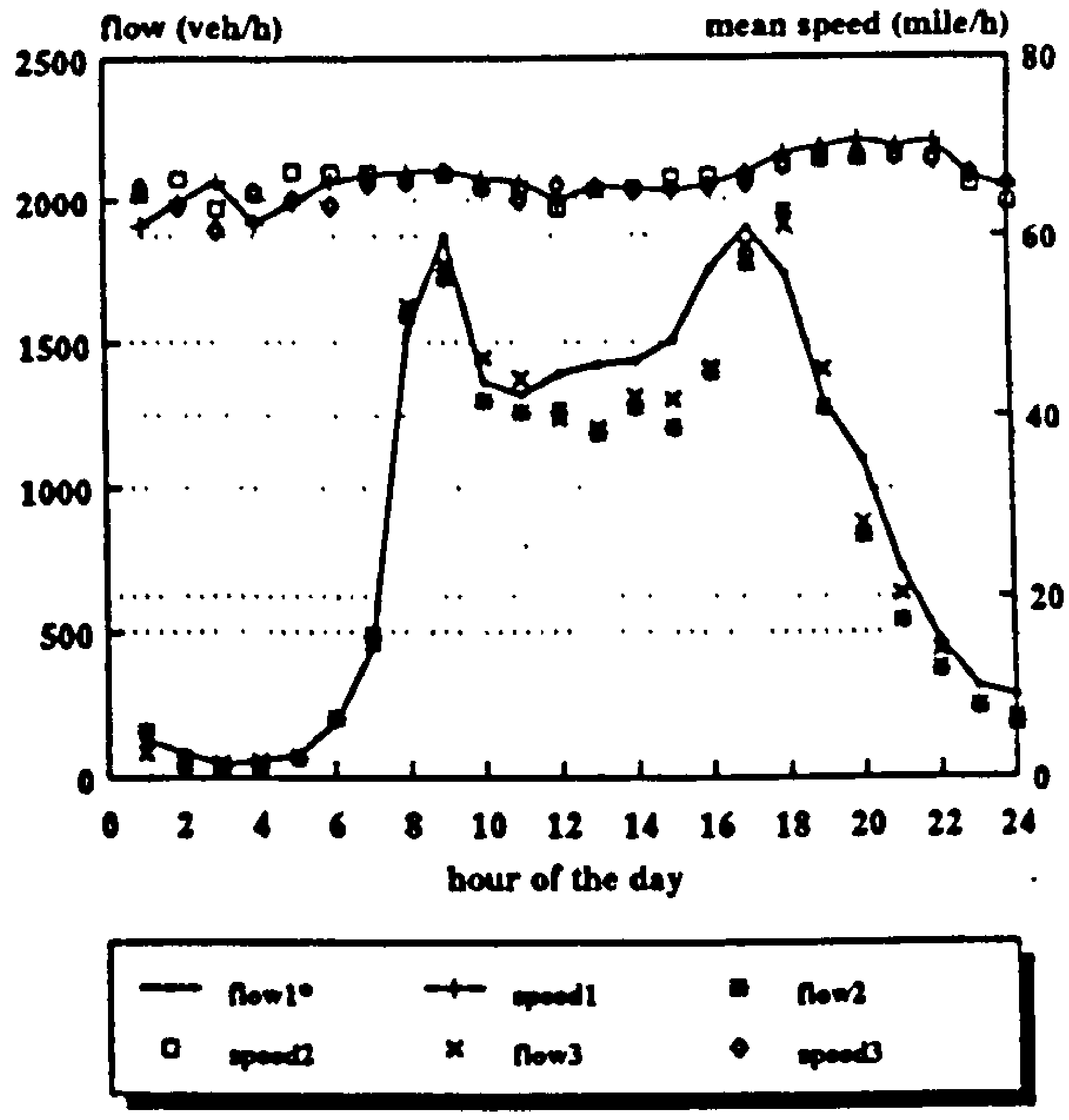
Figure 2.3a: The Relationships between the Hourly Mean Speed, the Hourly Flow of Traffic and the Time of Day (Tyne & Wear) (speed limit: 70 mile/h)
(e.g. flow1, speed1 = the flow and the speed of traffic of the first day of observation)

Site:EA1



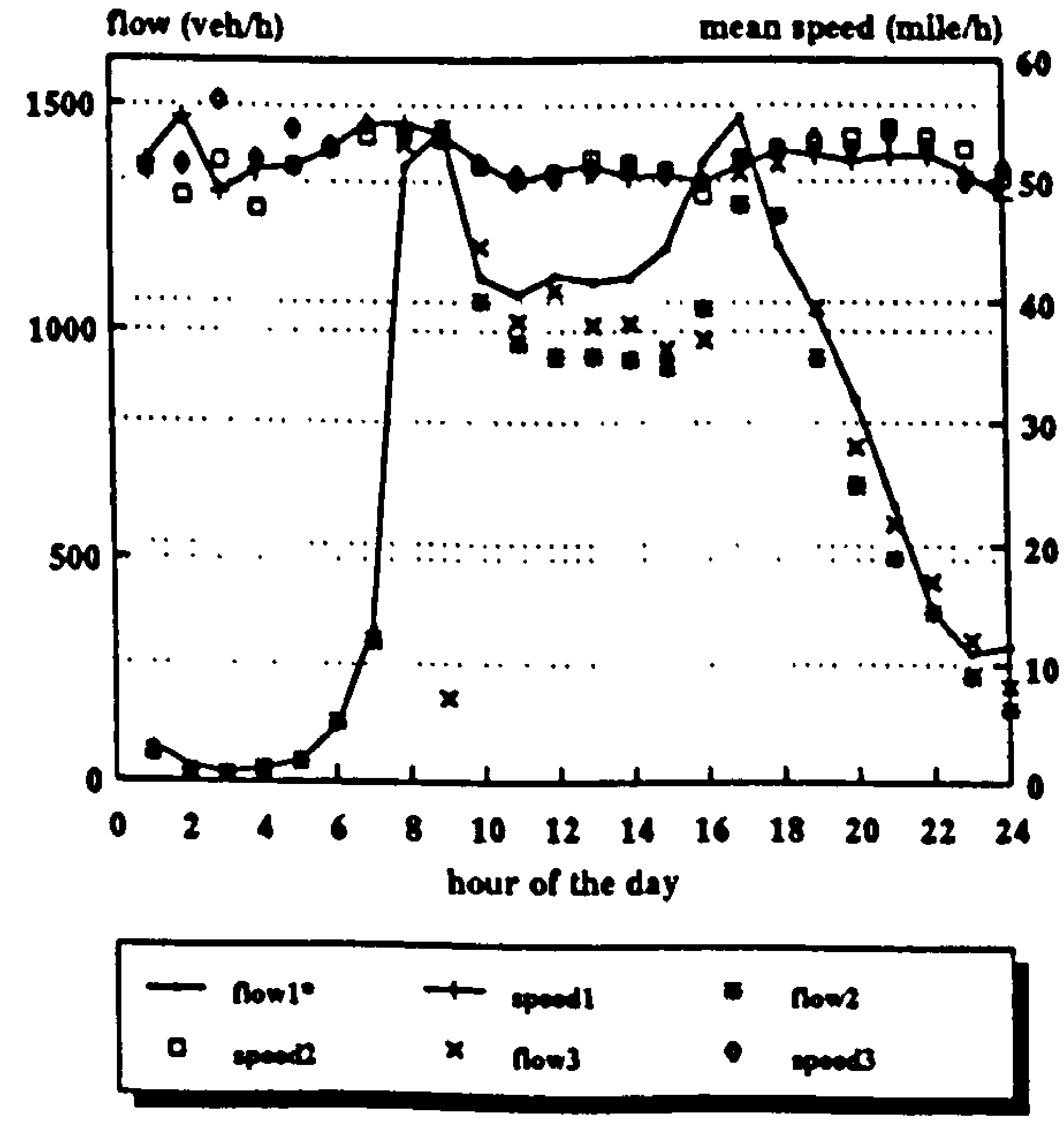
north bound
day time from 5-22 hour
*observation day

Site: E19



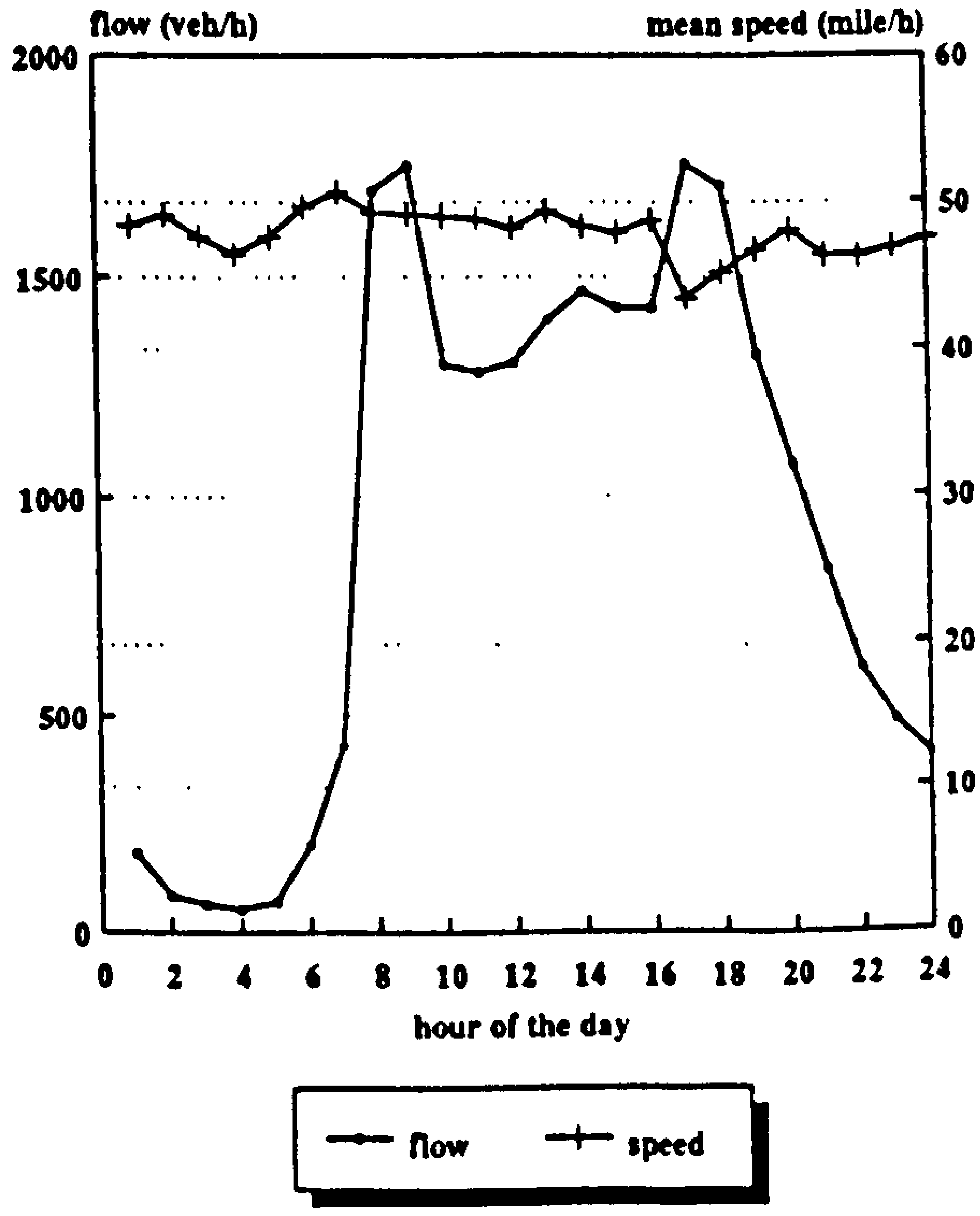
north bound
day time from 5-22 hour
* observation day

Site:E167



north bound
day time from 5-22 hour
* observation day

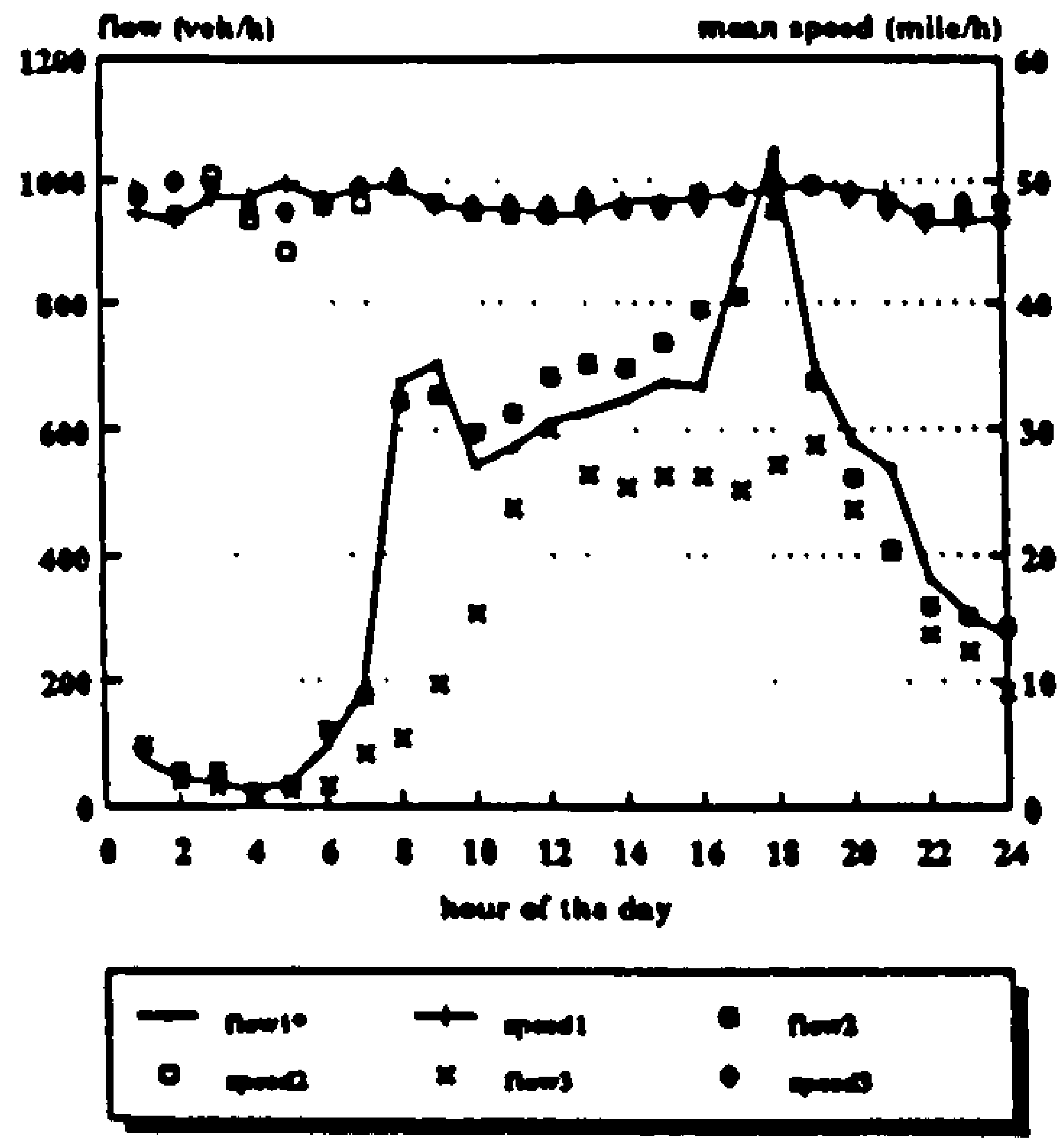
Site: EHW



Day From 5-22 Hour

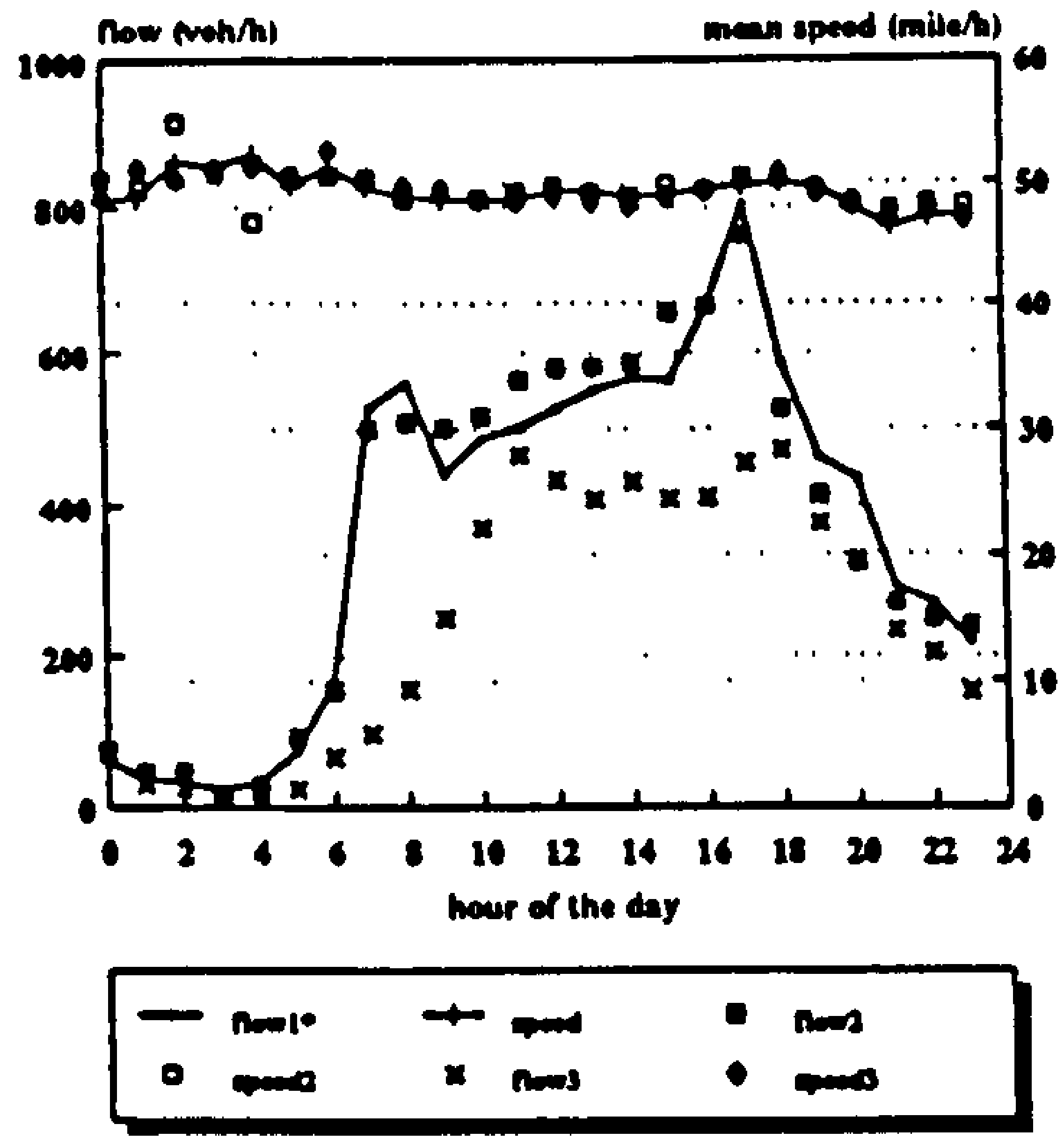
Figure 2.3a: Continued (speed limit: 50 mile/h)

Site:EGHN



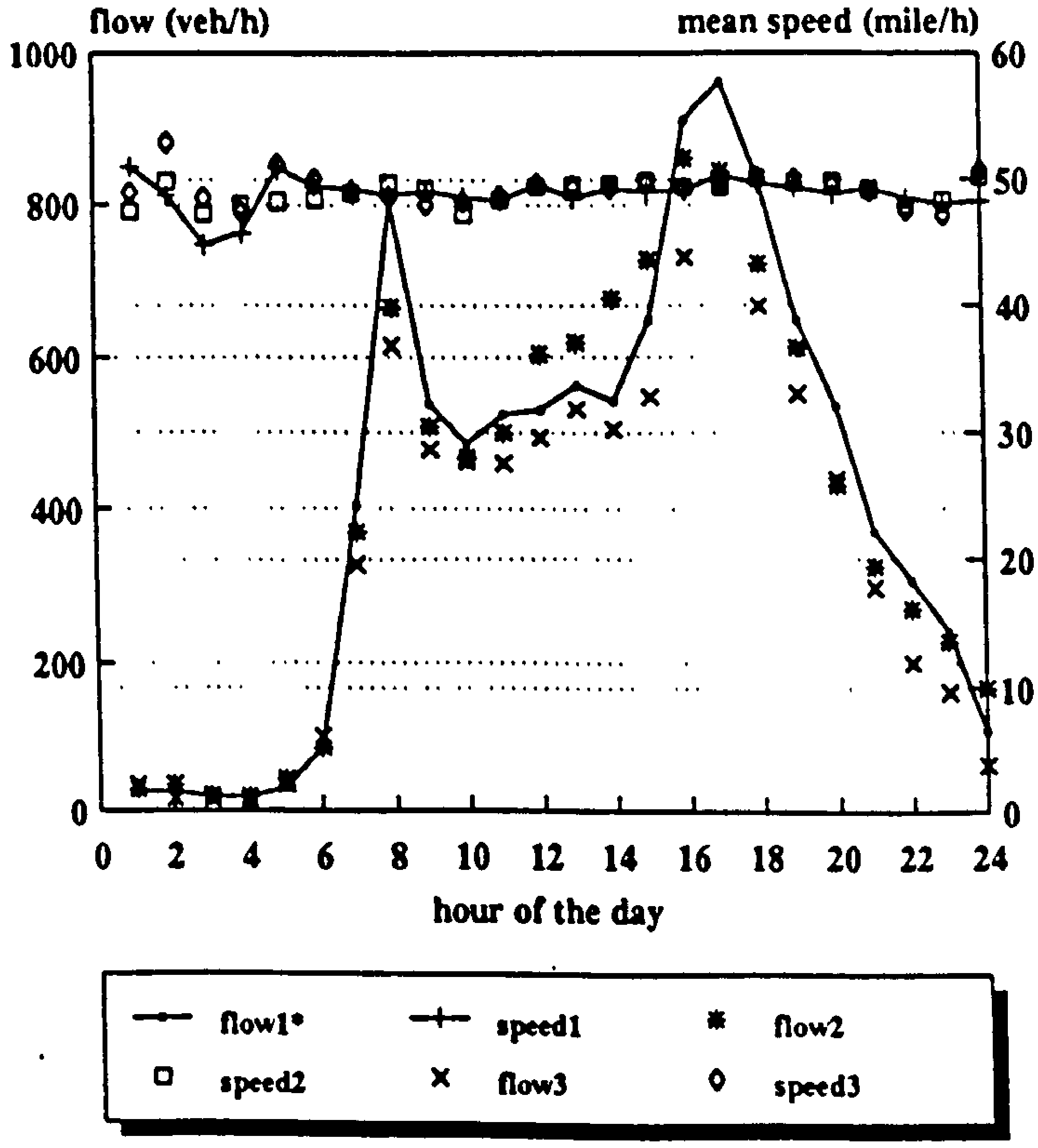
day time from 6-21 hour
*observation day

SITE:EGHS



day time from 6-21 hour
*observation day

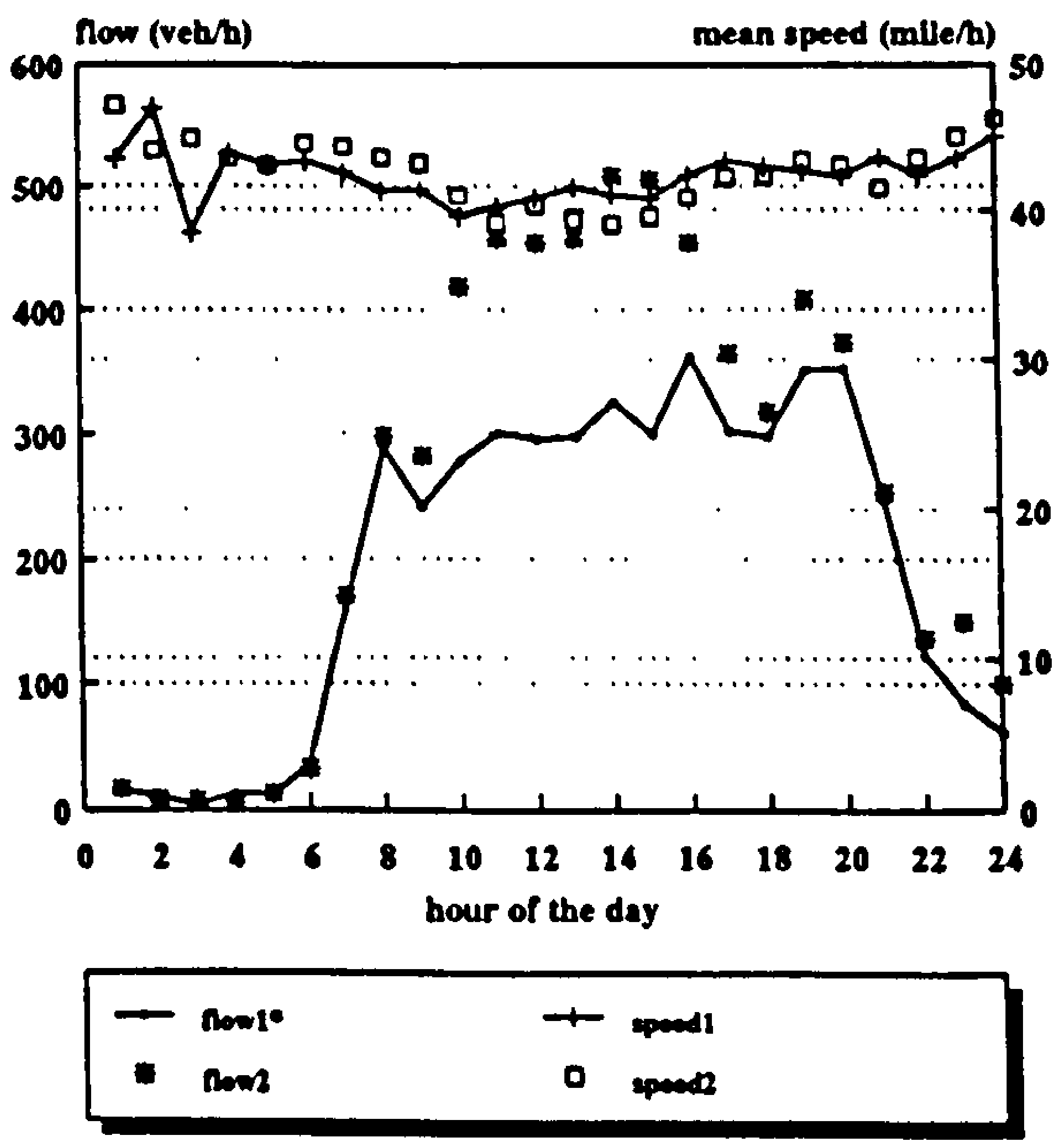
Site:EJR



day time from 5-22
*observation day

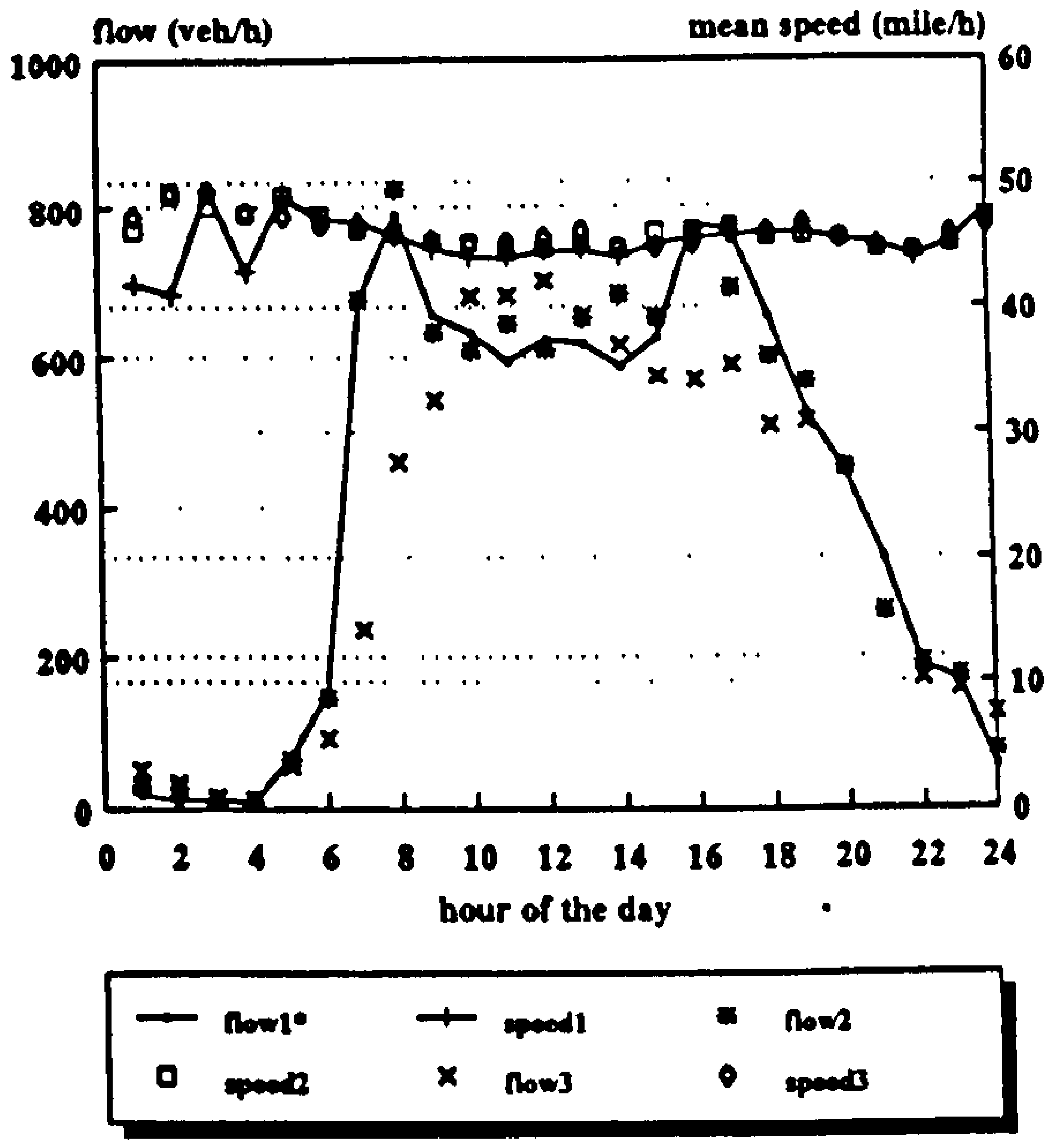
Figure 2.3a: Continued (speed limit 40 mile/h)

Site:ELN



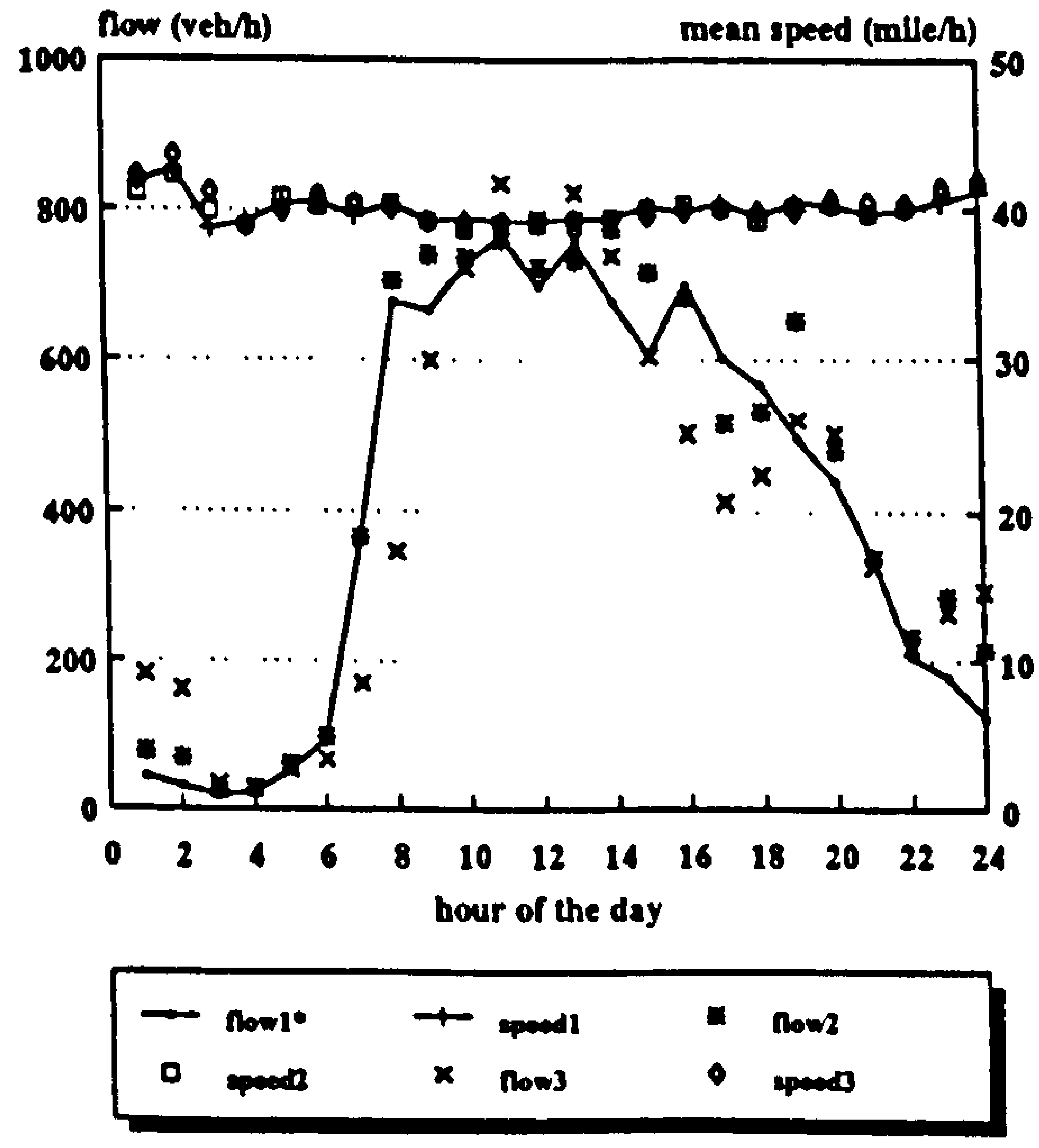
day time from 5-22 hour
*observation day

Site:EGN



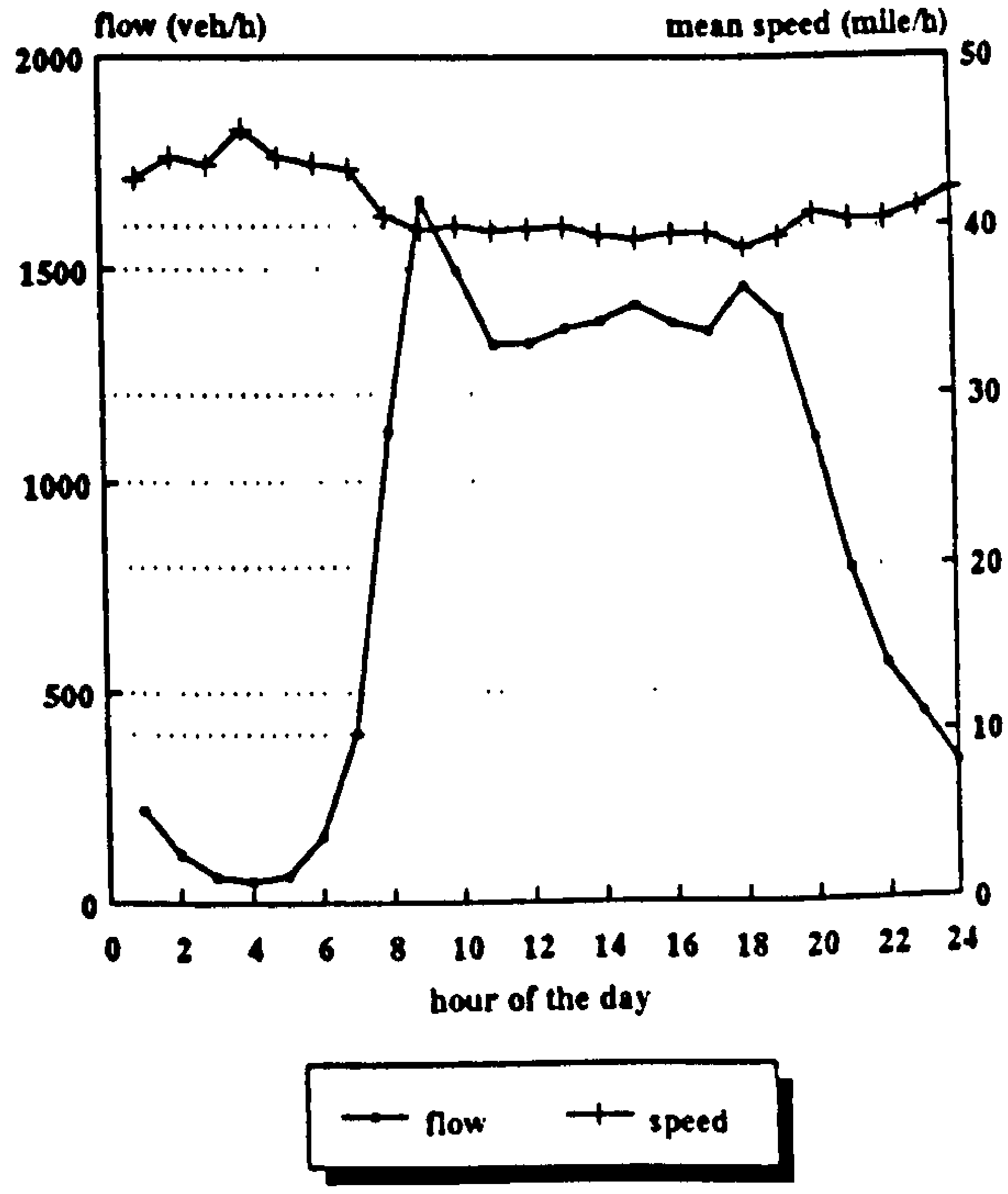
day from 6-21 hour
*observation day

Site:E194



day time from 5-22 hour
*observation day

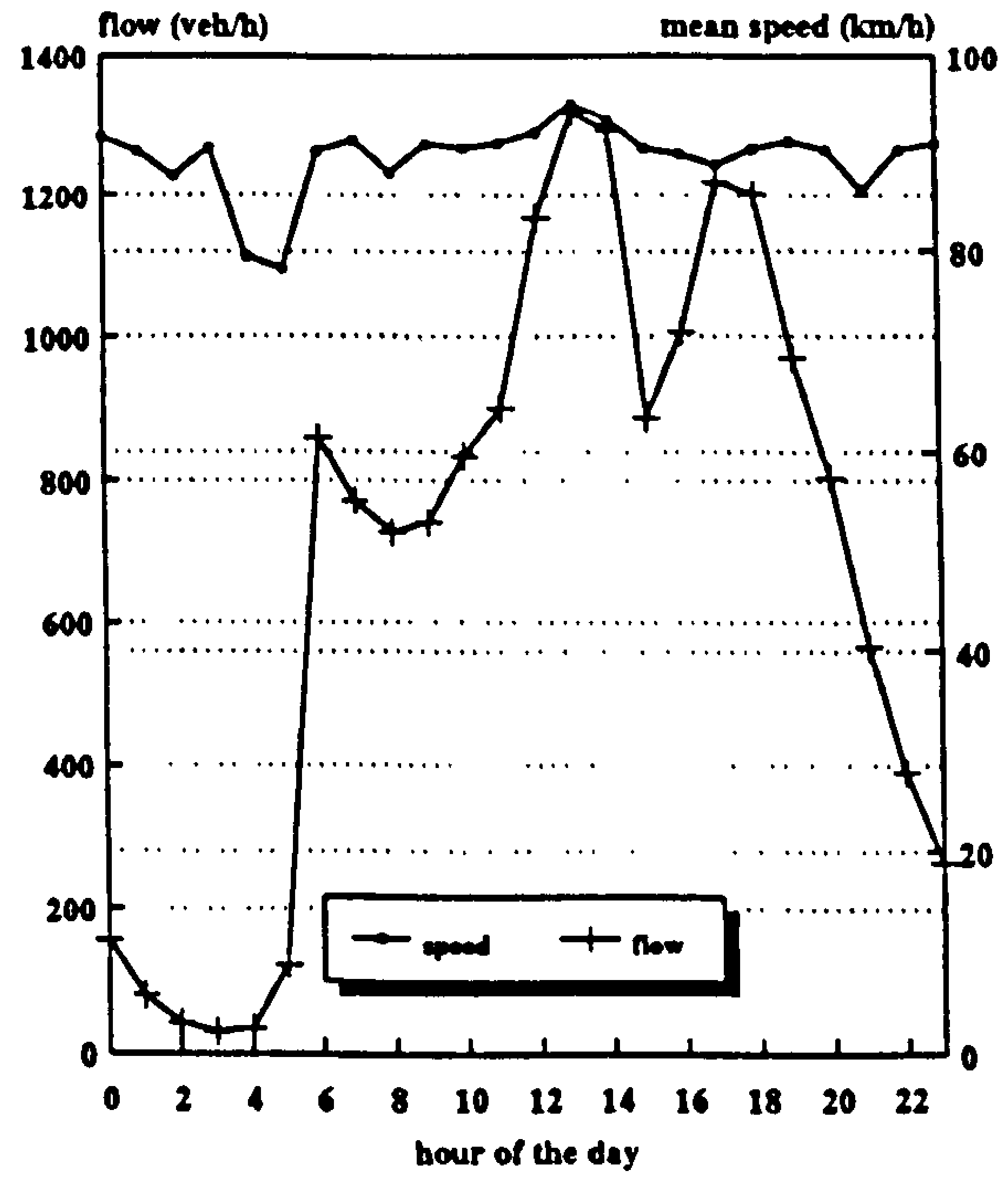
Site:EOC



day time from 7-20 hour

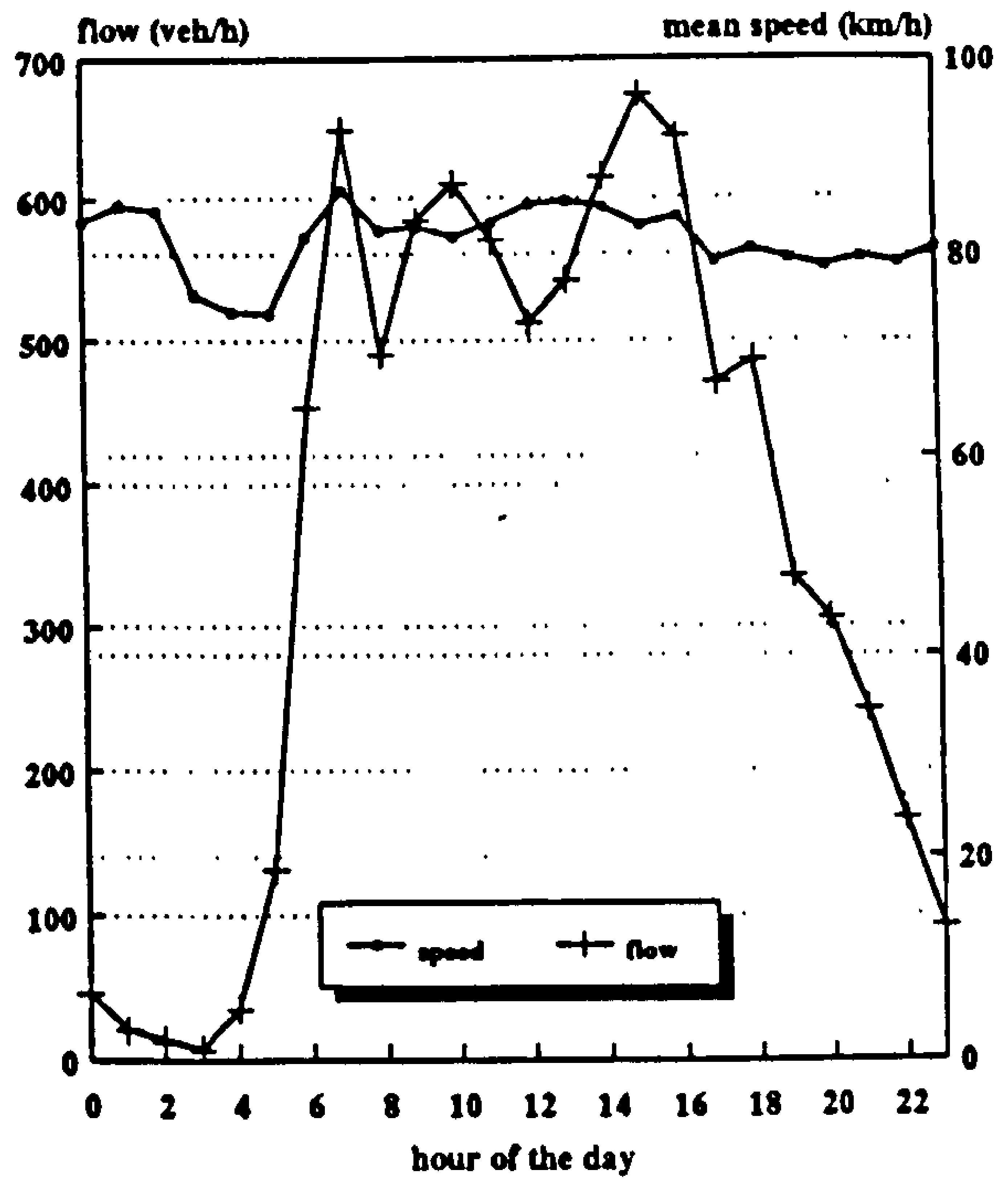
Figure 2.3b: The Relationship between the Hourly Mean Speed, the Hourly Flow of Traffic, and the Time of Day (Bahrain) (speed limit: 100 km/h)
(e.g. flow1, speed1 = the flow and the speed of traffic of the first day of observation)

Site:BKH100



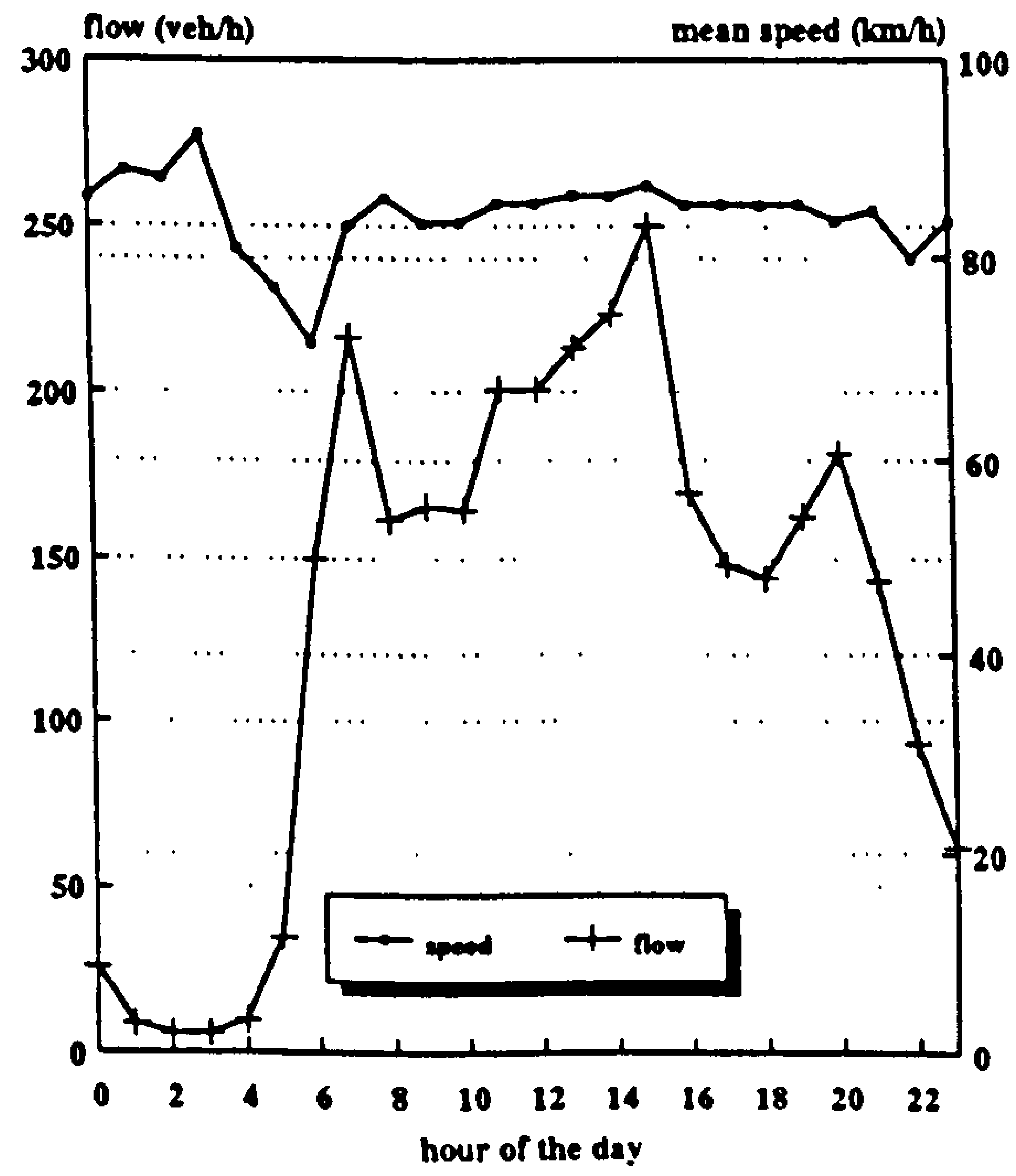
day time from 7-17 hour

Site:BSA100



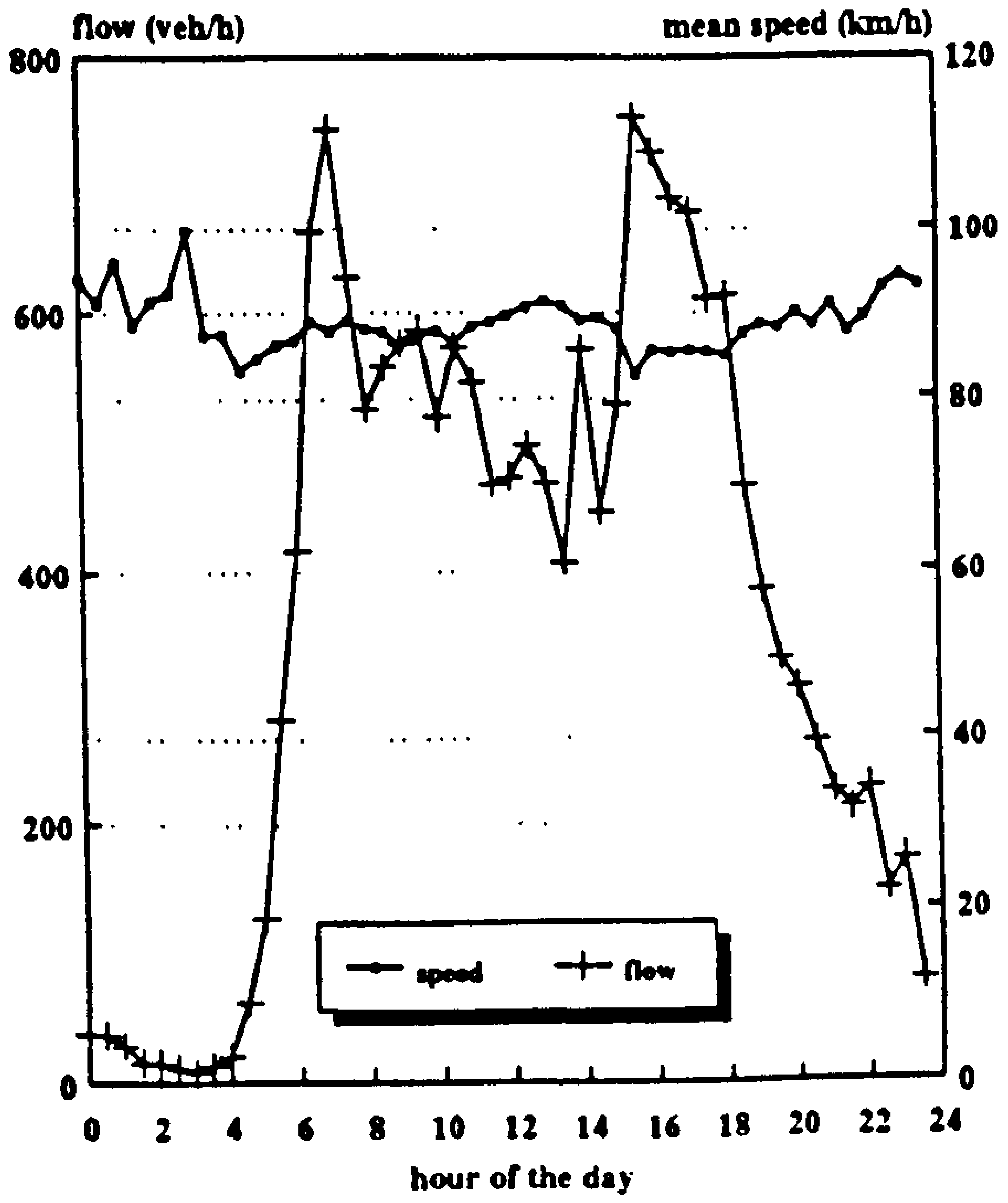
day time from 7-17 hour

Site:BMU100



day time from 7-17 hour

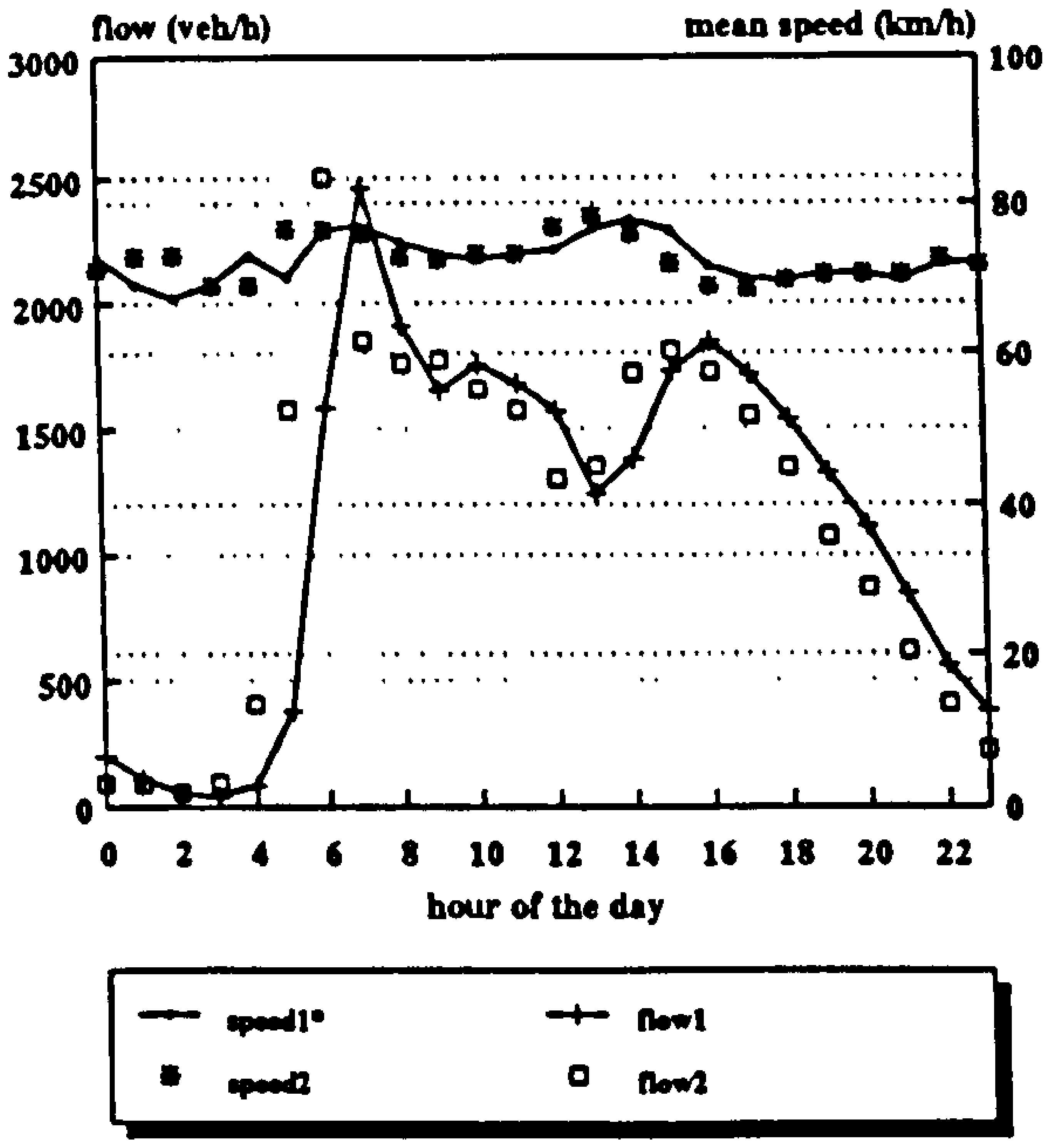
Site:BMJ100



day time from 7-17 hour

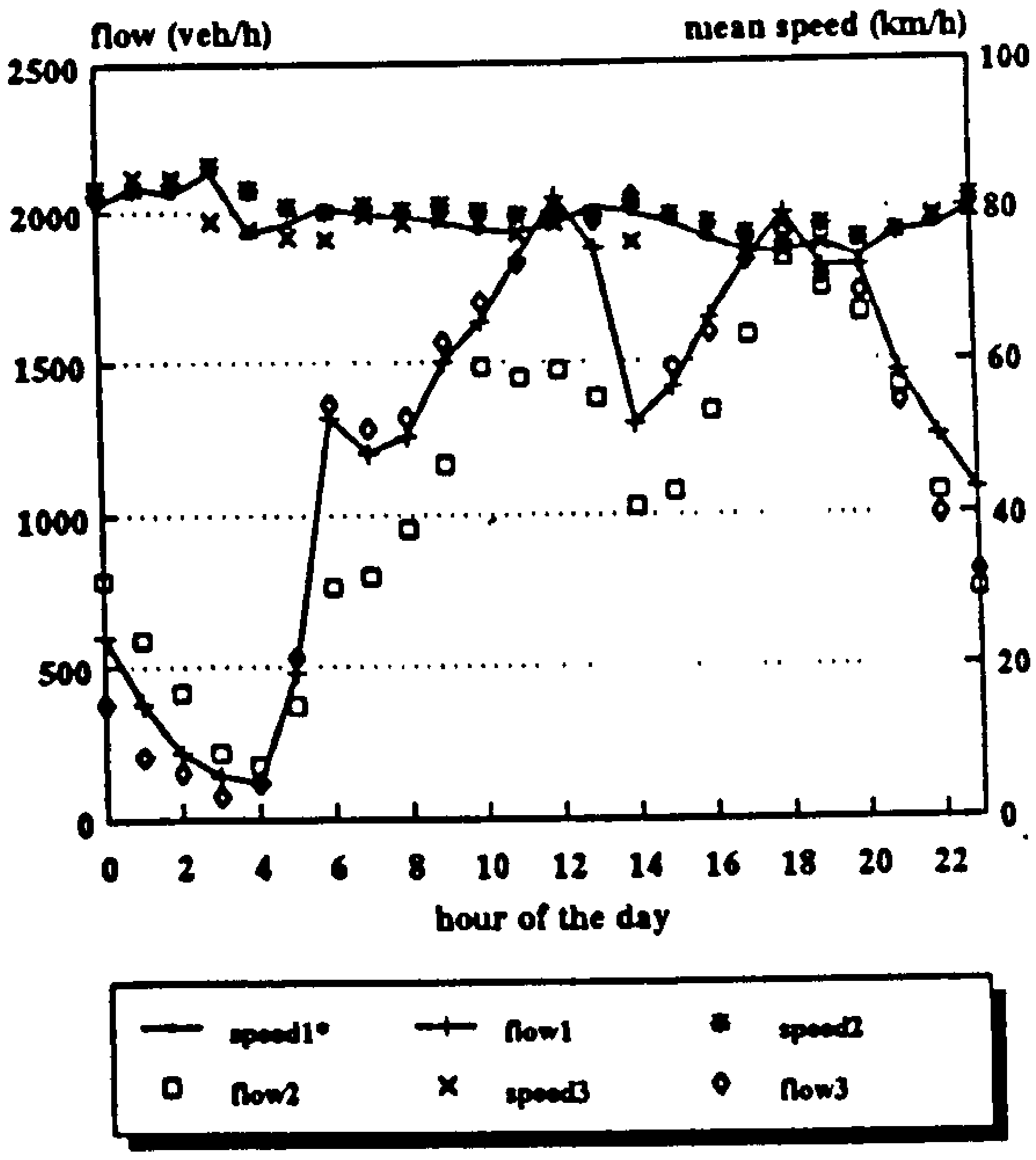
Figure 2.3b: Continued (speed limit 80 km/h)

Site:BFA80



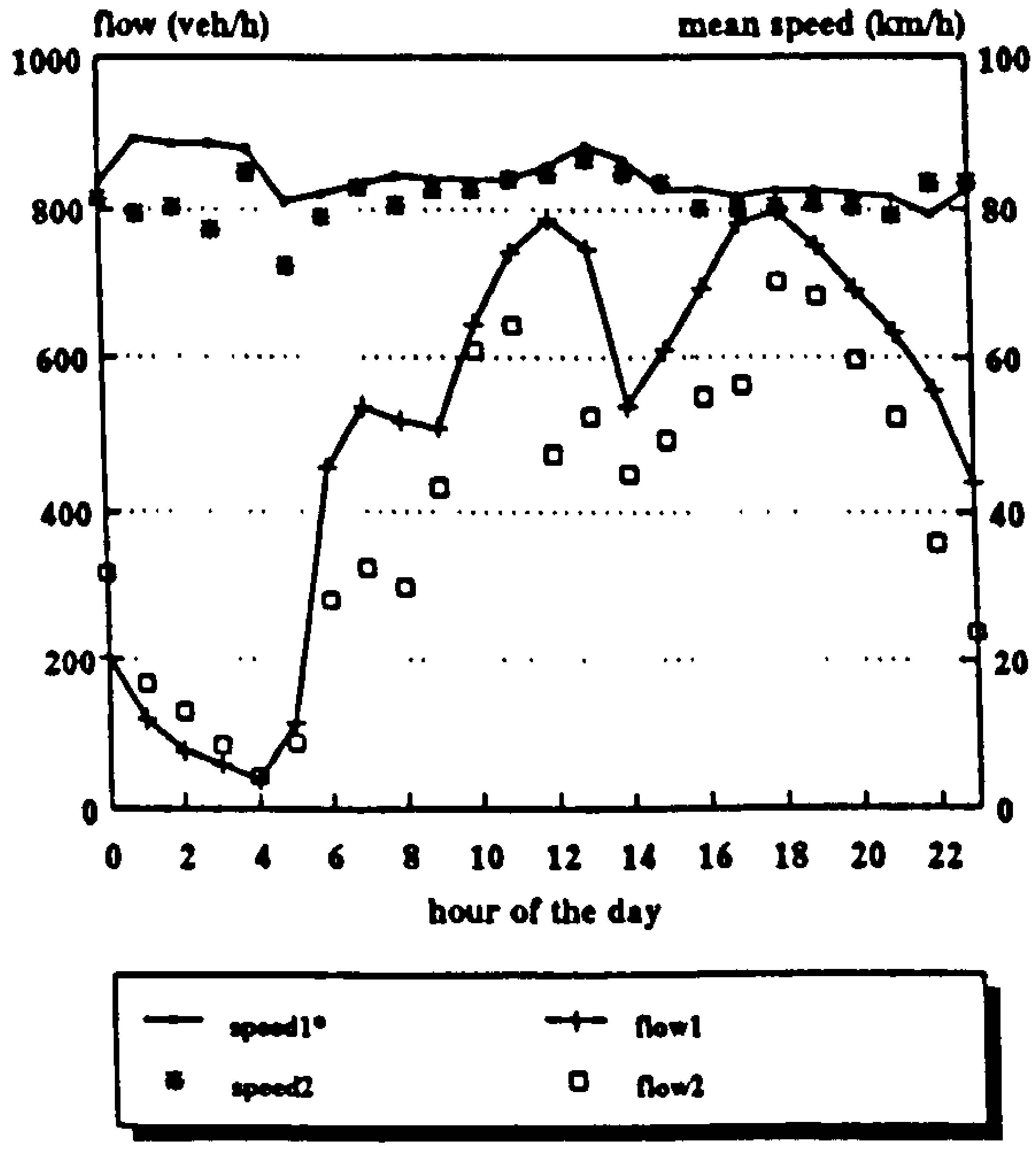
day time from 7-17 hour
*observation day

Site:BHA80



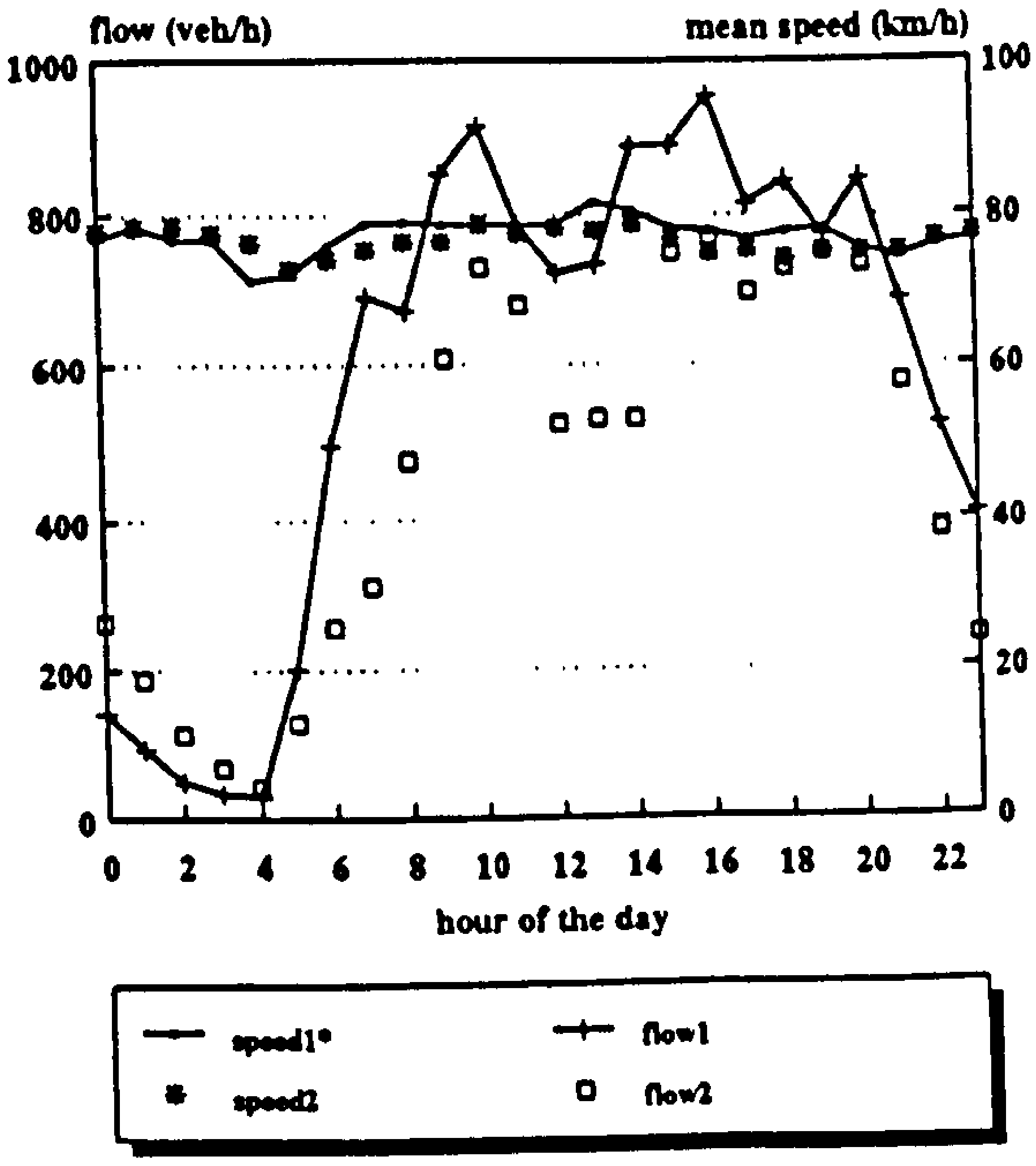
day time from 7-17 hour
*observation day

Site:BKH80



day time from 7-17 hour
*observation day

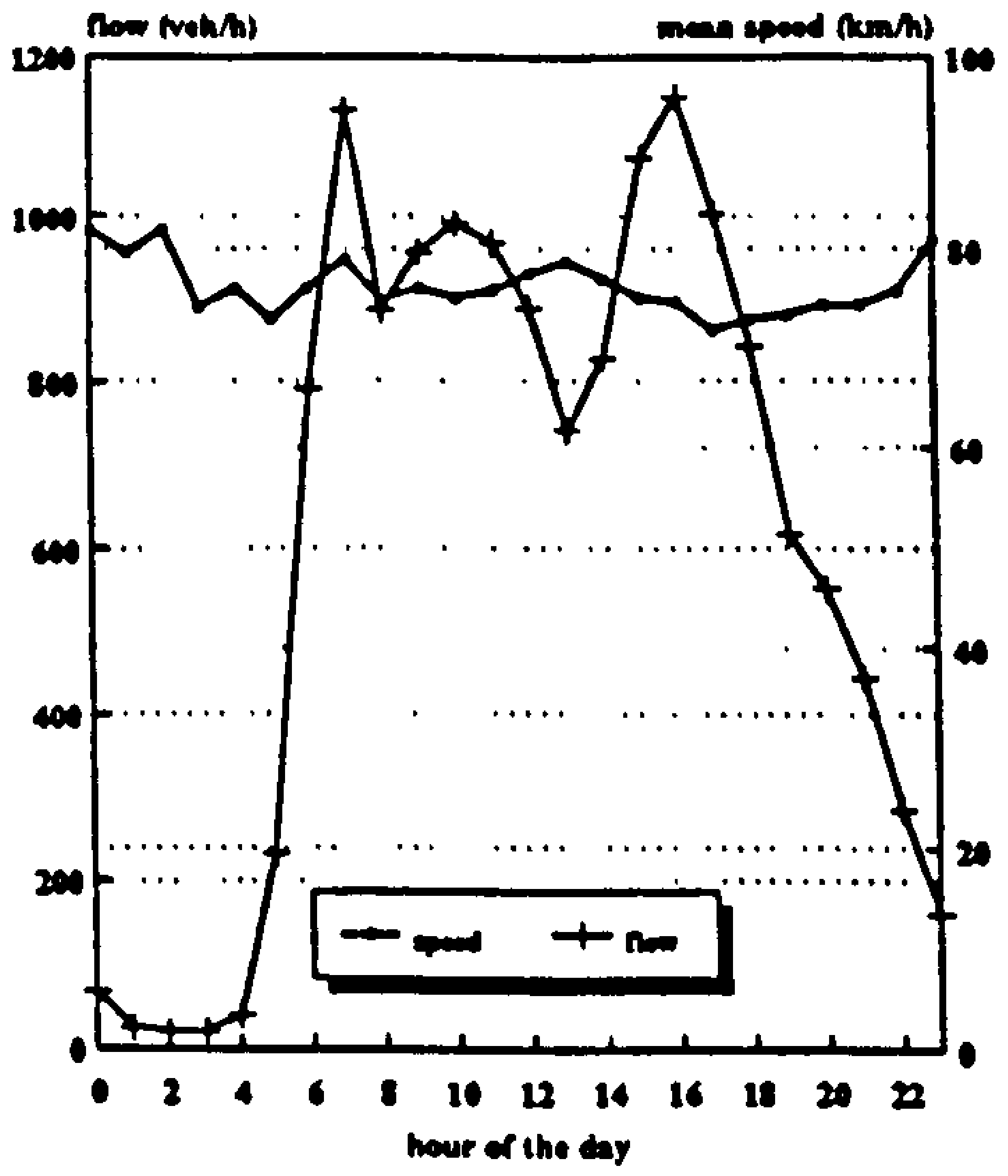
Site:BGH80



day time from 7-17 hour
*observation day

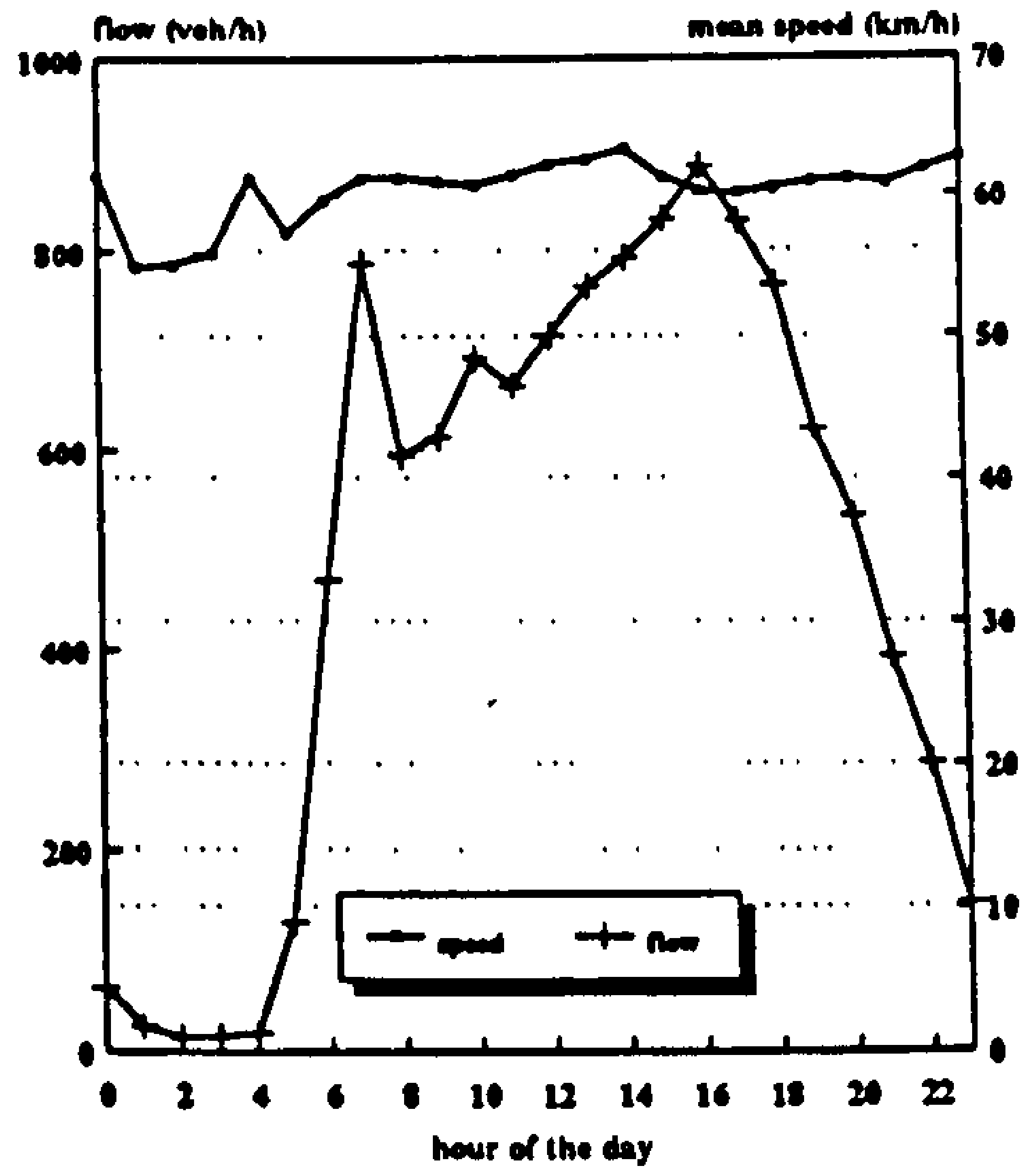
Figure 2.3b: Continued (speed limit 70 km/h)

Site:BSA70



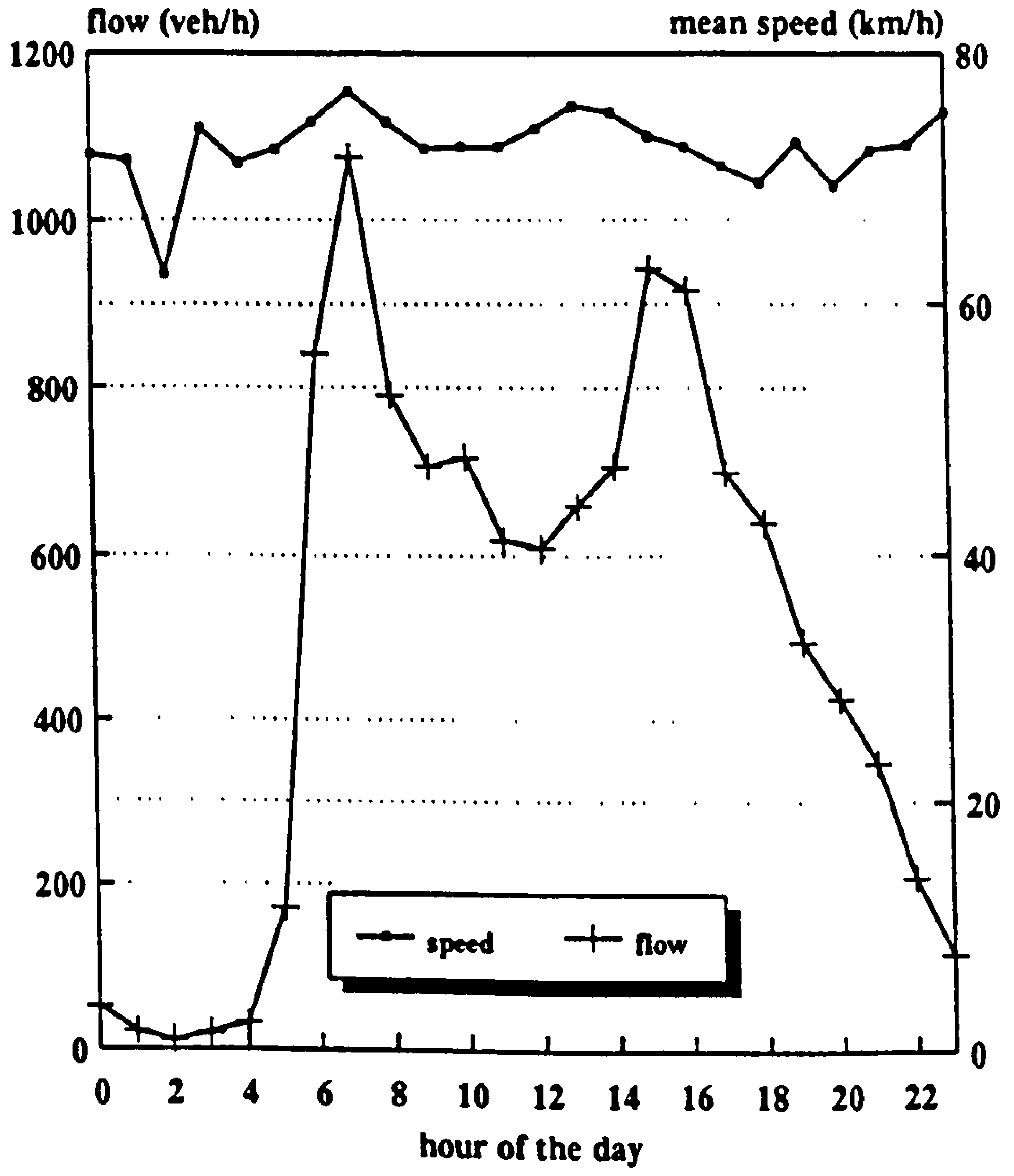
day time from 7-17 hour

Site:BSE70



day time from 7-17 hour

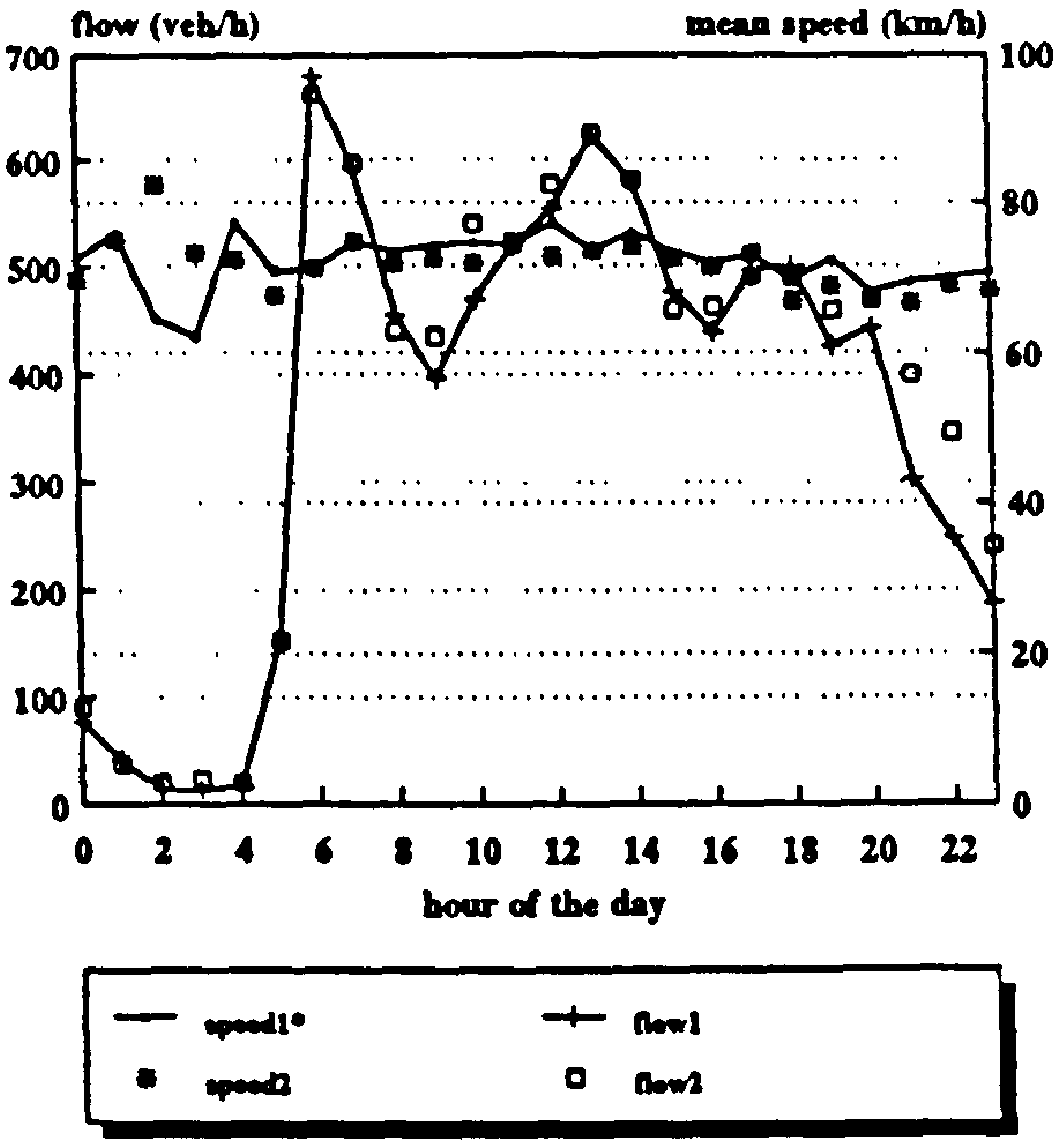
Site:BBU70



day time from 7-17 hour

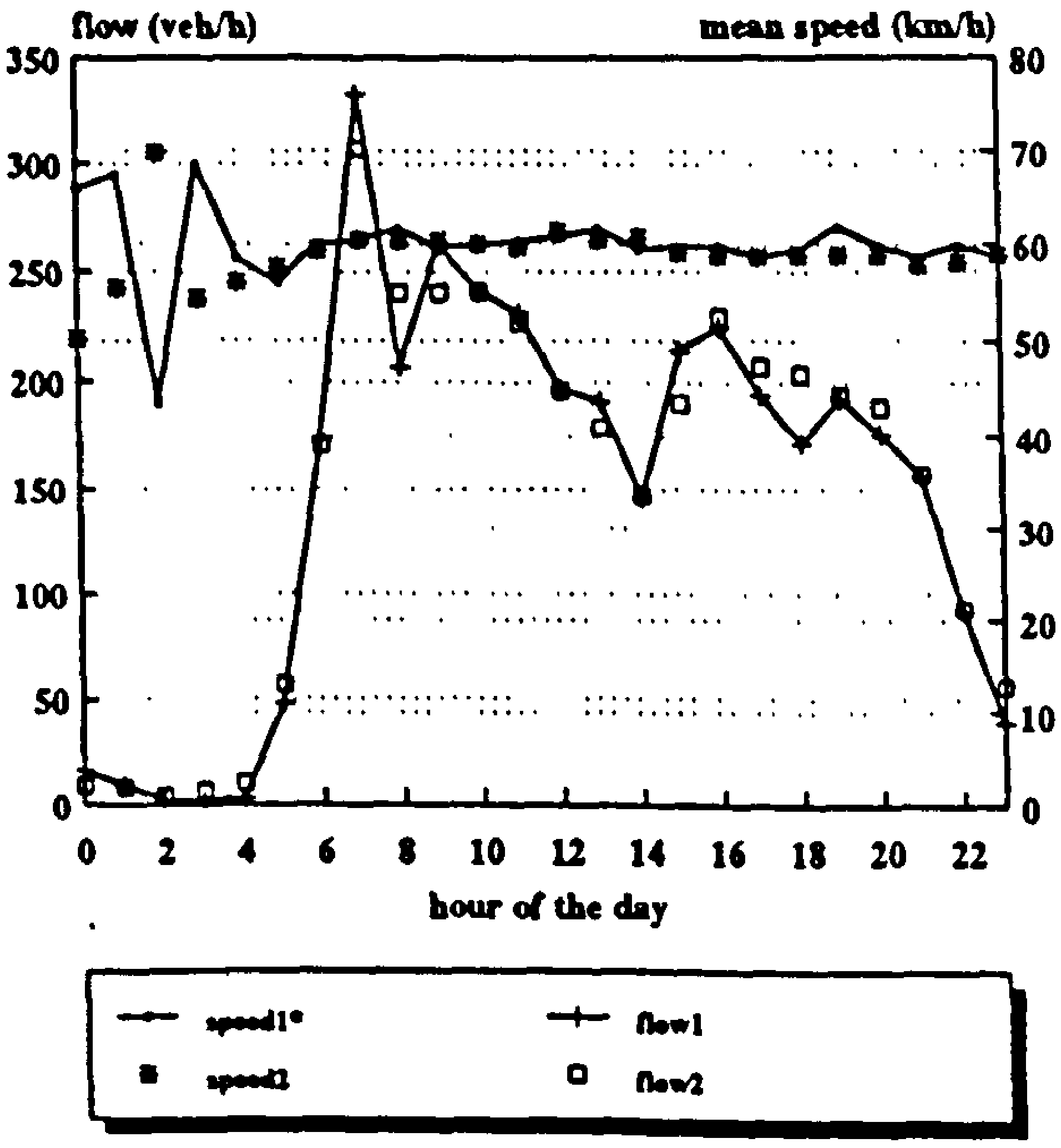
Figure 2.3b: Continued (speed limit 50 km/h)

Site:BKU50



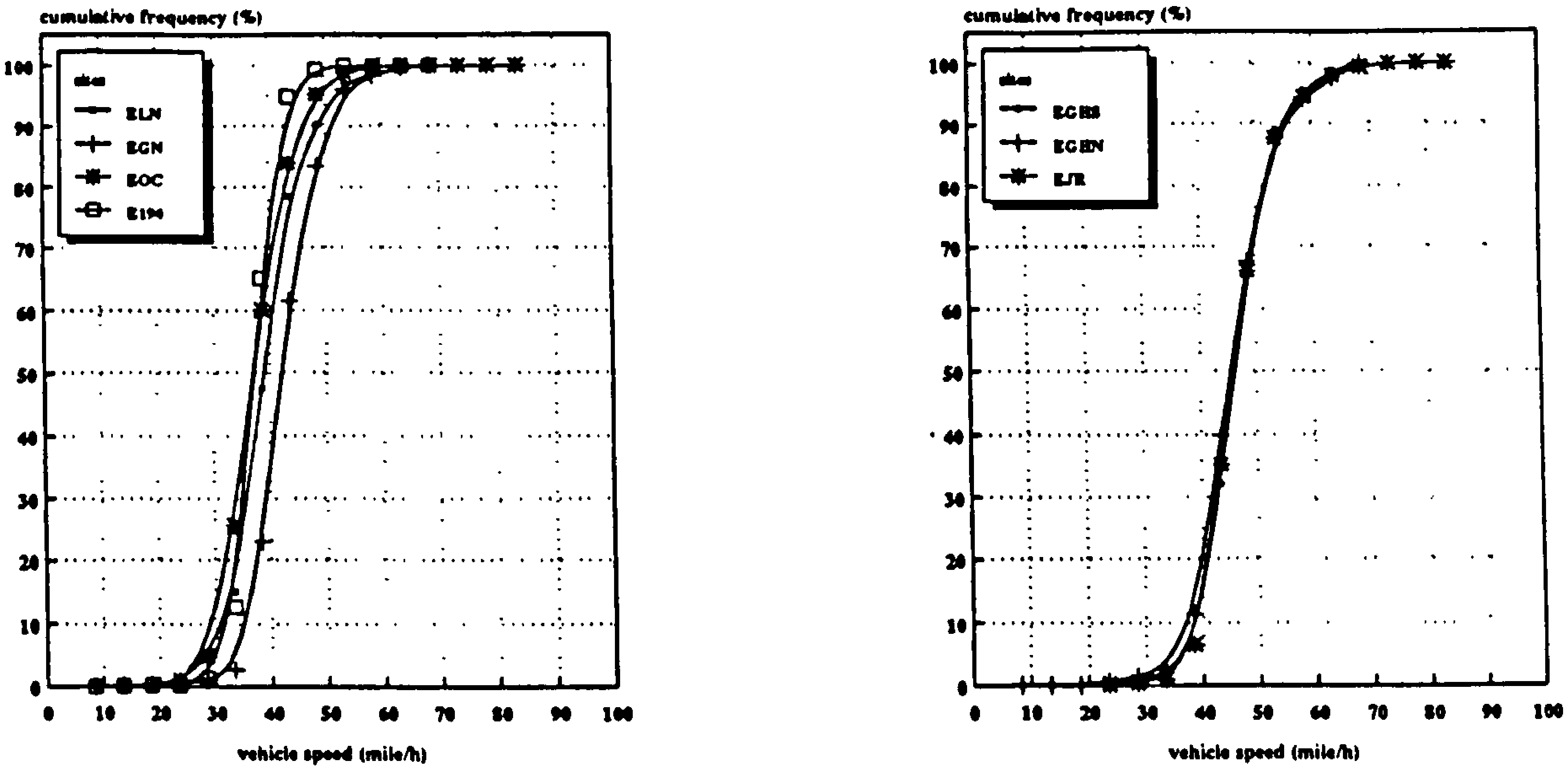
day time from 7-17 hour
*observation day

Site:BSA50



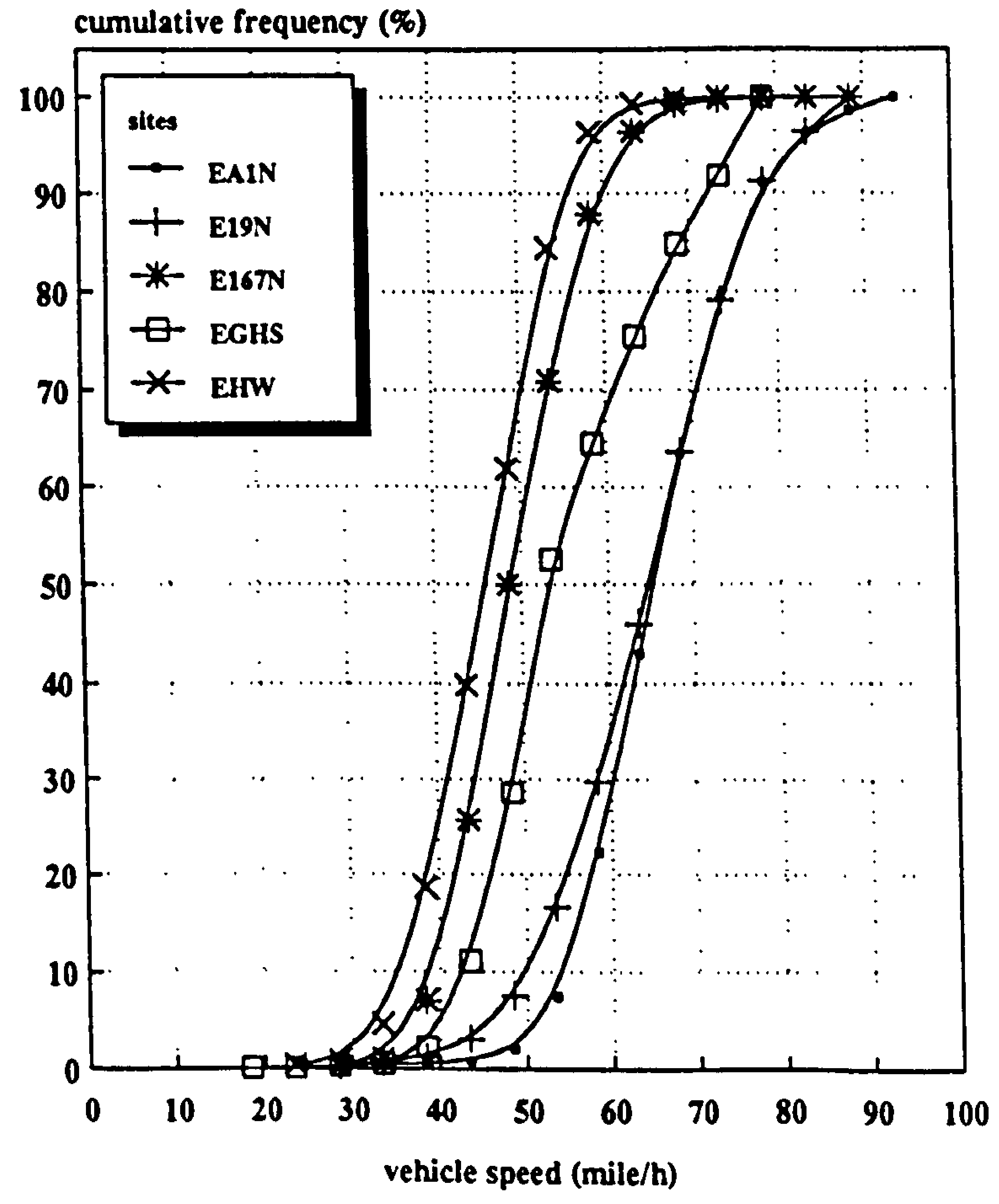
day time from 7-17 hour
*observation day

Figure 2.4a: Cumulative Speed Distributions (Tyne & Wear)



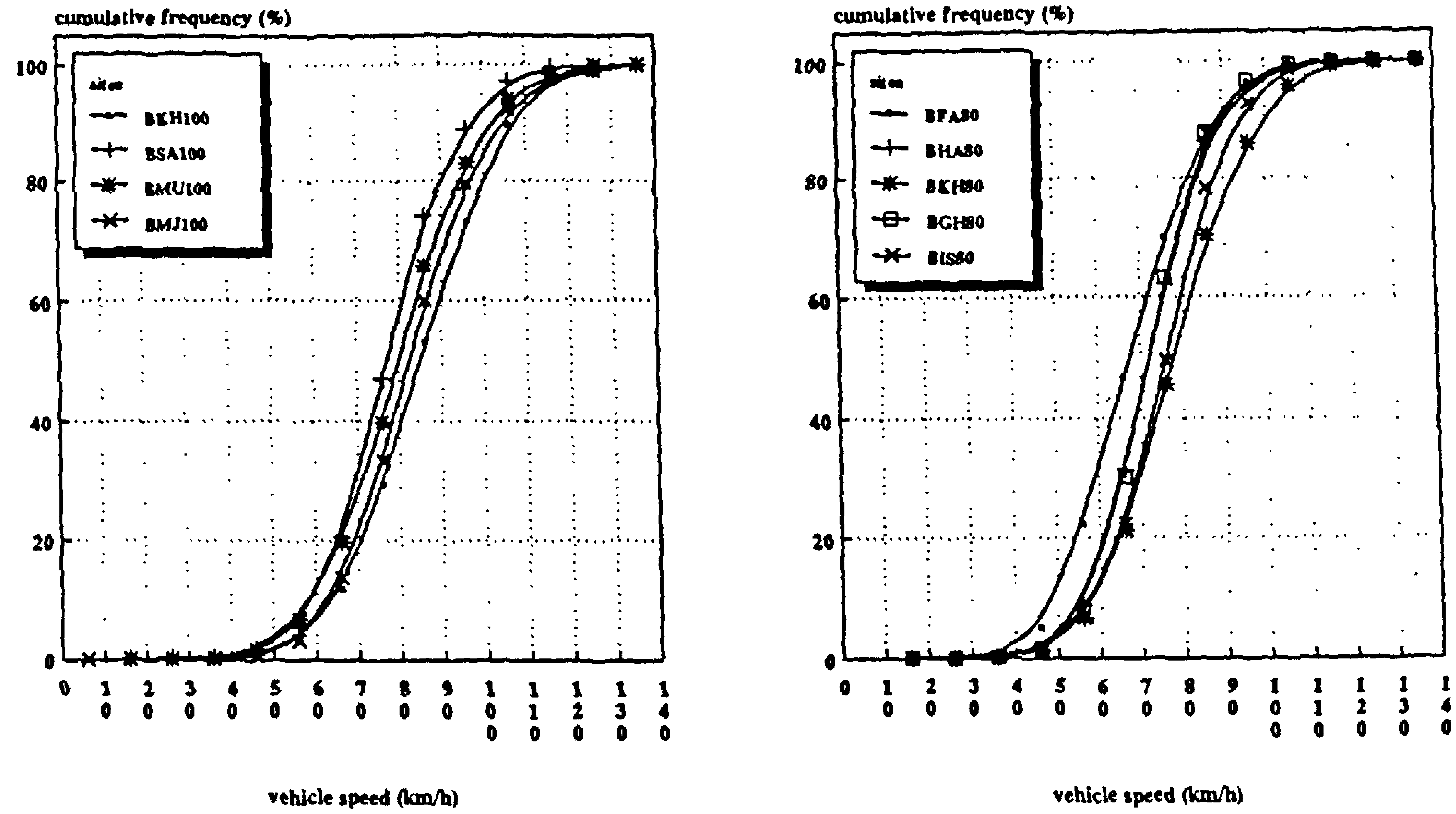
speed limit 40 mile/h

speed limit 50 mile/h



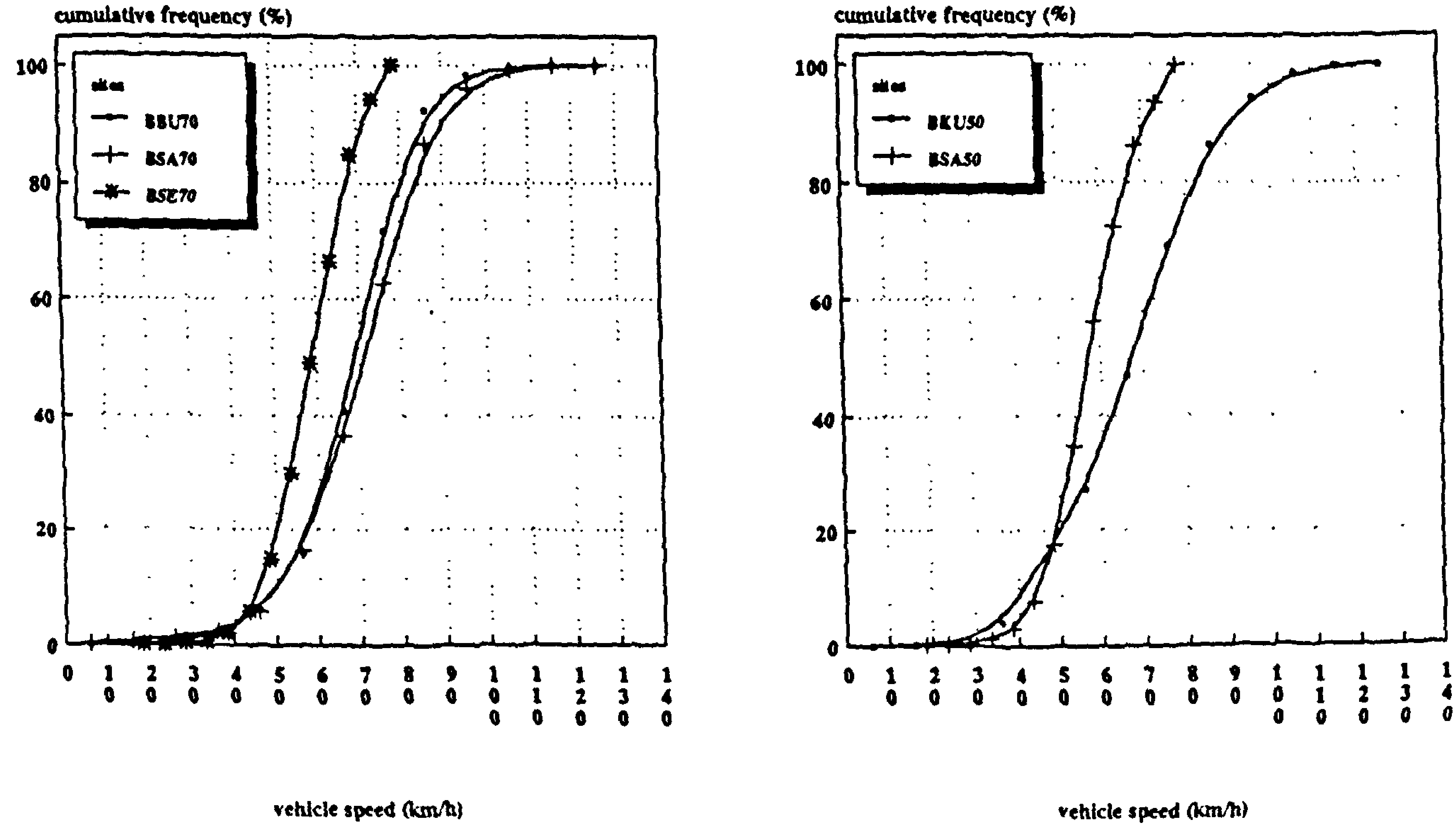
speed limit 70 mile/h

Figure 2.4b: Cumulative Speed Distributions (Bahrain)



speed limit 100 km/h

speed limit 80 km/h



speed limit 70 km/h

speed limit 50 km/h

Table 2.4a: The Speed Characteristics of the Sites (Tyne & Wear)

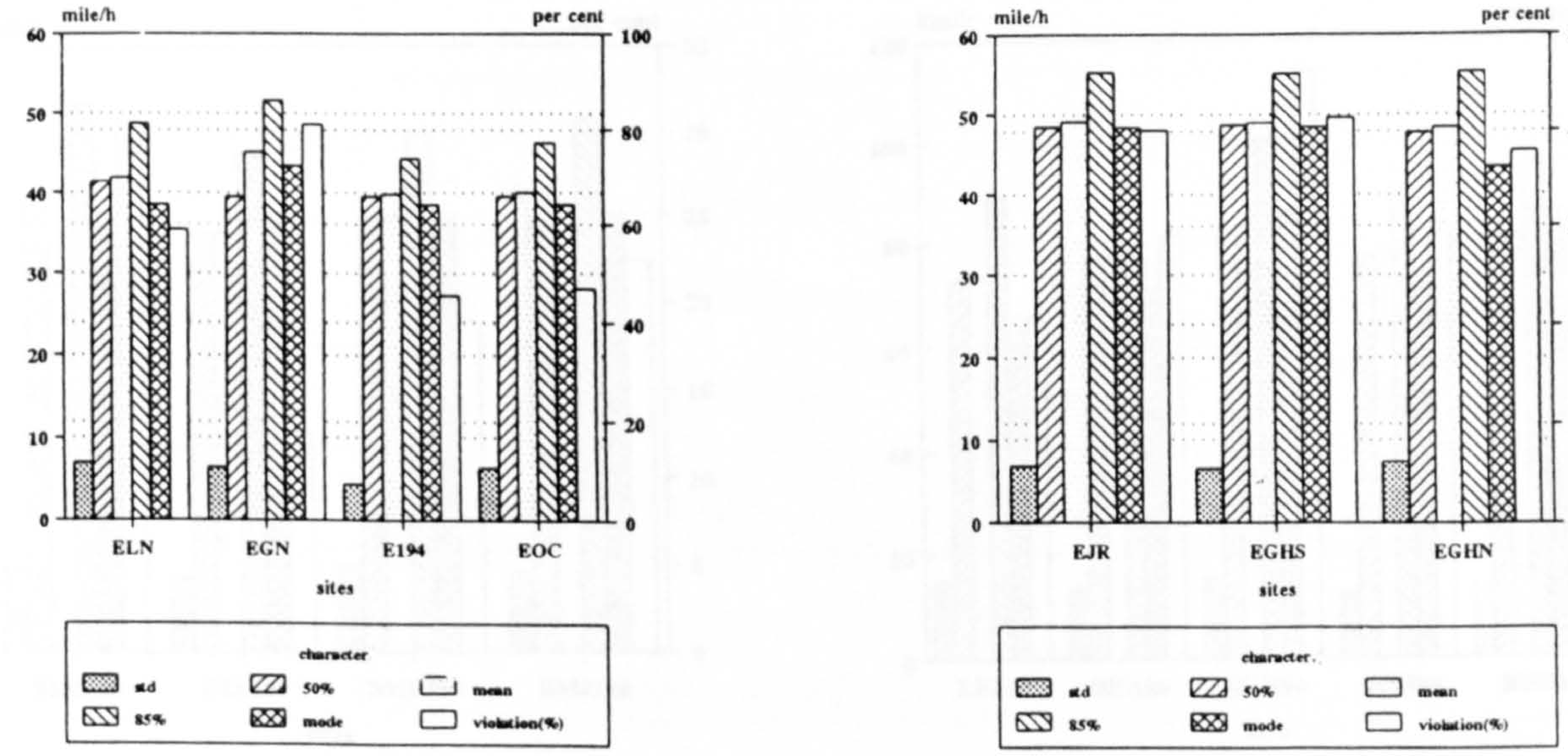
Characters. Sites (no. of days of observation) (speed limit)	Mean speed for each day of observation (mile/h)	Standard deviation of for each day of observation (mile/h)	Flow (veh /h/lane)	Fiftieth percentile speed (median) (mile/h)	Eighty-fifth percentile speed (mile/h)	Mode (mile/h)	Non-compliance (%)
E167N (4 days) (70 mile/h)	51.6 52.0 51.9 51.9	7.9 8.2 8.0 7.6	370	51.02	60.16	46-50	1.34
E167S (4 days) (70 mile/h)	51.4 52.7 52.3 51.6	8.7 8.3 8.3 8.2	402	50.68	60.54	46-50	2.04
EA1N (3 days) (70 mile/h)	68.3 68.4 66.7	9.0 9.3 8.5	386	67.70	78.35	61.-65	40.61
EA1S (2 days) (70 mile/h)	66.10 66.3	10.3 10.8	440	66.40	77.03	66-70	36.37
E19N (5 days) (70 mile/h)	66.7 66.9 67.3 66.2 66.1	11.0 10.7 10.7 10.7 10.8	380	67.12	78.44	66-70	39.84
E19S (5 days) (70 mile/h)	66.9 67.7 67.5 67.6 67.0	12.7 12.3 12.0 12.8 13.4	390	66.00	82.06	56-65	40.51
EGHSB (4 days) (70 mile/h)	57.9 58.3 57.7 58.3	10.7 10.6 10.5 10.6	189	55.47	71.12	51-55	17.05
EHW (1 day) (70 mile/h)	47.8	8.4	385	48.31	56.23	46-55	0.27
EJR (6 days) (50 mile/h)	49.1 49.3 49.1 48.9 49.2 48.5	6.8 6.8 6.9 6.7 6.8 6.7	212	48.41	55.34	46-50	40.12
EGHNA (11 days) (50 mile/h)	48.4 48.4 48.4 48.5 48.3 48.0 48.1 47.4 47.6 47.6 47.0	7.4 7.6 7.6 7.3 7.3 7.2 7.3 7.2 7.3 7.3 7.1	226	47.83	55.30	41-45	37.88

Characters. Sites (no. of days of observation) (speed limit)	Mean speed for each day of observation (mile/h)	Standard deviation of for each day of observation (mile/h)	Flow (veh /h/lane)	Fiftieth percentile speed (median) (mile/h)	Eighty-fifth percentile speed (mile/h)	Mode (mile/h)	Non-compliance (%)
EGHSA (10 days) (50 mile/h)	49.0 49.4 49.0 49.2 48.9 48.4 48.7 48.4 48.2 49.1	6.5 6.7 6.7 6.7 6.7 6.3 6.4 6.4 7.2 6.7	185	48.7	55.14	46-50	41.39
ELN (2 days) (40 mile/h)	41.9 41.5	7.0 7.1	99	41.41	48.78	36-40	59.01
EGN (4 days) (40 mile/h)	45.2 45.5 45.5 44.7	6.3 6.4 6.4 6.6	208	39.51	51.60	41-45	81.12
E194 (6 days) (40 mile/h)	39.8 39.9 39.8 39.9 39.5 39.5	4.4 4.2 4.0 4.4 4.1 4.1	205	39.56	44.36	36-40	45.40
EOC (1 day) (40 mile/h)	40.0	6.3	418	39.54	46.46	36-40	46.82

Table 2.4b: The Speed characteristics of the Sites (Bahrain)

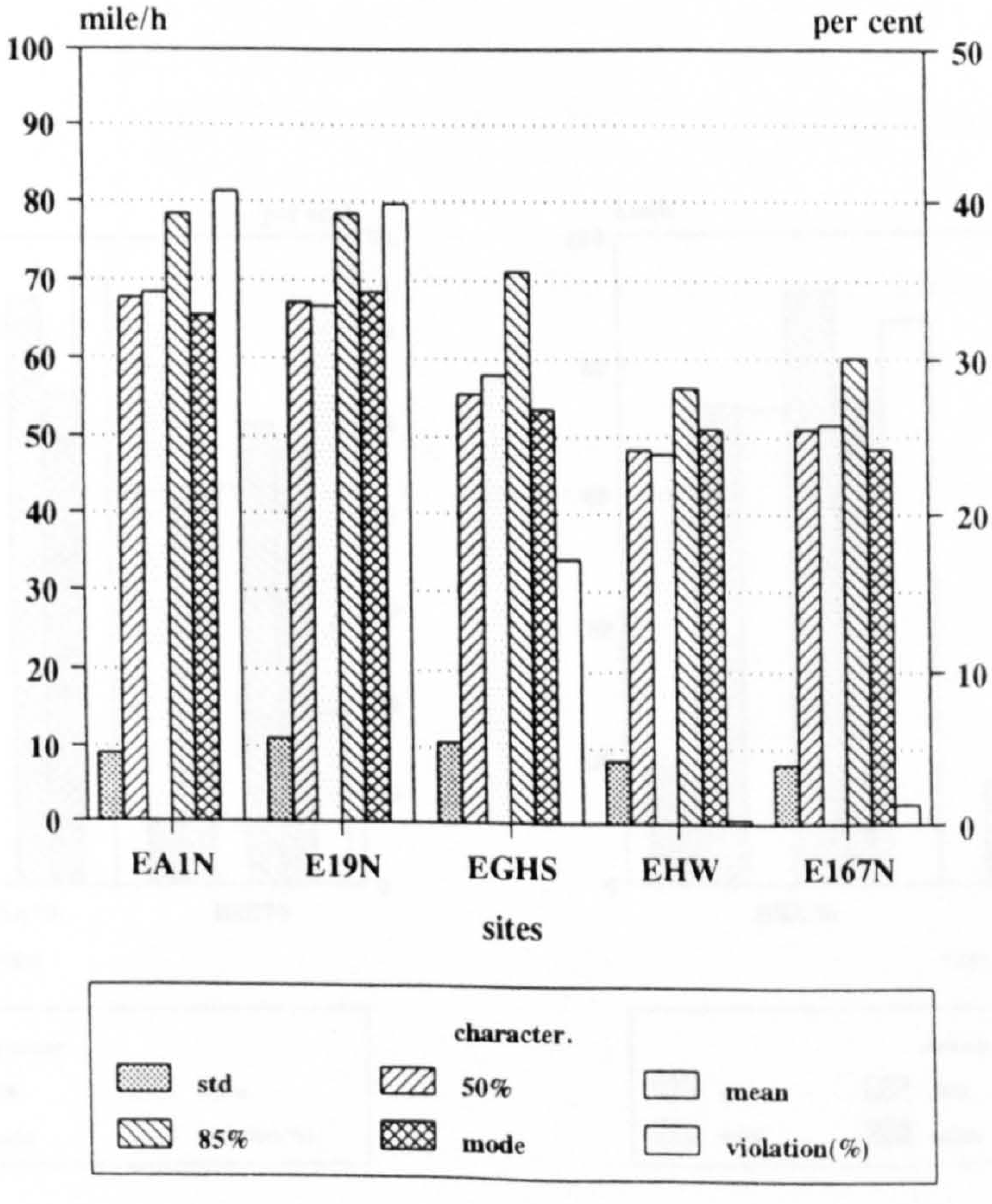
Characters. Sites	Mean speed (km/h)	Standard deviation (km/h)	Flow (veh /h/lane)	Fiftieth percentile speed (Median) (km/h)	Eighty-fifth percentile Speed (km/h)	Mode (km/h)	Non-compliance (%)
BKH100	90.8	17.0	228	90.4	108.6	81-91	30.8
BSA100	82.5	14.8	188	82.1	98.4	81-91	12.6
BMU100	85.0	16.9	66	84.9	102.9	81-91	18.9
BMJ100	87.8	15.7	247	87.2	105.2	81-91	22.3
BFA80	73.3	14.9	377	72.6	89.2	61-71	33.0
BHA80	77.5	13.3	419	77	90.6	71-81	40.6
BKH80	83.4	15.6	167	82.8	100.4	81-91	57
BGH80	77.8	12.6	195	77.4	90.3	71-81	41.6
BIS100	80.8	13.9	240	81	95.4	81-91	8.8
BBU70	73.3	13.8	246	74	87.4	71-81	62.1
BSA70	75.5	16	307	76.4	90.5	71-81	65.7
BSE70	61.2	9.6	243	61.4	71.2	66-71	18.9
BKU50	72.8	18.4	181	73.8	91.1	71-81	86.3
BSA50	60.1	10.1	73	60	70.7	56-61	84.3

Figure 2.5a: Speed Characteristics (Tyne & Wear)



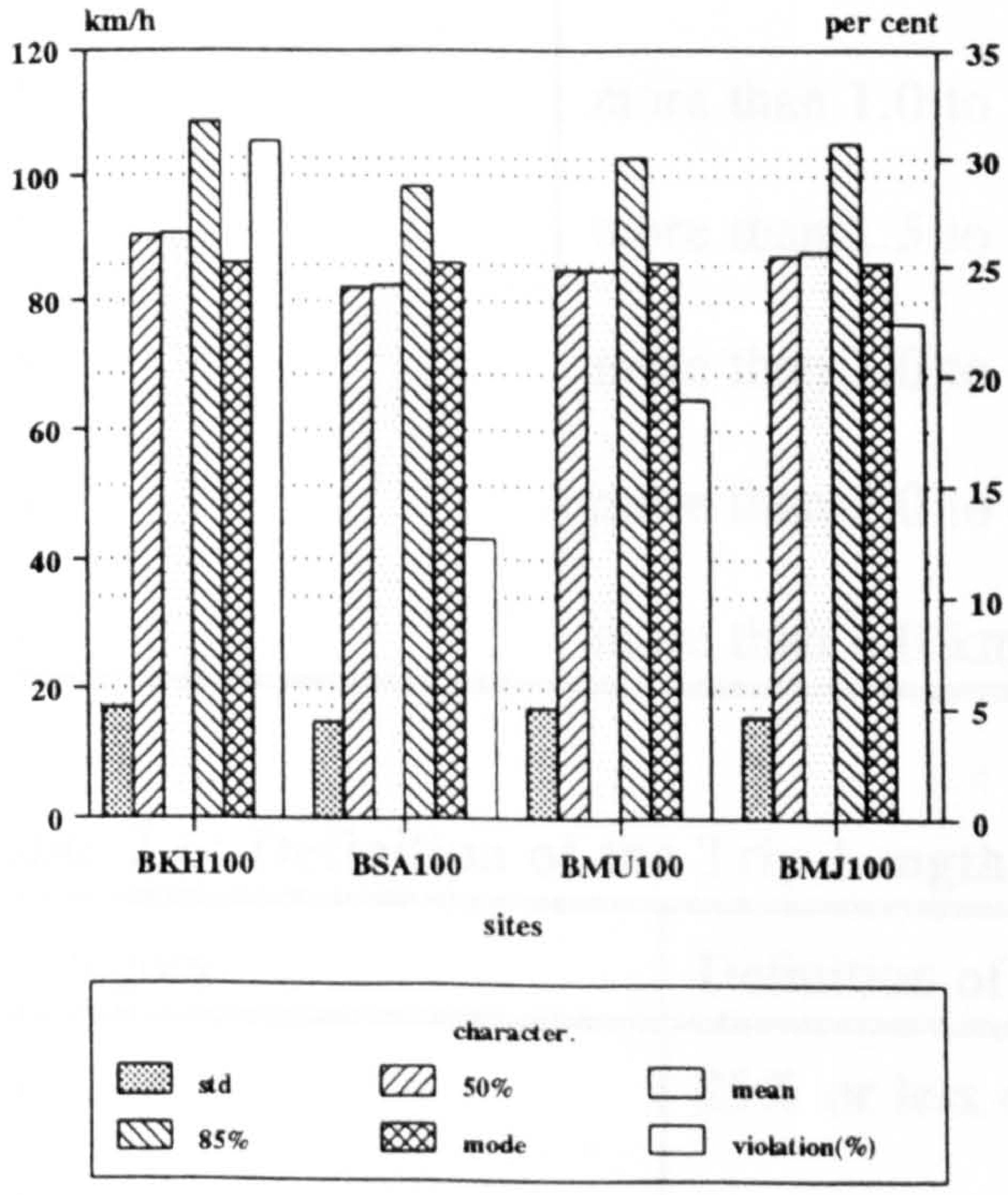
speed limit 40 mile/h

speed limit 50 mile/h

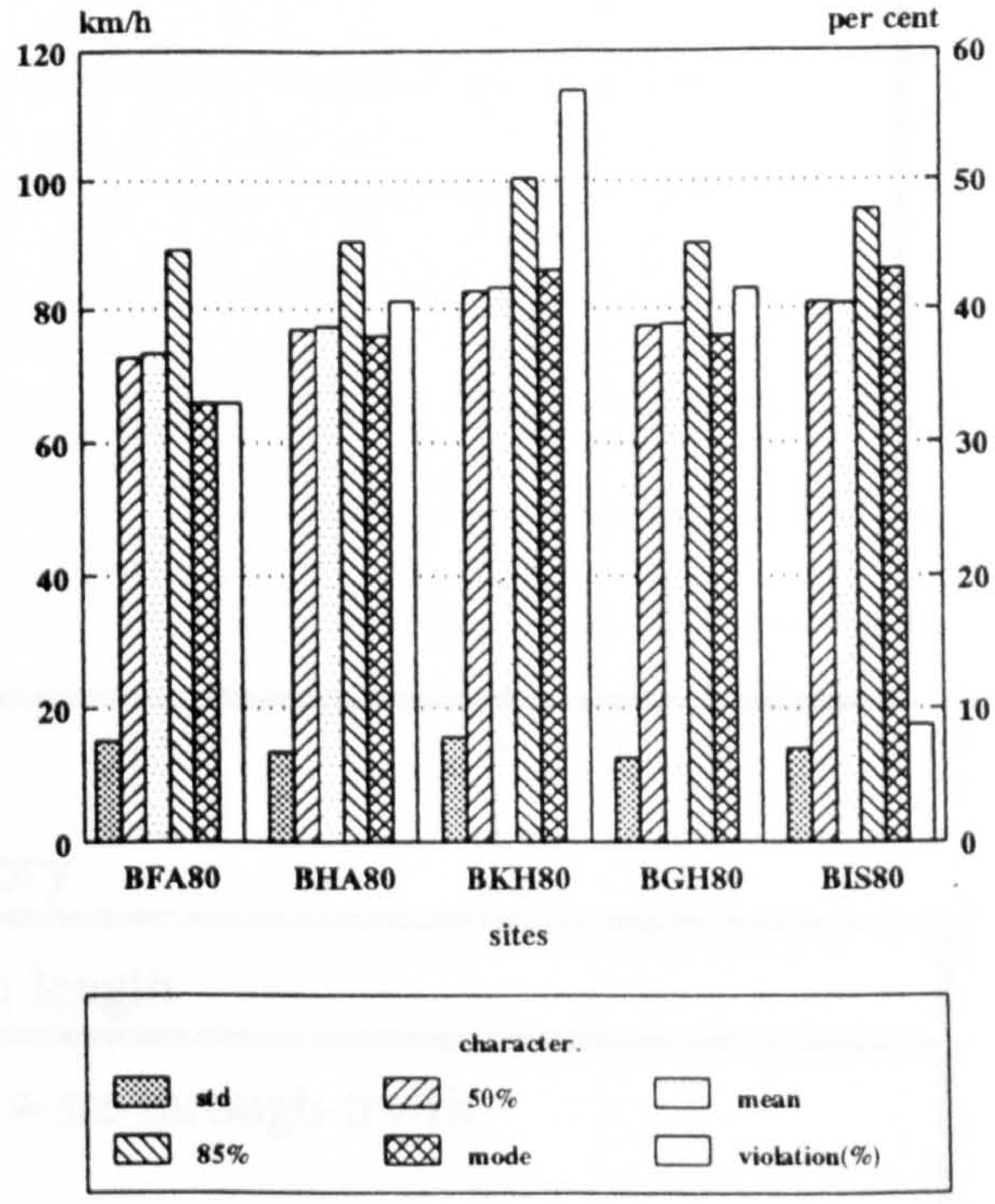


speed limit 70 mile/h

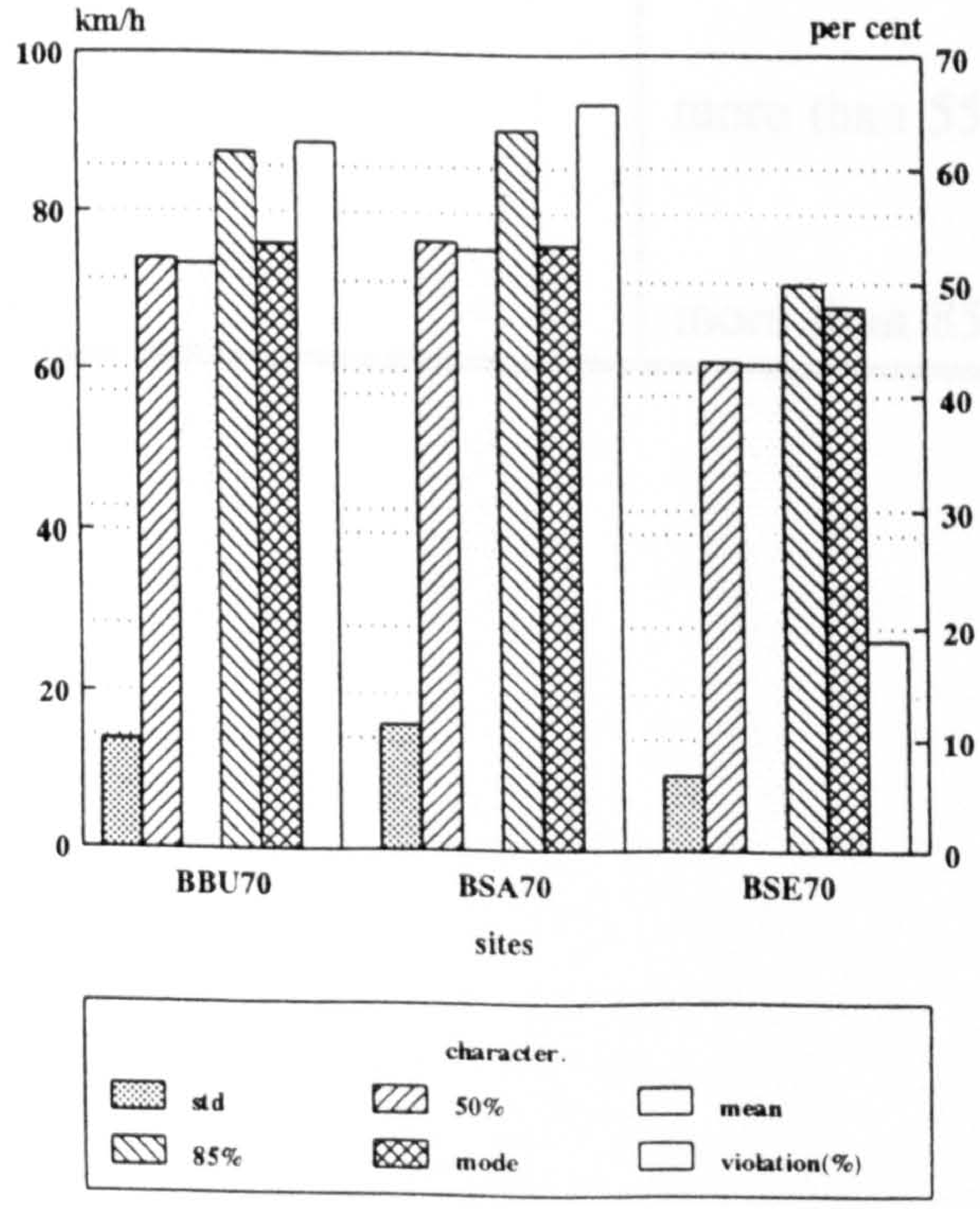
Figure 2.5b: Speed Characteristics (Bahrain)



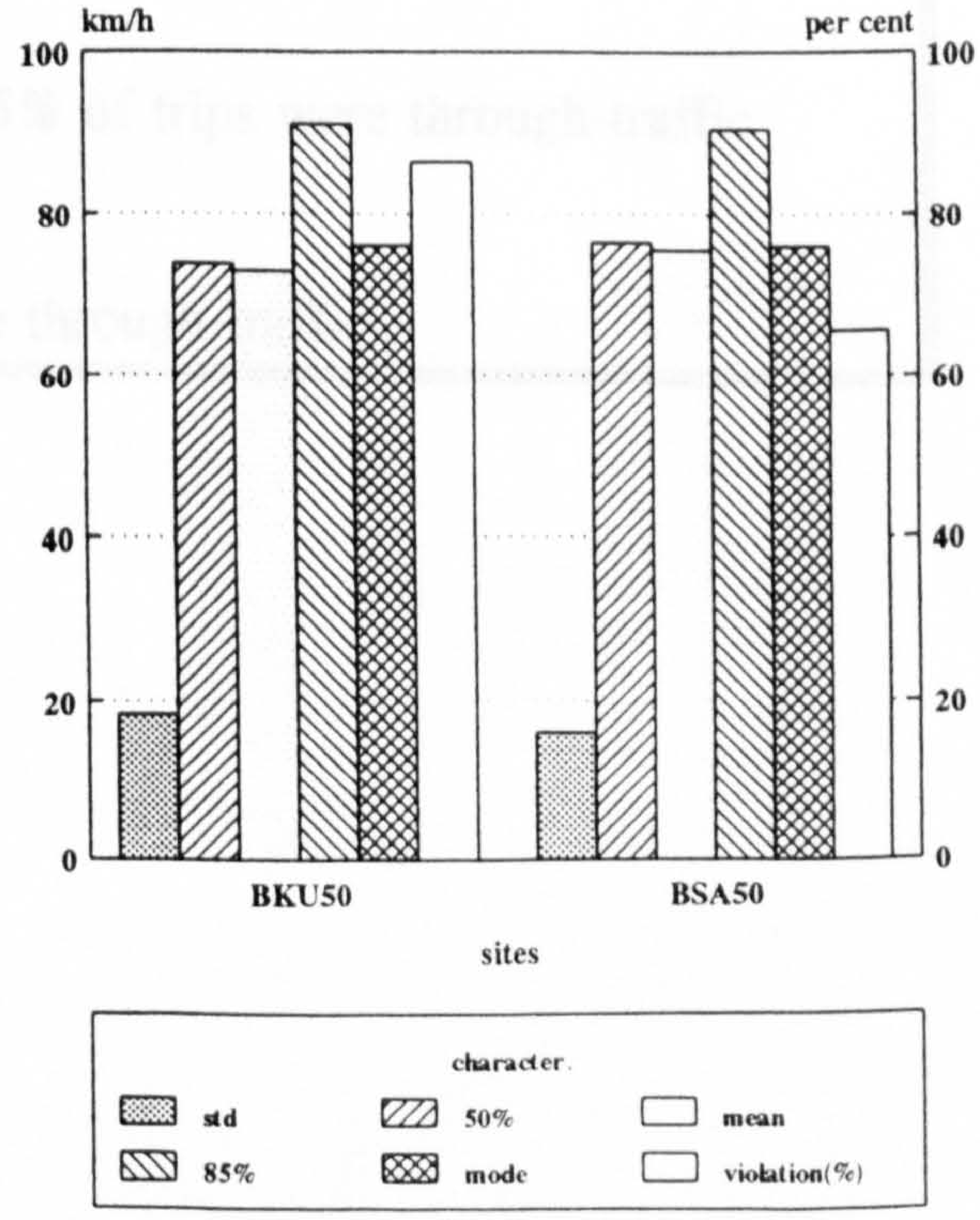
speed limit 100 km/h



speed limit 80 km/h



speed limit 70 km/h



speed limit 50 km/h

Table 2.5: Definition of the Section Length Category

Category	Length of the section
1	0.5 km or less
2	more than 0.5 to 1.0 km
3	more than 1.0 to 1.5 km
4	more than 1.5 to 2.0 km
5	more than 2.0 to 3.0 km
6	more than 3.0 to 4.0 km
7	more than 4.0 km

Table 2.6: Definition of the Trip Length Category

Category	Definition of the trip length
1	25% or less of trips were through-traffic
2	more than 25% to 45% of trips were through-traffic
3	more than 45% to 55% of trips were through-traffic
4	more than 55% to 85% of trips were through-traffic
5	more than 85% were through-traffic

Table 2.7a: Input Data for the Speed Limit Model (Tyne & Wear)

Site	Speed limit (mile/h)	Mean speed (mile/h)	85% speed (mile/h)	HVC (%)	Trip* length category	Length** category
E167	70	51.9	60.35	4.3	2	3
EA1	70	67.2	77.69	18.4	4	7
E19	70	67.0	80.25	6.1	3	6
EGHSB	70	58.1	56.23	7.7	3	2
EHW	70	47.8	71.12	11	2	1
EJR	50	49.0	55.34	10	3	3
EGHNA	50	48.0	55.30	7.7	2	2
EGHSA	50	48.8	55.14	7.7	3	2
E194	40	39.7	44.36	10	2	1
ELN	40	41.7	48.78	5	2	3
EGN	40	45.2	51.60	7	3	2
EOC	40	40	46.46	11	2	2

* See Table 2.6
** See Table 2.5

Table 2.7b: Input Data for the Speed Limit Model (Bahrain)

Site	Speed limit (km/h)	Mean speed (km/h)	85% speed (km/h)	HVC (%)	No. of lanes	Trip length cat.*	Length Cat.**
BKH100	100	90.8	108.60	3.9	3	5	5
BSA100	100	82.5	98.40	3.5	2	3	5
BMU100	100	85.0	102.90	7.9	2	5	2
BMJ100	100	87.8	105.20	15.7	3	4	4
BFA80	80	73.3	89.20	15.9	3	3	2
BKH80	80	83.4	100.40	8.0	3	4	4
BHA80	80	77.5	90.60	17.7	3	4	4
BGH80	80	77.8	90.30	6.5	3	4	3
BIS80	80	80.8	95.40	15.7	3	4	3
BBU70	70	73.3	87.40	6.4	2	3	3
BSA70	70	75.5	90.50	14	2	4	4
BSE70	70	61.2	71.20	21.2	2	2	2
BSA50	50	60.1	70.70	6.4	2	2	2
BKU50	50	72.8	91.10	7.5	2	4	4

* See Table 2.6
** See Table 2.5

2.7.3 The Effect of the Speed Limit on the Speed of Traffic Using Linear Regression Analysis

All Possible Variables

The possible variables that were considered to have an effect on the speed of traffic were regressed against the mean speed of the traffic and the eighty fifth percentile speed. Different forms of relationships were tested. The first relationship was a linear fit.

The equations had the following forms:

Tyne and Wear:

$$MST = 15.19 + 0.36\ SPL - 0.28\ HVC + 1.89\ LSEC + 4.82\ TRPLN$$

$$EFPS = 14.64 + 0.50\ SPL - 0.47\ HVC + 2.25\ LENGTH + 5.55\ TRPLN + 2.25\ LSEC$$

MST: the mean speed of traffic (mile/h)
EFPS: the eighty-fifth percentile speed of traffic (mile/h)
SPL: the speed limit (mile/h)
HVC: the heavy vehicle content (%)
LSEC: the length of section category (from 1 to 7)
TRPLN: the trip length category (from 1 to 5)

Bahrain

$$MST = 35.00 + 0.24\ SPL - 0.23\ HV + 2.34\ NLN + 1.50\ LSEC + 4.15\ TRPLN$$

$$EFPS = 43.59 + 0.25\ SPL - 0.32\ HV + 1.77\ NLN + 5.92\ TRPLN + 1.83\ LSEC$$

MST: the mean speed of traffic (km/h)
EFPS: the eighty fifth percentile speed of traffic (km/h)
SPL: the speed limit (km/h)
NLN: number of lanes
Other variables have been defined previously.

The Significant Variables Only

Only the significant variables were included in the final forms of the regression equations. The final equations had the following form:

Tyne and Wear

$$MST = 14.59 + 0.36\ SPL + 4.07\ TRPLN + 1.87\ LSEC$$

$$EFPS = 13.7 + 0.50\ SPL + 4.31\ TRPLN + 2.21\ LSEC$$

The variables were defined previously.

Bahrain

$$MST = 33.50 + 0.26\ SPL + 4.62\ TRPLN + 1.93\ LSEC$$

$$EFPS = 41.93 + 0.30\ SPL + 7.35\ LSEC$$

The variables were defined previously.

(Appendix I, Exhibits 2.2a and 2.2b, and Tables 2.8a and 2.8b)

(Appendix I, Exhibits 2.3a and 2.3b, and Tables 2.9a and 2.9b)

Table 2.8a: Results of Linear Regression Analysis: the Effect of the Speed Limit on the Mean Speed of Traffic (Tyne and Wear)

i) All the variables

Predictor	Coefficient	t-ratio	p-value
Constant	15.19	3.91	0.006
Speed Limit	0.36	6.31	0.000
Heavy Vehicle	-0.28	-1.32	.230
Length Categ.	1.89	3.48	0.010
Trip Length	4.82	3.15	0.020

R^2 =93.8%

ii) The significant variables

Predictor	Coefficient	t-ratio	p-value
Constant	14.59	3.62	0.007
Speed Limit	0.36	6.07	0.000
Length Categ.	1.87	3.30	0.011
Trip Length	4.06	2.74	0.026

R^2 =93.2%

Table 2.8b: Results of Linear Regression Analysis: the Effect of the Speed Limit on the Mean Speed of Traffic (Bahrain)

i) All the variables

Predictor	Coefficient	t-ratio	p-value
Constant	34.97	9.24	0.000
Speed Limit	0.24	5.75	0.000
No. of lanes	2.34	1.85	0.100
Heavy vehicle	-0.23	-2.01	0.080
Length categ.	1.50	2.41	0.040
Trip length	4.15	5.35	0.000

R^2 =94.9%

ii) The significant variables

Predictor	Coefficient	t-ratio	p-value
Constant	33.47	9.80	0.000
Speed Limit	0.26	5.59	0.000
Length categ.	1.93	2.81	0.018
Trip length	4.62	5.27	0.000

R^2 =93.0%

Table 2.9a: Results of Linear Regression Analysis: the Effect of the Speed Limit on Eighty-Fifth Percentile Speed (Tyne and Wear)

i) All the variables

Predictor	Coefficient	t-ratio	p-value
Constant	14.64	2.46	0.043
Speed Limit	0.50	5.65	0.000
Heavy Vehicle	-0.47	-1.42	0.200
Length categ.	2.25	2.70	0.030
Trip length	5.55	2.36	0.050

R^2 =90.8%

ii) The significant variables

Predictor	Coefficient	t-ratio	p-value
Constant	13.67	2.18	0.060
Speed limit	0.50	5.36	0.000
Length categ.	2.21	2.50	0.040

R^2 =89.7%

Table 2.9b: Results of Linear Regression Analysis: the Effect of the Speed Limit on the Eighty-Fifth Percentile Speed (Bahrain)

i) All the variables

Predictor	Coefficient	t-ratio	p-value
Constant	43.59	6.20	0.000
Speed Limit	0.25	3.29	0.010
No. of lanes	1.77	0.75	0.470
Heavy vehicle	-0.32	-1.52	0.170
Length categ.	1.83	1.59	0.150
Trip length	5.92	4.11	0.000

R^2 =88.7%

ii) The significant variables

Predictor	Coefficient	t-ratio	p-value
Constant	41.93	6.69	0.000
Speed Limit	0.30	3.47	0.010
Trip Length	7.36	4.73	0.000

R^2 =84.2%

The Predictions from the Models

A comparison was carried out between the observed and the predicted mean speed and the eighty-fifth percentile speed of the traffic at different sites. The mean speeds and eighty-fifth percentile speeds of traffic at various speed limits were predicted for the sites: EA1 and BKH100, have been included in the thesis as examples (see Appendix I Exhibits 2.5a and 2.5b and Figures 2.6a, 2.6b, 2.7a and 2.7b).

The Confidence Intervals for the Coefficients

The confidence intervals for the coefficients used in the equations were determined using the following equation:

$$a \pm t\,(\text{stdev of a})$$

a= the quantity of the coefficient
t= the t-value at 95% confidence level
stdev a = the estimated standard deviation of the quantity of the coefficients

(stdev a and t-values could be found in the regression analysis results in Appendix I for the relevant parts of the analysis)

The Significance of the Variables

The significance of the variables were derived from the following t-test equation:

$$t=\frac{v\text{-hypothesized value}}{\text{estimated stdev of } v}$$

where
v=the value of the variable
hypothesized value= 0

2.7.4 The Effect of the Speed Limit on the Speed of Traffic Using Non-Linear (Multiplicative) Regression Analysis

The same approach was used as in Section 2.8.3.

All the Possible Variables

Tyne and Wear:

$$MST = 6.89\ SPL^{.43}\ HV^{-.01}\ LSEC^{.08}\ TRPLN^{.24}$$

$$EFPS = 6.42\ SPL^{.49}\ HV^{-.03}\ LSEC^{.09}\ TRPLN^{.23}$$

The variables were defined previously.

Bahrain:

$$MST = 21.76\ SPL^{.22}\ NLN^{.05}\ HV^{-.03}\ LSEC^{.05}\ TRPLN^{.22}$$

$$EFPS = 29.37\ SPL^{.19}\ NLN^{.02}\ HV^{-.04}\ LSEC^{.05}\ TRPLN^{.26}$$

The variables were defined previously.

The Significant Variables

Tyne and Wear:

$$MST = 6.74\ SPL^{.43}\ LSEC^{.09}\ TRPLN^{.23}$$

$$EFPS = 6.17\ SPL^{.49}\ LSEC^{.10}\ TRPLN^{.20}$$

The variables were defined previously.

Bahrain:

$$MST = 18.34\ SPL^{.24}\ LSEC^{.08}\ TRPLN^{.22}$$

$$EFPS = 24.78\ SPL^{.21}\ TRPLN^{.30}$$

The variables were defined previously.

(see Appendix I Exhibits 2.6a and 2.6b, and Tables 2.10a and 2.10b)

(see Appendix I Exhibits 2.7a and 2.7b, and Tables 2.11a and 2.11b)

Table 2.10a: Results of Non-Linear (Multiplicative) Regression Analysis: the Effect of the Speed Limit on the Mean Speed of Traffic (Tyne & Wear)

i) All the variables

Predictor	Coefficient	t-ratio	p-value
Constant	6.890		
Speed limit	0.43	7.37	0.00
Heavy vehicle	-0.014	-0.36	0.73
Length categ.	0.08	2.73	0.03
Trip length categ.	0.24	3.06	0.02

R^2 =93.5%

ii) The significant variables

Predictor	Coefficient	t-ratio	p-value
Constant	6.74		
Speed limit	0.43	7.81	0.00
Length categ.	0.09	3.18	0.01
Trip length	0.23	3.48	0.01

R^2 =94.2%

Table 2.10b: Results of Non-Linear (Multiplicative) Regression Analysis: the Effect of the Speed Limit on the Mean Speed of Traffic (Bahrain)

(i) All the variables

Predictor	Coefficient	t-ratio	p-value
Constant	21.76		
Speed limit	0.22	5.62	0.00
No. of lanes	0.05	1.22	0.26
Heavy vehicle	-0.03	-2.15	0.06
Length categ.	0.05	1.91	0.09
Trip length categ.	0.22	6.47	0.00

$R^2 = 95.4\%$

(ii) The significant variables

Predictor	Coefficient	t-ratio	p-value
Constant	18.34		
Speed limit	0.24	5.91	0.00
Length categ.	0.08	2.75	0.00
Trip length categ.	0.22	5.94	0.00

$R^2 = 94.1\%$

Table 2.11a: Results of Non-Linear (Multiplicative) Regression Analysis: the Effect of the Speed Limit on the Eighty-Fifth Percentile Speed of Traffic (Tyne and Wear)

(i) All the variables

Predictor	Coefficient	t-ratio	p-value
Constant	6.42		
Speed limit	0.49	6.81	0.00
Heavy vehicle	-0.029	-0.58	0.58
Length categ.	0.09	2.29	0.06
Trip length categ.	0.23	2.35	0.05

R^2 =91.5%

(ii) The significant variables

Predictor	Coefficient	t-ratio	p-value
Constant	6.17		
Speed limit	0.49	7.11	0.00
Length categ.	0.10	2.73	0.03
Trip length	0.20	2.47	0.04

R^2 =92.2%

Table 2.11b: Results of Non-Linear (Multiplicative) Regression Analysis: the Effect of the Speed Limit on the Eighty-Fifth Percentile Speed of Traffic (Bahrain)

(i) All the variables

Predictor	Coefficient	t-ratio	p-value
Constant	29.37		
Speed limit	0.19	2.97	0.02
No. of lanes	0.02	0.36	0.73
Heavy vehicle	-0.04	-1.52	0.17
Length categ.	0.05	1.12	0.29
Trip length categ.	0.26	4.84	0.00

R^2 =94.9%

(ii) The significant variables

Predictor	Coefficient	t-ratio	p-value
Constant	24.78		
Speed limit	0.21	3.18	0.01
Trip length categ.	0.30	5.69	0.00

R^2 =86.0%

The Confidence Interval of The Coefficient

Same as in Section 2.8.3

The Significance of The Variables

Same as in Section 2.8.3

The Predictions of the Models

Same as in Section 2.8.3
(see Appendix I Exhibits 2.8a, 2.8b, 2.9a and 2.9b, and Figures 2.6a, 2.6b, 2.7a and 2.7b)

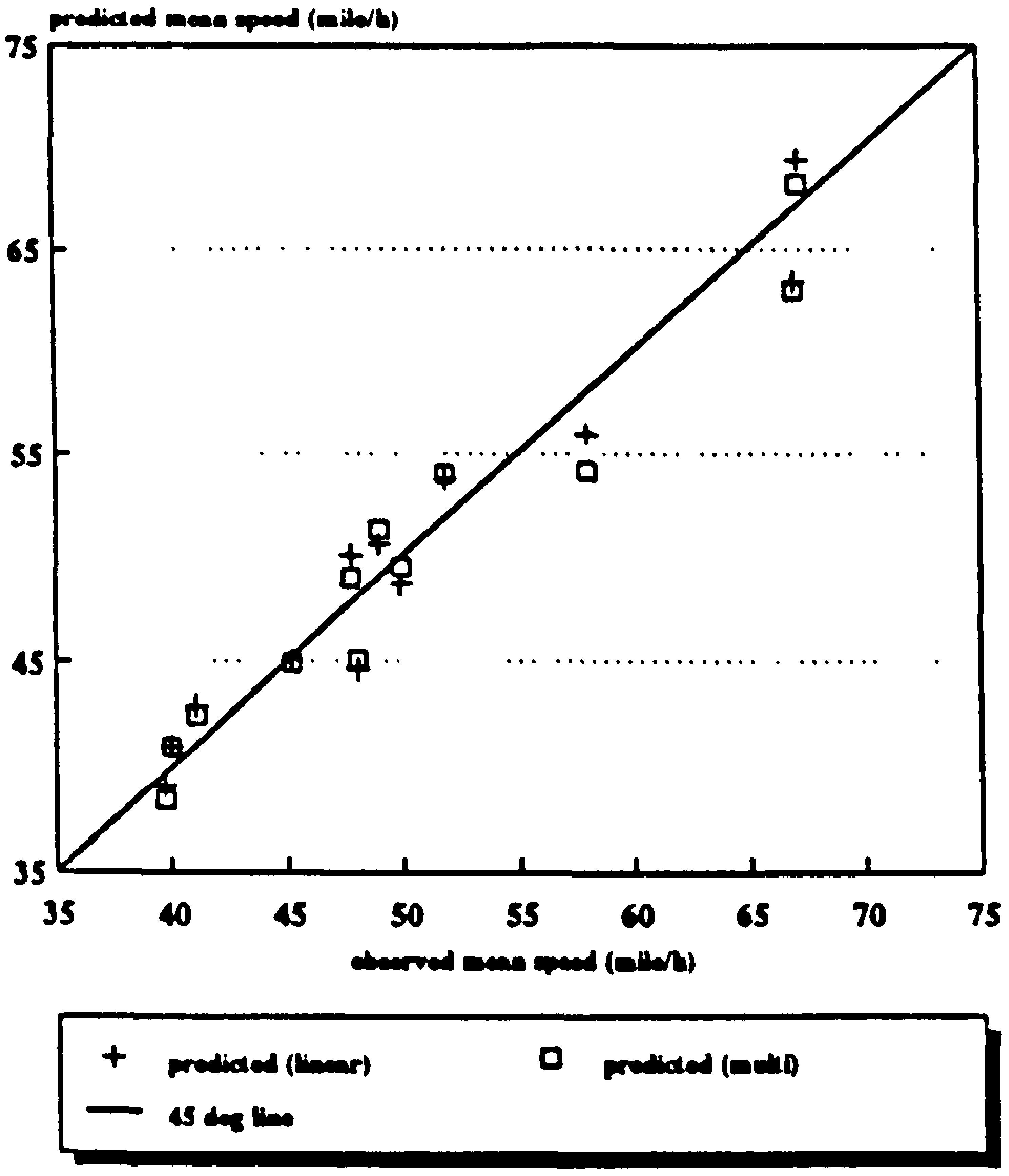
2.7.5 Non-Linear Regression Analysis (Additive Form)

The possible variables that could have affected the speed of traffic were regressed non-linearly in additive form against the mean speed and the eighty-fifth percentile speed of the traffic. The equation had the following form:

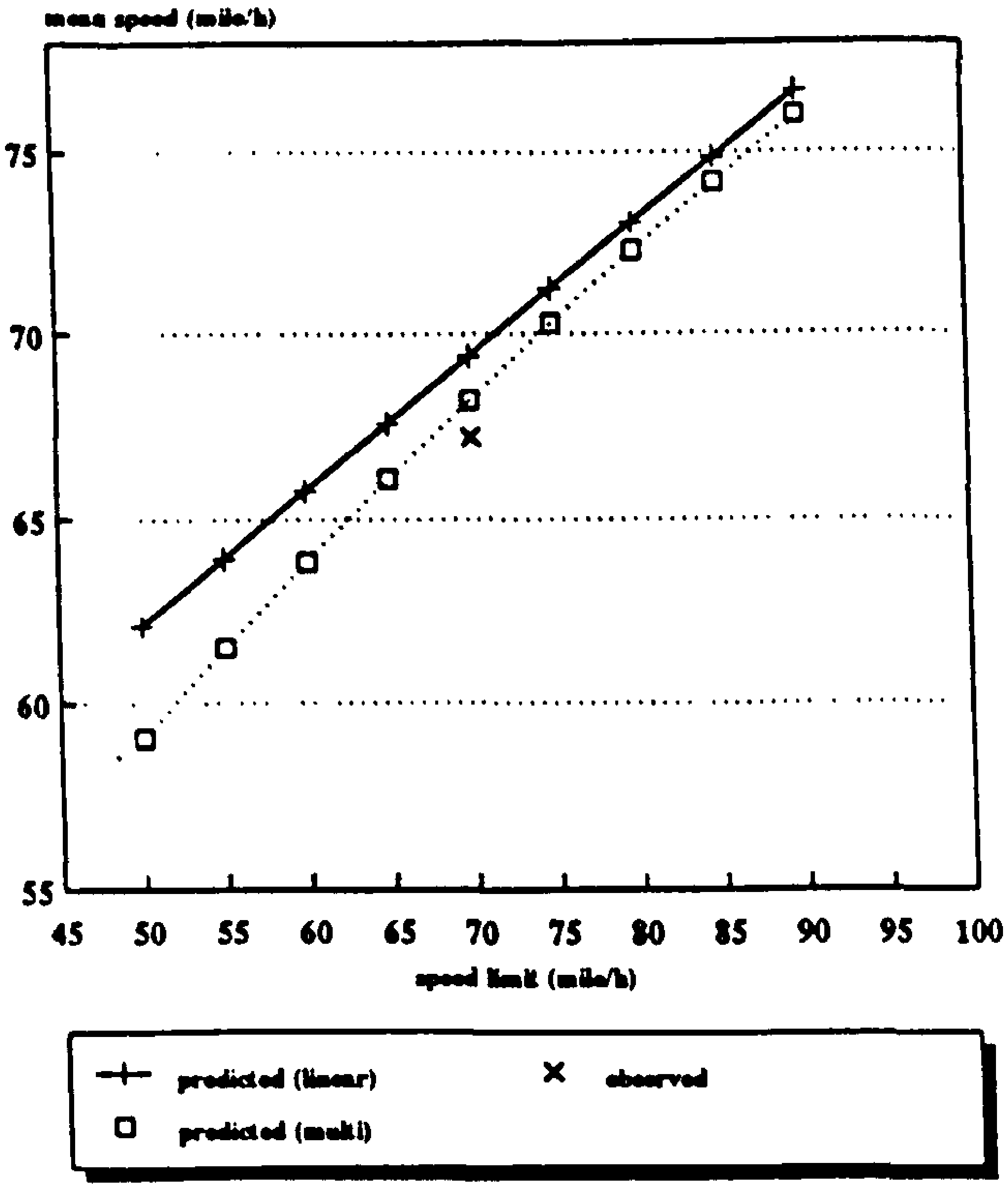
$$MST\ (EFPS) = a_0 + a_1\ SPL^{b_1} + a_2\ NLN^{b_2} + a_3\ HVC^{-b_3} + a_4\ LSEC^{b_4} \\ + a_5\ TRPLN^{b_5}$$

The initial parameters had to be estimated. The statistical package, STATGRAPHICS, was used. No significant results were obtained (see Appendix I Exhibits 2.10a, 2.10b, 2.11a, and 2.11b).

Figure 2.6a: Predictions of the Mean Speed of Traffic Using the Linear and Non-Linear (Multiplicative) Speed Models (Tyne & Wear)

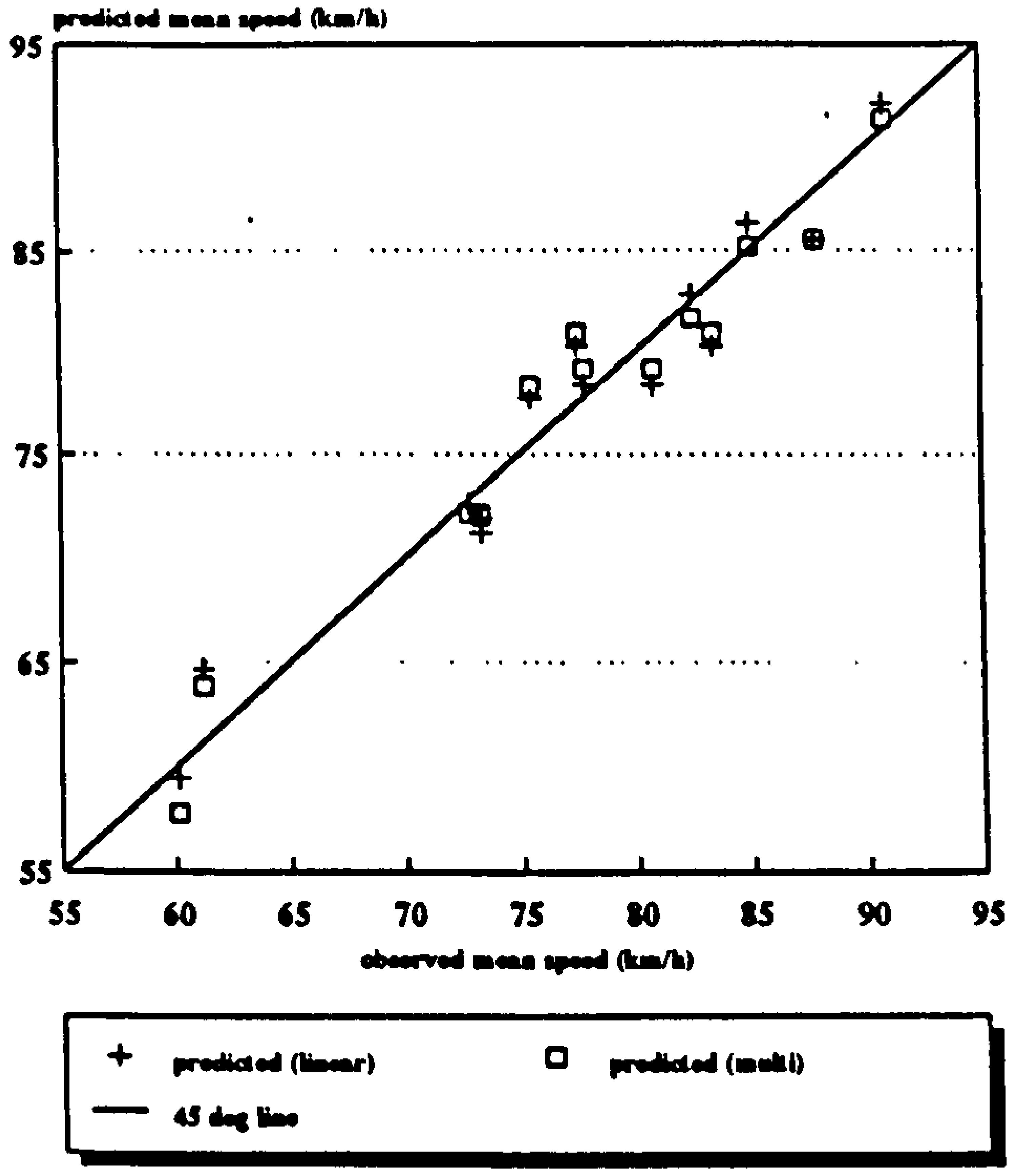


(i) Comparison between the observed and the predicted mean speeds of traffic as predicted by the linear and non-linear (multiplicative) speed limit models

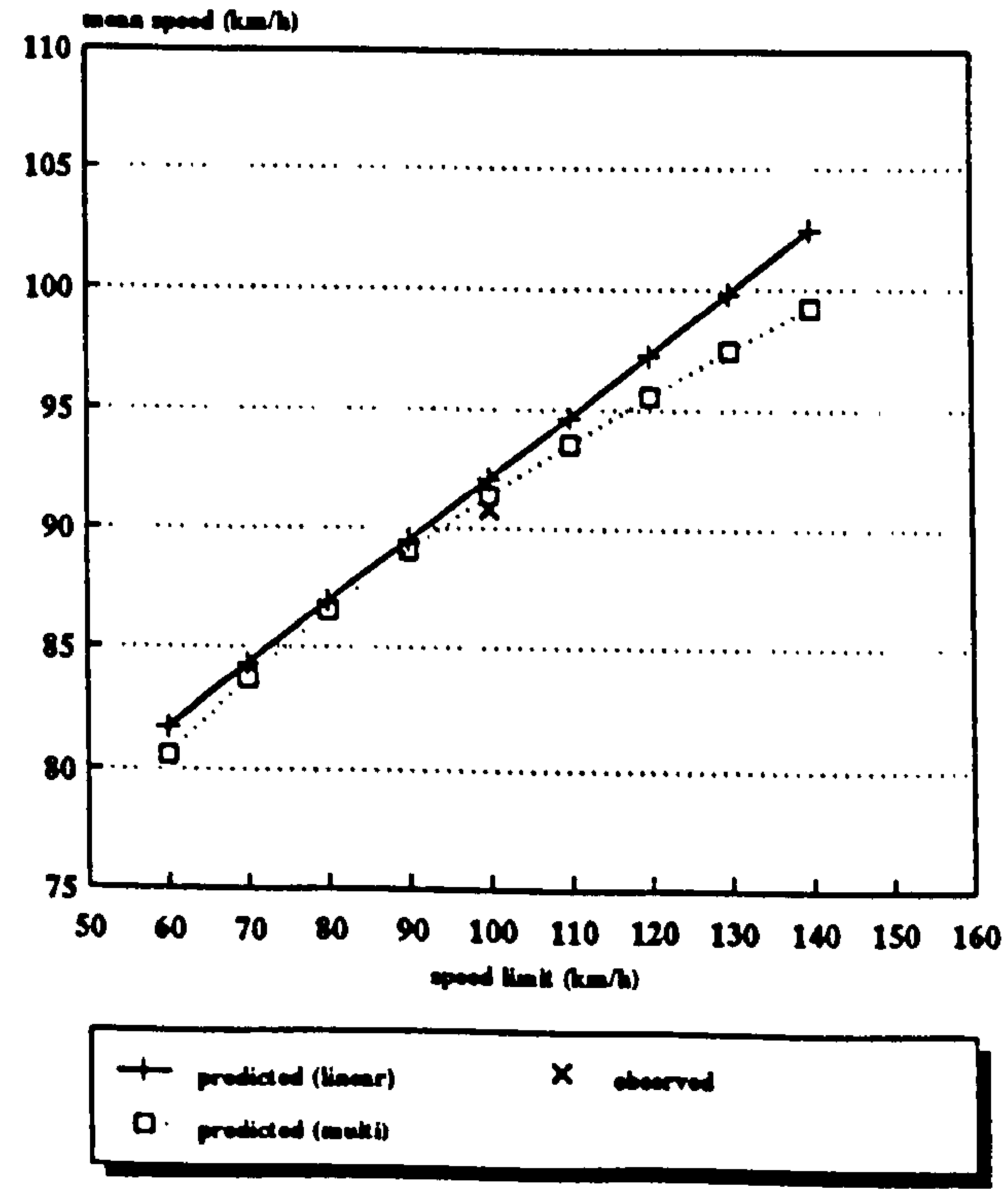


(ii) the expected changes in the mean speed of traffic as predicted by the linear and non-linear and Non-Linear (multiplicative) speed limit models for various speed limits at Site: EA1

Figure 2.6b: Predictions of the Mean Speed of Traffic Using the Linear and Non-Linear Speed (Multiplicative) Models (Bahrain)

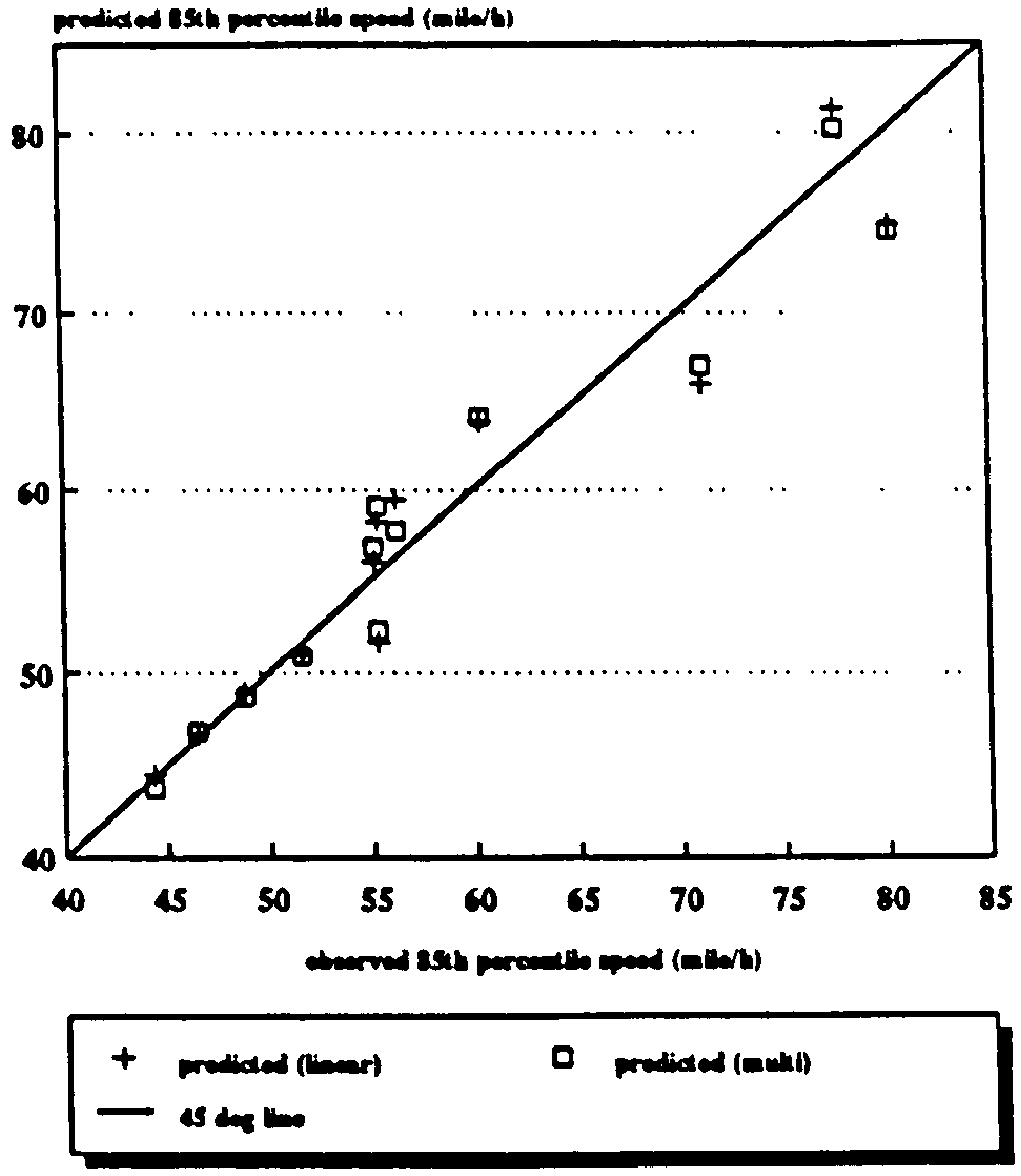


(i) Comparison between the observed and the predicted mean speeds of traffic as predicted by the linear and non-linear (multiplicative) speed limit models

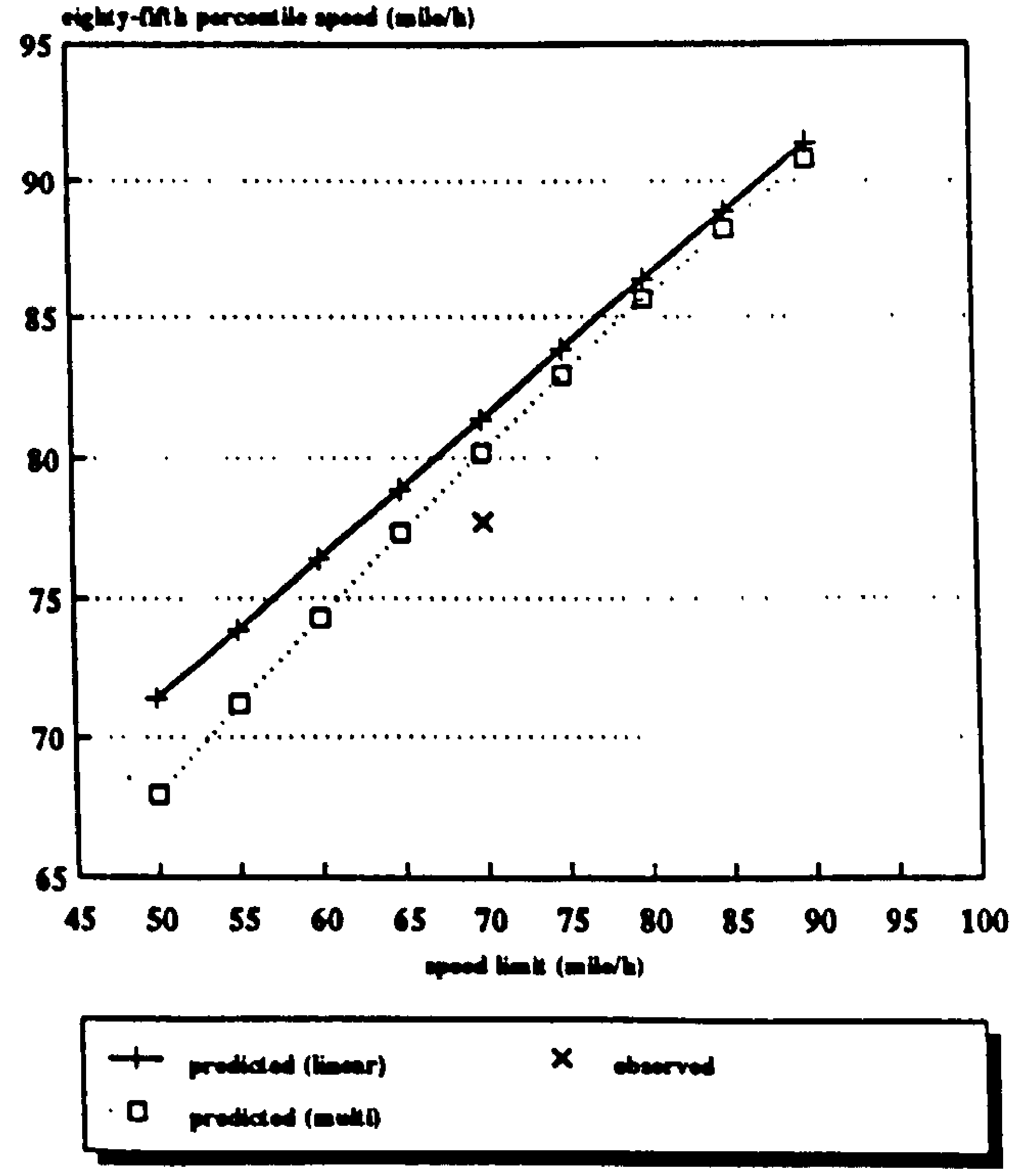


(ii) the expected changes in mean speed of traffic as predicted by the linear and non-linear (multiplicative) speed limit models for various speed limits at Site: BKH100

Figure 2.7a: Predictions of the Eighty-Fifth Percentile Speed of Traffic Using the Linear and Non-Linear (Multiplicative) Speed Limit Models (Tyne & Wear)

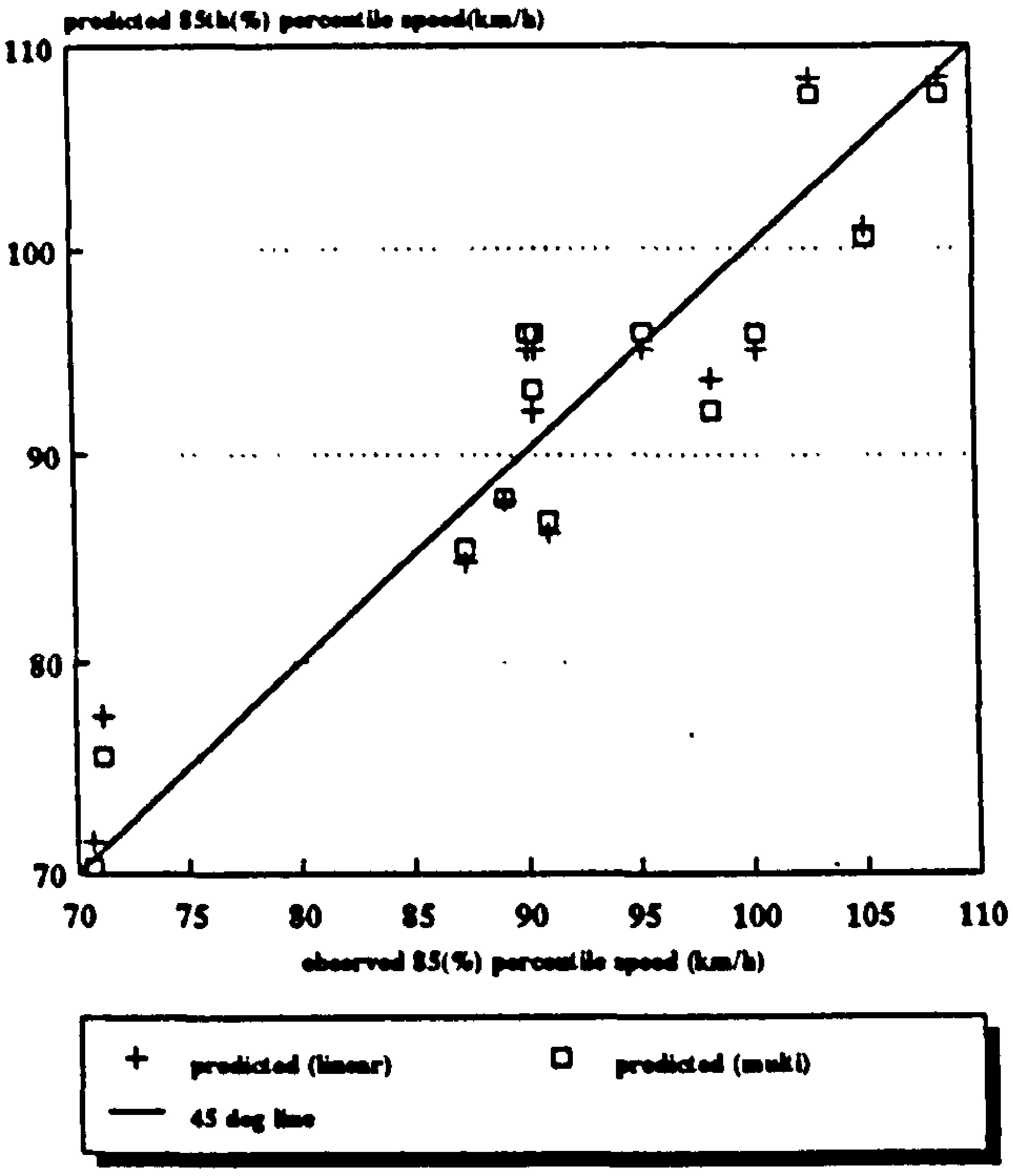


(i) Comparison between the observed and the predicted eighty-fifth percentile speeds of traffic as predicted by the linear and non-linear (multiplicative) speed limit models

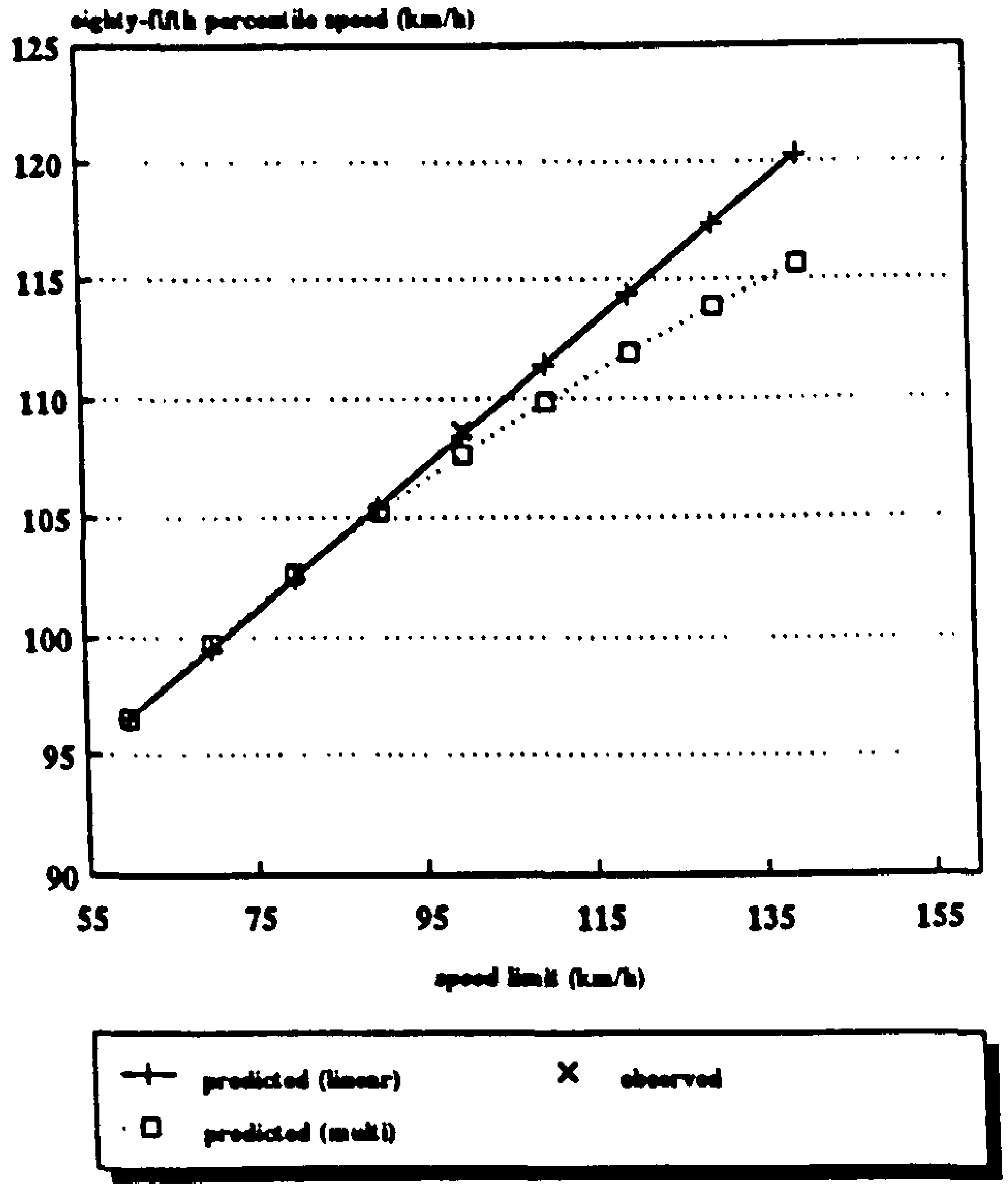


(ii) the expected changes in the eighty-fifth percentile speed of traffic as predicted by the linear and non-linear (multiplicative) speed limit models for various speed limits at Site: EA1

Figure 2.7b: Predictions of the Eighty-Fifth Percentile Speed of Traffic Using the Linear and Non-Linear (Multiplicative) Speed Limit Models (Bahrain)



(a) Comparison between the observed and the predicted eighty-fifth percentile speeds of traffic as predicted by the linear and non-linear (multiplicative) speed limit models



(ii) the expected changes in the eighty-fifth speed of traffic as predicted by the linear and non-linear (multiplicative) speed limit models for various speed limits at Site: BKH100

2.8 Discussion

2.8.1 The Observation Sites

Tyne & Wear

Most of the highway network in this area, and some areas beyond, have been inspected by car to find suitable sites; this exercise took a considerable time. The choice of sites was limited because of the lack of sections of roads satisfying the criteria set for the project. The posted speed limits at the chosen sites were 40, 50, and 70 mile/h. No dual-carriageway road was found with a speed limit of 60 mile/h. The 30 mile/h roads, in this area, did not fulfil the site requirements. It was difficult to find high quality links with low speed limits.

Bahrain

A Brief Description of The State of Bahrain

The State of Bahrain is a small island in the Arabian Gulf off the coast of Saudi Arabia, with a population of over half a million people. The population density of the island is one of the highest in that part of the world. Its economy is, mainly, based on the export of crude and refined oil. It is a banking centre linking the east and west money markets. There are over 124,000 vehicles on the roads. There is quite a modern road network covering most of the island. In 1989, there was 0.4 fatality per 10,000 vehicles, 10.2 fatality per 100,000 persons and 1.9 fatality per 100 million vehicle kilometres (Ministry of Interior,1990).

Again, it was hard to find suitable sites, especially for the lower speed limits. Most of the road network was surveyed by car with the aid of detailed plans. The sites chosen had speed limits of 100 (i.e. the maximum speed limit on the island), 80, 70, and 50 km/h. Sites with lower speed limits did not fulfil the requirements.

2.8.2 The Installation of the Speed Measuring Equipment

Tyne & Wear

An automatic speed recorder (GK 5000) was borrowed from the Peek Traffic Company. The equipment was installed at the observation sites with the help of the Traffic Accident Data Unit (TADU) at Gateshead Metropolitan Borough Council and the Highway Division of Durham County Council. At the sites in Durham County, permanent measuring stations (GK 6000) were used, with inductive loops used instead of pneumatic tubes for safety reasons due to the speed and volume of traffic on these roads. This permitted even less choice for the precise location of the measuring station. Before each observation, the local authorities and the police had to be contacted to coordinate the operation with them . The operation was conducted with the utmost care to prevent any accidents occurring.

Bahrain

At all the sites, an automatic speed recorder was used (GK-5000 Series). The installation was carried out by a team from the Road Division in The Ministry of Public Works, with the cooperation of the Traffic Police, Ministry of Interior. The presence of the traffic police, who diverted the traffic, made the installation less hazardous.

2.8.3 The Speed Characteristics of The Sites

In Tyne and Wear, the speeds of the vehicles, at most of the sites, were observed by either a radar speed meter (Muniquip) or the automatic speed recorder (GK 5000 or GK 6000). The results were very similar (Table 2.2 and Figure 2.2), and it was assumed from this that the speed of the vehicles recorded by the automatic speed recorders represented the actual speeds.

Both in Tyne and Wear and the State of Bahrain most of the speed distributions at the sites were found to be nearly normal (see Figures 2.4a and 2.4b). The speed did not vary much through the day, though, in most cases, the mean speed of the traffic dropped slightly during the hours of darkness (see Figures 2.3a and 2.3b). The mean speed of the traffic did not exhibit a definite trend against the traffic flow demonstrating that the friction between vehicles did not play a major role in determining the speed of the traffic, especially at the LOS_B (see Tables 2.3a and 2.3b). Where there was more than one day of observation, the mean speed of the traffic, in most cases, did not show significant differences indicating that the value of the mean speed of the traffic was representative of a typical day. The same observation stands true for the sites where the data was available for both directions of the traffic. Within each speed limit, there were differences in the mean speed of the traffic (see Tables 2.4a and 2.4b). Comparing different speed limits, it was noticed that the mean speed of the traffic dropped as the speed limit decreased; the same was true for the eighty-fifth percentile speeds and the median (the fiftieth percentile) speeds; also, the speed limit violations decreased. The standard deviation of the speed of the vehicles did not have a particular trend.

2.8.4 The Speed Limit Models

It was assumed that the sites under observation had similar characteristics. This was true to a certain extent but not for all characteristics. The trip length and the length of the sections varied between sites. They had to be included in the model to test their significance. The length of vehicle trips at each site were not available. Such data would have had to be collected by road-side interviews of the drivers. It was not possible to carry out such an activity due to the limited resources, time, and facilities. Engineering judgement of professionals (i.e. the local highway authority engineers) was used, along with some existing data on flow (i.e. for some sites, only) which enabled a category to be produced for each site according to the description provided (see Table 2.5). The length of trips were categorized in order to make it easier to rank each site using subjective assessment.

The length of each section was available (see Table 2.6). Generally, it was believed that there was a positive relationship between the speed of the traffic and the length of the section of road. The exact relationship was not obvious. It was assumed that the speed of traffic was more sensitive to the 'short' sections of road than the 'long' sections. The length of the sections were allocated into seven categories. The ranges of the categories that were used reflected this assumption.

The variables that could have affected the mean speed of traffic, were included in the regression. Three types of regression analysis were performed: linear (additive), non-linear (multiplicative), and non-linear (additive). The non-linear (additive) fit did not produce significant results, so it was discarded. Both, the linear (see Tables 2.8a and 2.8b) and the non-linear (multiplicative) equations (see Tables 2.10a and 2.10b) produced satisfactory results exhibiting very high coefficients of fit. The regression fit for the eighty-fifth percentile speed of traffic gave similar results to the mean speed of traffic. The confidence intervals were relatively large which was due to the limited number of observations (See Appendix I). The predictions from the two forms of regression were similar from a practical point of view (see Figures 2.6a, 2.6b, 2.7a, and 2.7b). Generally, the models tended to over-predict the results for higher speed limits. The heavy vehicle content and the number of lanes (i.e. only in Bahrain) showed insignificant t-values which implied that they did not contribute, significantly, in explaining the variability in the speed observations. The heavy vehicle content showed a negative correlation with the mean speed of the traffic which was expected. The heavy vehicles, usually, decreased the mean speed of traffic by running slower than other vehicles and by slowing down other vehicles travelling behind them. All the observation sites were dual carriageway roads so the heavy vehicles did not impose an obstacle to other lighter vehicles wishing to overtake. The observations were during periods of free-flow where there was no restriction on manoeuvring which could be the reason for the heavy vehicle content variable being insignificant, despite the fact that it had showed a slight effect. The number of lanes (i.e. the variable existed only in the Bahrain data) exhibited a positive relationship with the mean speed of traffic which was expected, too. More lanes meant more freedom for manoeuvre for the drivers which could have led to higher speeds. The observations were carried out during free-flow, where the traffic volume was low, so not all the lanes were utilised fully which could be the reason for the insignificance of the number of lanes variable. The variable representing the length of the section variable was not significant in the effect of the speed limit on the eighty-fifth percentile speed of the traffic model for Bahrain. It seemed that the upper part of the speed distribution was not influenced by the length of the section of the road.

Generally, the average ratio between the change in the mean speed of the traffic to the change in the speed limit was about 1 to 3, in the linear model. In the multiplicative model, the average ratio was more conservative which was about 1 to 5. Generally, in Tyne and Wear speed limit effect model, the mean speed of the traffic was more sensitive to the speed limit than the Bahrain Model.

2.8.5 Comparison with Similar Studies

Harkey (1990), in U.S.A., observed the mean speed of traffic at different speed limit zones. He concluded that the mean speed of traffic, the fifty percentile speed, and the eighty-fifth percentile speed increased with the speed limits, where the non-compliance proportion dropped as the speed limit increased, in most cases. Lee and Forni (1991), TRL, England, noticed that the mean speed of the light vehicles decreased as the speed limit increased but they warned that the relationship was not significant. In most historical experiences which were reviewed in this study (see Section 2.3.1), every time the speed limit has been altered, the mean speed of traffic, the fiftieth percentile speed, and the eighty-fifth percentile speed were affected positively. The speed limit violations behaved negatively. An exception was reported in the recent experience in the U.S.A. where the violations increased, in some situations. It is difficult to carry a direct comparison between this study and the other ones because, either, there was a lack of comprehensive data or the scope of the studies were different.

2.9 Conclusion

The influence of speed limits on the mean speed of traffic was clearly a debateable issue. An attempt was made in this study to investigate the relationship. The matter was complicated and it was difficult to issue a definitive opinion. The complication arises from many sources. The speed of traffic is influenced by many components like the desired speed of the drivers, road conditions, environmental conditions, and vehicle types. To find, solely, the effect of the speed limit on the speed of traffic, other components should be controlled. It might be easy to control variables in laboratory conditions, but it was far more difficult to control them on an open road. The historical experiences could not be used fully, for the reasons discussed before. There is a fairly strong indication from the two sets of data examined in this study, that the speed of the traffic was influenced by speed limits. The mean speed of the traffic tended to behave positively with the speed limits, as well as, the eighty-fifth and the fiftieth (median) percentile speeds. The violation of the speed limits decreased as the speed limits increased, in most cases. A large proportion of drivers ignored the speed limits, nevertheless, their violations were relative to the speed limits (i.e. their chosen speeds were influenced by the speed limits). The final form of the models were:

Tyne and Wear

$$MST = 14.59 + 0.36\ SPL + 4.07\ TRPLN + 1.87\ LSEC$$

$R^2 = 93.2\%$

$$MST = 6.74\ SPL^{.43}\ LSEC^{.09}\ TRPLN^{.23}$$

$R^2 = 94.2\%$

$$EFPS = 13.7 + 0.50\ SPL + 4.31\ TRPLN + 2.21\ LSEC$$

$R^2 = 89.7\%$

$$EFPS = 6.17\ SPL^{.49}\ LSEC^{.10}\ TRPLN^{.20}$$

$R^2 = 92.2\%$

Bahrain

$$MST = 33.50 + 0.26\ SPL + 4.62\ TRPLN + 1.93\ LSEC$$

$R^2 = 93.0\%$

$$MST = 18.34\ SPL^{.24}\ LSEC^{.08}\ TRPLN^{.22}$$

$R^2 = 94.1\%$

$$EFPS = 41.93 + 0.30\ SPL + 7.35\ LSEC$$

$R^2 = 84.2\%$

$$EFPS = 24.78\ SPL^{.21}\ TRPLN^{.30}$$

$R^2 = 86.0\%$

The variables were defined previously.

Similar studies and, most, of the past experiences supported this conclusion. In the Tyne and Wear Model, the mean speed of the traffic was more sensitive to the speed limit than in the Bahrain Model.

Both models, tended to over-predict the mean speed of the traffic at higher speed limits.

Even though much care had been exercised in this work there are some deficiencies (i.e. presented in the Section 2.9 and the final chapter) to bear in mind while scanning through the results. The general conclusion seems firm and consistent with other sources; the specific values predicted by models should be treated within the accuracy of the model and scope of the study.

Chapter Three

Road Traffic Speed and the Frequency and Severity of Personal Injury Accidents

3.1 Introduction

Road traffic accidents happen due to numerous different reasons. The speed of vehicles (or excessive speed of vehicles) is often considered to be one of the major causes of accidents. Speed limit signs were introduced, mainly as a safety tool, to reduce the speed of vehicles in order to reduce the risk of accidents (Harkey et al., 1990). Since that time, the relationship between the speed of vehicles, speed limits, and accidents has been debated each time the speed limit has been altered. The general objective of this study was to examine the economic consequences of changing speed limits. The cost of accidents forms a vital part of the analysis and there seems to be no clear relationship between speed limits and the frequency and severity of accidents in the literature with opinions divided on the matter.

The object of this part of the study was to investigate the relationship, if any, between the speed characteristics of traffic and the frequency and severity of personal injury accidents following a change in a speed limit. Personal injury accidents (PIA) were investigated because the cost of a PIA forms most of the total cost of an accident. The scope of this part of the study was compatible with the scope of the study as a whole which was restricted to high quality links, and free-flow traffic conditions where speed limits were likely to have most effect on the speed of traffic.

Criteria were established to select suitable sites and suitable accident data. Accident data from Tyne & Wear, England and the State of Bahrain were used. A methodology for the analysis has been suggested to examine the relationship between the frequency and the severity of personal injury accidents and the speed of traffic.

3.2 Literature Review

3.2.1 Speed Limits and Accidents: A Historical Background and a Review of Observations

In the U.K., when a maximum speed limit of 70 mile/h was imposed, the number of injury accidents reduced by 20 per cent on motorways but was only slightly reduced on all-purpose main roads (Ministry of Transport, 1967). The Ministry of Transport in U.K. stated that: "the evidence is fairly conclusive that speed limits, both in Britain and elsewhere, markedly reduce speeds and casualties, even though they are not universally obeyed" (Leeming, 1969). In Northern Ireland, a similar experience was observed by Newby (1970) who concluded that imposing a speed limit, in most cases, led to fewer accidents. There was a drop in fatalities in the U.S.A. when the 55 mile/h speed limit was imposed (ITE Special Technical Council Task Force, 1987), (ITE Metropolitan section of New York and New Jersey Sub-Committee, 1977), (ITE Technical Council Committee 4M-2, 1977), (U.S. Department of Transport, 1981). The 55 mile/h speed limit was believed to have saved 41,951 lives during 1974-1979 (Johnson et al., 1981). In another experience in the U.S.A., after increasing the speed limit to 65 mile/h from 55 mile/h, in 1989, there was a corresponding increase in the injury accident rate and this increase, also, happened on roads where the 55 mile/h speed limit was kept unchanged, which was explained as a "spill-over effect" though it was less in magnitude than for the 65 mile/h roads (Wagenaar et al., 1990), (McKnight and Klein, 1990), (McKnight et al., 1989), (Garber and Graham, 1990). In France, it was noticed that when the speed was limited, the number and the severity of injury accidents decreased sharply (Gerondeau, 1975), (Cooper, 1972), (Silyanov, 1973). It was mainly pedestrian accidents that were reduced in Denmark when speed limits were introduced in 1973, but there was no clear evidence about other groups of road users (Nielsen et al., 1975). In Sweden, it was found that when 70 km/h and 90 km/h speed limits were imposed, a significant reduction in accidents happened but the same trend was not noticed following the introduction of a 110 km/h speed limit (Svensson, 1975). A similar decrease in accidents was noticed in Norway (Egede Larssen, 1975) when a speed limit was imposed. In Germany, a significant decrease in accidents (especially personal injury) was observed when the speed limit was lowered but there was a cautionary note that other factors might have contributed

(Lenz, 1975). The historical experiences in Europe revealed that the frequency and severity of injury accidents decreased when speed limits were imposed (Newly et al., 1986), (OECD, 1972). West-Oram (1991) and Sabey et al. (1980) shared the opinion that a better use of speed limits would lead to a reduction in accidents. In predicting the consequences of raising the speed limit, it was found that more deaths would result but it was admitted that a precise forecast was difficult to obtain (Hoskin, 1986).

Despite the fact that experience has showed that there were reductions in accidents after imposing lower speed limits, it could not be justified, solely, by the reduction of the speed limit. Middleton and Kenyon (1981) claimed that most people concerned in road safety shared this opinion. The conclusion was supported by Leeming (1969). Scott (1983) found that the 50 mile/h speed limit which was imposed during the energy crisis in the U.K., had little effect on two-vehicle accidents. In the USA, when the Maximum National Speed Limit was lowered to 55 mile/h, there was a reduction in the number of injury accidents but it was not believed that the speed limit was the only cause of this reduction. Other factors might have contributed such as: the random occurrence of accidents, the general reduction in road accident fatalities before imposing the new speed limit, the reduction in travel on roads after the energy crisis, the introduction of new traffic laws, improvements in standards of driving, improvements in standards for both highways and vehicles, and the change in the type of travel as the higher risk trips were reduced (Johnson et al., 1981) (Copulos, 1986). More recently when the speed limit was raised in the USA, McKnight and Klein (1990) could not detect from their study whether the increase in fatalities was due to the change in the road traffic laws (i.e. raising the speed limit) or to the change in public attitude. This view was echoed by Sidhu (1991) who concluded in a report that the effect of the increase in the speed limit was minimal, in some cases, and insignificant in others. In assessing the criteria for speed limit speed zones in the U.S.A, it was found that the highest overall accident rates happened within 25 mile/h speed limit zones (Harkey et al., 1990). Sabey (1975) did not find that lowering the speed limit, in itself, was effective. Some other researchers warned that lowering the speed limit could lead to higher accidents (Fiander, 1974).

3.2.2 The Role of the Mean Speed of Traffic in Generating Accidents

It was reported that it was difficult to relate the cause of any accident to the speed factor in particular (Traffic Safety Committee, 1965) even though a reduction in the frequency and severity of accidents was observed when speed limits were lowered. Graber and Gadiraju (1990) found that: "the accident rate on a highway does not necessarily increase with an increase in average speed". Munden (1966) concluded the following, from an experiment he carried out enforcing speed limits in 1964/1965: "the fall in accidents was not necessarily due only to the lower speeds. It may have been due in part to a general improvement in the aspects of road behaviour". Indiana University (1970) reported that: " there is no apparent relationship between the mean speed of traffic and the number of accidents". Munden (1967) demonstrated that both the 'fast' and 'slower' drivers tended to be involved in accidents more than other groups and concluded that: "...a high accident rate does not in itself necessarily mean that relatively high and low speeds are the only cause of the situation".

3.2.3 The Effect of Differential Speeds on Accidents

Solomon (1964) concluded, after a comprehensive study of the relationship of the speed of vehicles and the frequency and severity of accidents, that: "... thus, the greater the variation in speed of any vehicle from the average speed of all traffic, the greater its chance of being involved in an accident. The severity of accidents increased as speed increased, especially at speeds exceeding 60 miles per hour". Similar conclusions were reported by Garber and Gadiraju (1990), Middleton and Kenyon (1981), and Harkey et al. (1990). The argument was supported by another study (Heimbach and Vick, 1970) which revealed a relationship between 'traffic noise' (i.e. the amount of the deviation of the speed of vehicles from the mean speed of traffic) and accidents. These findings were similar to the findings reported by Indiana University (1970). Beilock et al. (1989) reported similar results after the speed limit was raised in U.S.A. The same opinion was reached by the ITE Metropolitan section of New York and the New Jersey Sub-Committee (1977) and the ITE Special Technical Council Task Force (1987) when they reviewed the implications of the imposition of the 55 mile/h speed limit. Overtaking which is a result (or a form) of vehicles travelling at differential speeds was considered to be the main cause of accidents on divided highways by Hauer (1971). It was found, mathematically, that the lowest accident risk was when the speed of the vehicle was at the median speed. Lowering the speed limit did not, always, lead to lower accidents because the speed differential might increase which could be a source of accidents (Fiander, 1974).

3.2.4 The High Accident Risk of Vehicles Travelling at Excessive Speeds

The insurance companies in France, noticed that whenever the car manufacturers increased the top speed of a model, the accidents for that type tended to increase (Gerondeau, 1975). The same conclusion for some other countries was reached by Preston (1972). In a study of heavy truck accidents, it was found that the major cause was that vehicles were travelling too fast (Beilock et al., 1989). The judgement was supported by a report from South Africa which came to a similar result (Wium et al., 1974). The severity of the accidents were, also, found to be related positively to speed. Brenac (1990) noticed that speed had a very clear role in "generating and aggravating accidents", an opinion shared by West-Oram (1991). O'Flaherty (1986) suggested that the high speeds of vehicles contributed to accidents by reducing the stopping and overtaking distances, the vehicles separation distance, the skid resistance, sign legibility, pedestrian risk, and the control of the vehicle.

3.2.5 Traffic Volumes and Accidents

There was strong evidence that the number of accidents tended to increase as the traffic volume increased (Silyanov, 1973) (Oppe, 1989). Others found that the rate of single-vehicle accidents tended to decrease and the rate of multi-vehicle accidents tended to increase as the traffic volume increased (Satterthwaite, 1981). This conclusion was supported by an extensive study carried out by Kihlberg and Tharp (1968). On the other hand, Scott (1983) had some doubt about this judgement, as well as Hall and Pendleton (1991) who, also, found that single-vehicle accidents increased at night. McGuigan (1987) found that the rate of accidents increased with traffic volume in rural areas but not in built-up areas.

3.2.6 The Effect of the Design Elements on Accidents

Mclean (1980) stated that the relationship between accidents and the geometric elements of roads was difficult to assess. He concluded that the vertical alignment had more effect on accidents than the horizontal alignment and that the overall standard of the road was the most important factor. Other investigations found that the lack of access control and the presence of certain geometric elements (i.e. such as, curves and gradients) raised the number of accidents, especially if they co-existed (Kihlberg and Tharp, 1968), (Silyanov, 1973). Sabey et al. (1980) found that improvements to the geometric design of the road might reduce the number of accidents by as much as eleven per cent.

3.2.7 Other Factors Influencing Accidents

Generally, accidents are influenced by many factors such as: petrol prices which are related to the amount of travelling (i.e. a negative effect on the accidents) (Scott, 1983), (Gerondeau, 1975), the weather ('fine' and, especially, 'dry' weather leads to fewer accidents) (Scott, 1983), (Sabey, 1973), the wearing of seat belts which reduces the severity of accidents (Gerondeau, 1975) by an estimated seven per cent (Sabey et al., 1980), the purpose of the trip which could have an effect on accident exposure (ITE Technical Council Task Force, 1987) (e.g. leisure trips are thought to be less exposed to accidents than work trips), the type of road (Saccomanno and Buyco, 1989), the population density, the number of motor vehicles in the country (Silyanov, 1973), the distance travelled by vehicles (Hall et al., 1970), the time of day (i.e. light or dark) (Sabey, 1973), the lighting of roads (Sabey and Johnson, 1973), (Sabey et al. (1980) concluded that a reduction of three per cent in accidents might be expected if better lighting was provided), the lack of skid resistance (Sabey and Storie, 1968), the mechanical failure of vehicles, drinking alcohol and taking drugs (Sabey et al., 1980), the overestimation of personal ability, and economic pressure (i.e. saving time in order to save money, especially for commercial vehicles) (Beilock et al., 1989).

3.2.8 The Effect of Speed Limit Enforcement on Accidents

An experiment was conducted in England in 1964/1965 to test the effect of the 'full' police enforcement of an existing 30 mile/h speed limit at a number of different sites on the speed of vehicles and the number of accidents (Mudden, 1966). The results showed that both the speeds of vehicles and the number of accidents were reduced at the selected locations and, also, in the surrounding areas. Other studies revealed similar findings (Armour, 1984a), (Preston, 1972). In another study, it was reported that the reduction of accidents could be up to five per cent (Sabey et al., 1980). French experience showed that a continuous police presence on roads led to fewer drivers exceeding the speed limit (Gerondeau, 1975).

Other forms of speed enforcement techniques have been suggested such as automatic speed warning signs (Jarvis and Hoban, 1988) which caused the number of injury accidents to reduce but not significantly.

3.2.9 The Effect of Drivers' Behaviour on Accidents

The abnormal behaviour of drivers, for example driving too fast or too slow, might lead to an increase in accident exposure (Munden, 1967). Drivers realised the consequences of such behaviour but, nevertheless, they did not abandon the practice (Biecheler-Fretel and Moget-Monseur, 1990), (Hogg, 1977). The way drivers perceive risk on the road and its relation with actual risk, has a great effect on generating accidents (Saad, 1989). Insufficient training for heavy truck drivers has been found to be one of the key elements in heavy goods vehicle accidents (Beilock et al., 1989); on the other hand, proper education, training and propaganda has been shown to decrease the number of accidents (Sabey et al., 1980).

3.3 Hypothesis

There would be a need to conduct proper 'before' and 'after' studies to examine the relationship between the speed characteristics of road traffic and accidents if a speed limit was changed. Such a study was not possible within this project due to the time needed to collect reliable data so an alternative approach was adopted.

The approach was to compare personal injury accident records on a number of high quality road links that were operating within free-flow traffic conditions. In this way, any differences in accident risk could be associated with the speed characteristics of the traffic in the absence of other factors. To investigate this hypothesis a methodology was outlined that could fulfil the requirements needed. The methodology consisted of the description of the sites, the collection of the speed and accident data, and the method of analysis.

3.4 Criteria Adopted to Select Accident Data

3.4.1 Objectives

Three objectives were set:

(i) to analyse, only, accidents that were related to the speed of free-flow traffic;

(ii) to select sites with similar physical and environmental characteristics in order to compare their accident records; and

(iii) to conduct the analysis within the objectives and scope of the project.

3.4.2 Location of Accidents

In order to minimise the effect of the geometric features of the sites and to achieve consistency in the characteristics of the sites, the following criteria were set for the selection of highway links chosen for the study:

(i) horizontal curves of less than four degrees and longitudinal gradients of up to three per cent;

(ii) link accidents, only (no accidents to be considered within 20 metres of a junction);

(iii) dual-carriageways;

(iv) good pavement surface conditions;

(v) no bus-stops or pedestrian crossings; and

(vi) low land use activity.

3.4.3 Pedestrian Accidents

Some of the sites under observation were closer to urban areas than others and at these sites pedestrian accidents were, likely, to be more. In order to compare sites with similar physical characteristics, accidents involving pedestrians have been discarded for all sites.

3.4.4 Accident Records: Data Collection Periods

The period over which personal injury accident records were examined had to be long enough to avoid the random occurrence of accidents. No specific time span was recommended in the literature. The time span for this study was taken to be five years for Tyne & Wear and four years for Bahrain (i.e. accident data for Bahrain was held on permanent computer systems for four years, only).

3.4.5 Traffic Flow Conditions at the Time of Accidents

The aim was to acquire accident data that was related to free-flow conditions (i.e. as defined in Section 2.5.2). The hours of the day when the traffic was determined to be operating under free-flow conditions (see Chapter Two), were assumed to represent the free-flow hours during which accidents records would be investigated. Accidents which happened outside those periods could not be associated with the investigation as the speed of traffic would have been constrained and were excluded from the analysis.

3.5 Observation Sites

3.5.1 Site Location

The following sites fulfilled the criteria set for this investigation :

Tyne & Wear

EA1, E19, E167, EHW, EGHN, EGHS, EJR, EGN, and E194.

Bahrain

BMJ100, BSA100, BFA80, BHA80, BIS80, BBU70, BSA70, BSE70, BSA50, and BKU50.

(for a description of these sites, see Chapter Two, Section 2.5.1, Figures 2.1a and 2.1b and Appendix I: Tables 2.1a and 2.1b).

3.5.2 Accident Data

Personal injury accident records that fulfilled the criteria were selected. No major changes had happened to the sites during the period under investigation (i.e. this information was collected verbally from personnel in the respective local highway authorities).

Tyne & Wear

The accident data were acquired from the Traffic Accident Data Unit (TADU), Gateshead Metropolitan Borough Council and the Highways Department, Durham County Council. The accident data represented a five year period (1988-1992) (see Table 3.1a, Figure 3.1a, and Appendix II: Table 3.1a).

Bahrain

The accident data were collected from the Planning and Organisation Division, Traffic and Licensing Department, Ministry of Interior. The data represented a four year period (1987-1990) (see Table 3.1b, Figure 3.1b, and Appendix II: Table 3.1b).

3.5.3 Speed Data

A historic record of the speed characteristics of the sites for the previous years were not available. As a substitute, the present speed characteristics of the sites were obtained; the procedure was described in Chapter Two (see Tables 2.4a for Tyne & Wear and 2.4b for Bahrain). The mean values of these traffic speed characteristics were assumed to represent the typical mean values for the time span of the accident records. It was assumed, also, that any variation (i.e. growth rate) in the mean speed of traffic was similar for all the sites.

(see Tables 3.1a and 3.1b and Figures 3.1a and 3.1b)

3.5.4 Traffic Volume Data

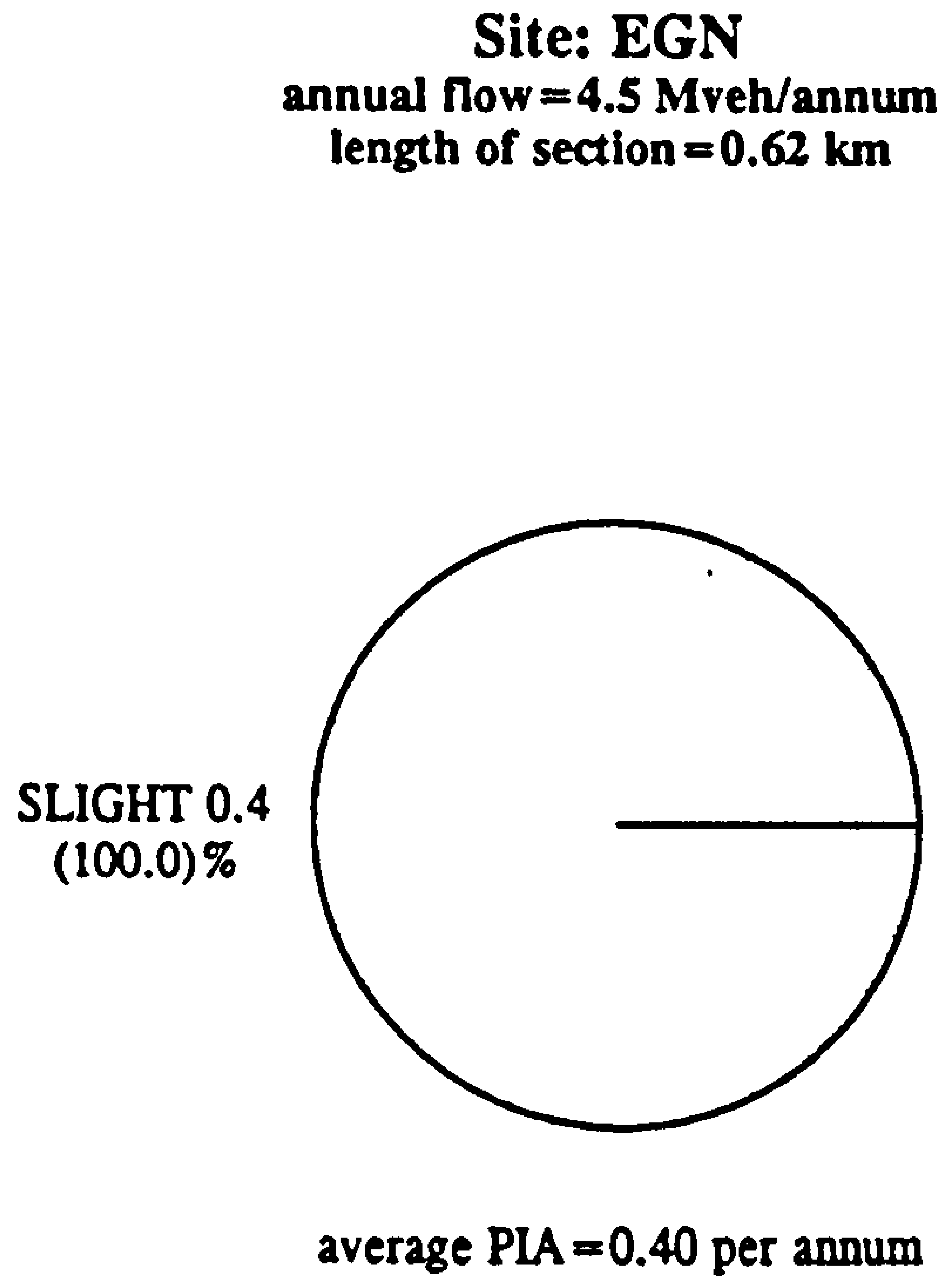
Tyne & Wear

The Annual Average Daily Traffic (AADT) was obtained from previous traffic count records. In cases where the count for any year was not available, the local growth rate of traffic was used (see Table 3.1a, Figure 3.1a, and Appendix II: Exhibit 3.1a).

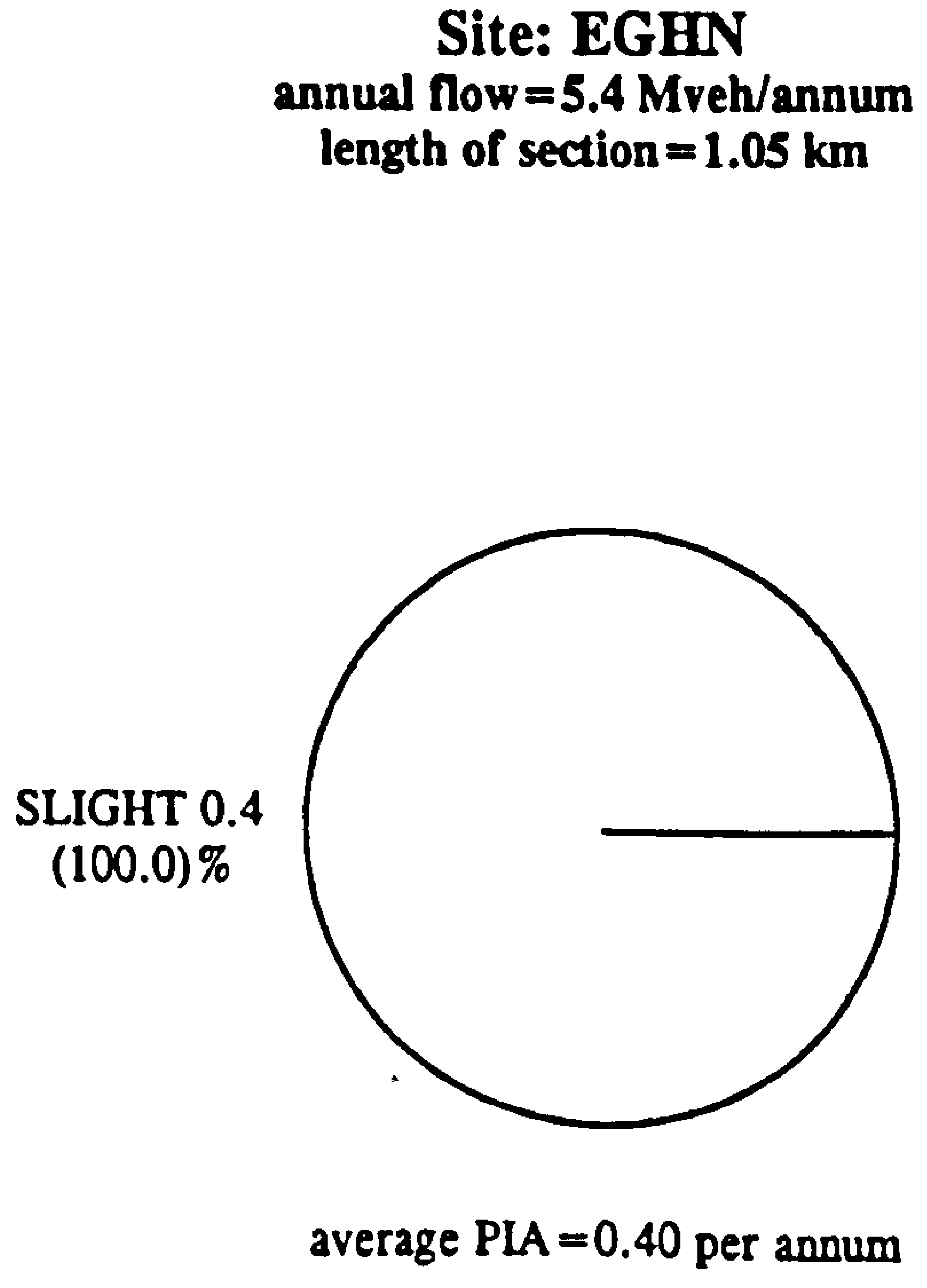
Bahrain

There were no historic traffic flow data for Bahrain and, therefore, the data referred to in Chapter Two, have been used (see Table 2.4b). It was assumed that the traffic growth was the same for all the sites (see Table 3.1b and Figure 3.1b).

Figure 3.1a: The Frequency and Severity of Personal Injury Accidents (PIA) for the Sites investigated (Tyne & Wear)
(PIA records for five years)


Site: EGN
annual flow=4.5 Mveh/annum
length of section=0.62 km

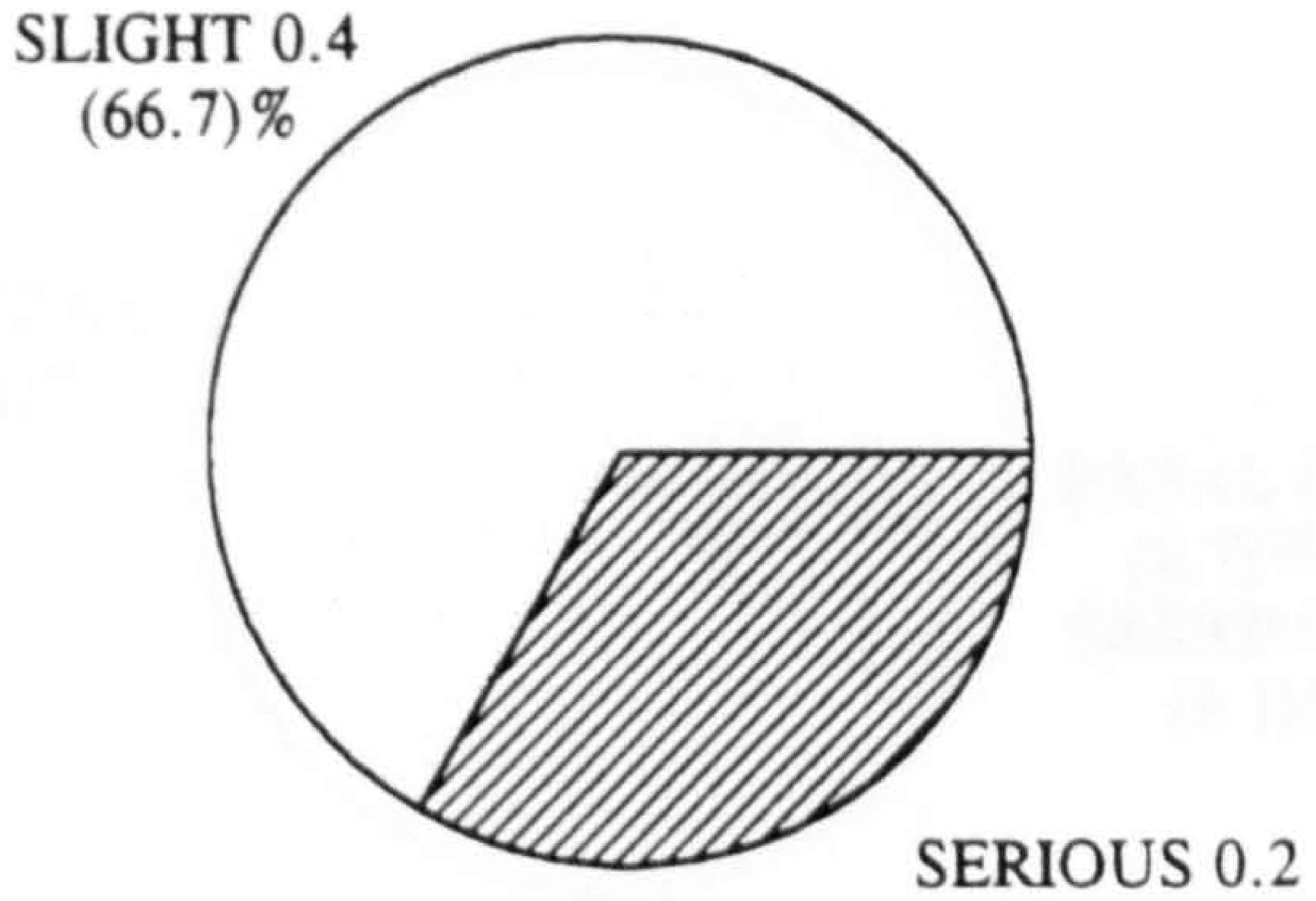
average PIA=0.40 per annum


Site: EGHN
annual flow=5.4 Mveh/annum
length of section=1.05 km

average PIA=0.40 per annum

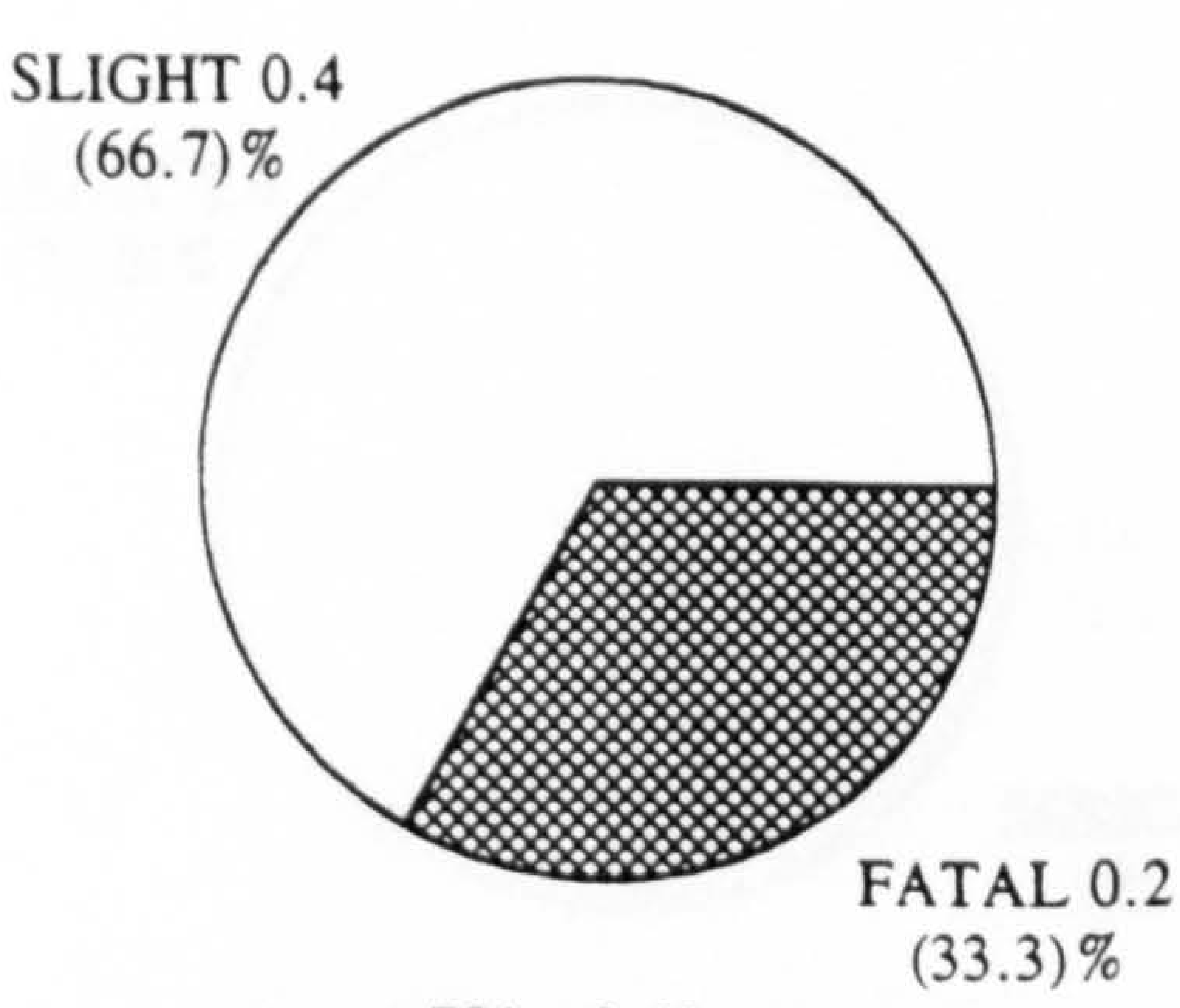
Figure 3.1a: (Continued)

Site: EJR
annual flow=3.3 Mveh/annum
length of section=1.6 km



average PIA=0.60 per annum

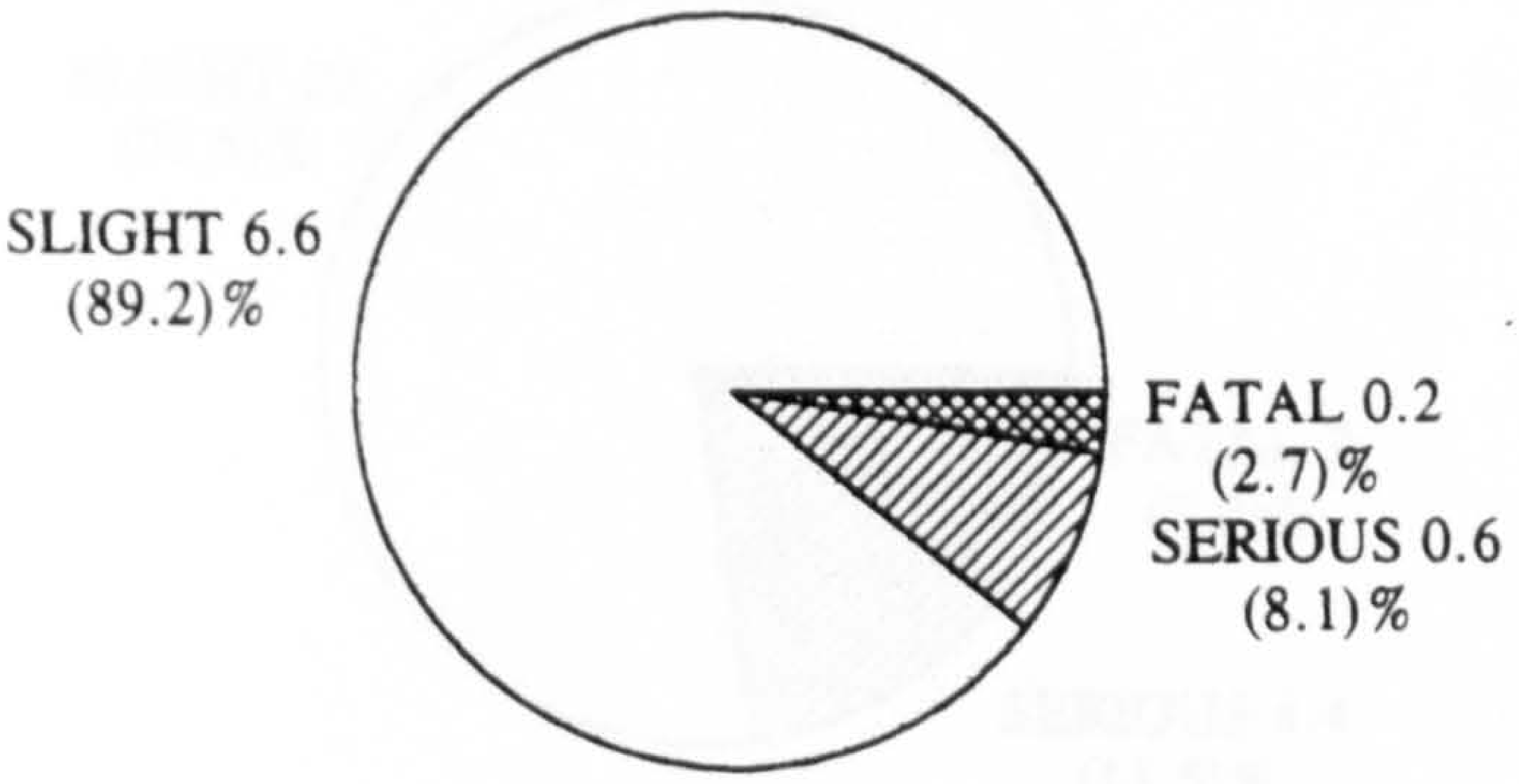
Site: EHW
annual flow=52.5 Mveh/annum
length of section=0.47 km



average PIA=0.60 per annum

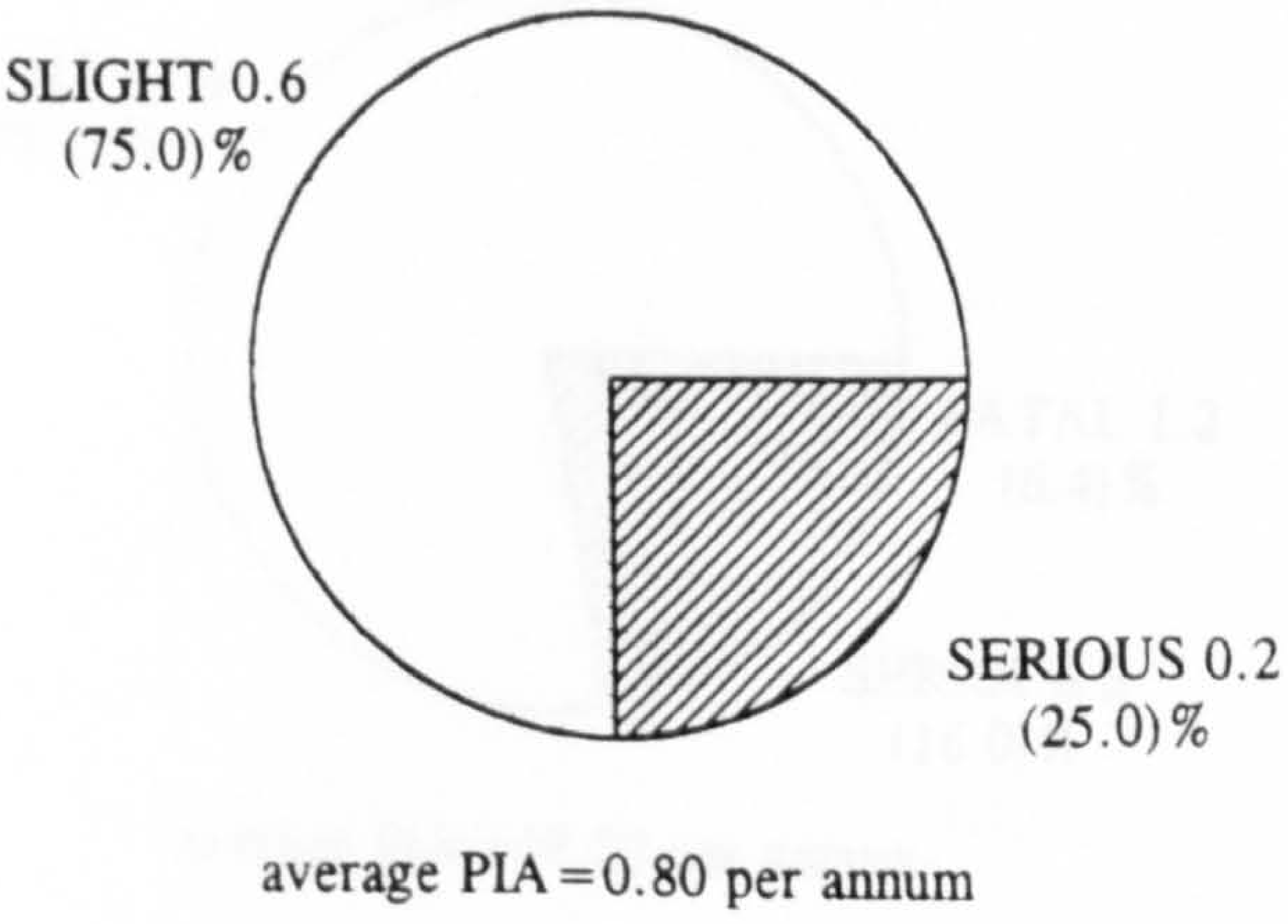
Figure 3.1a: (Continued)

Site: E167
annual flow = 4.8 Mveh/annum
length of section = 7 km



average PIA = 7.40 per annum

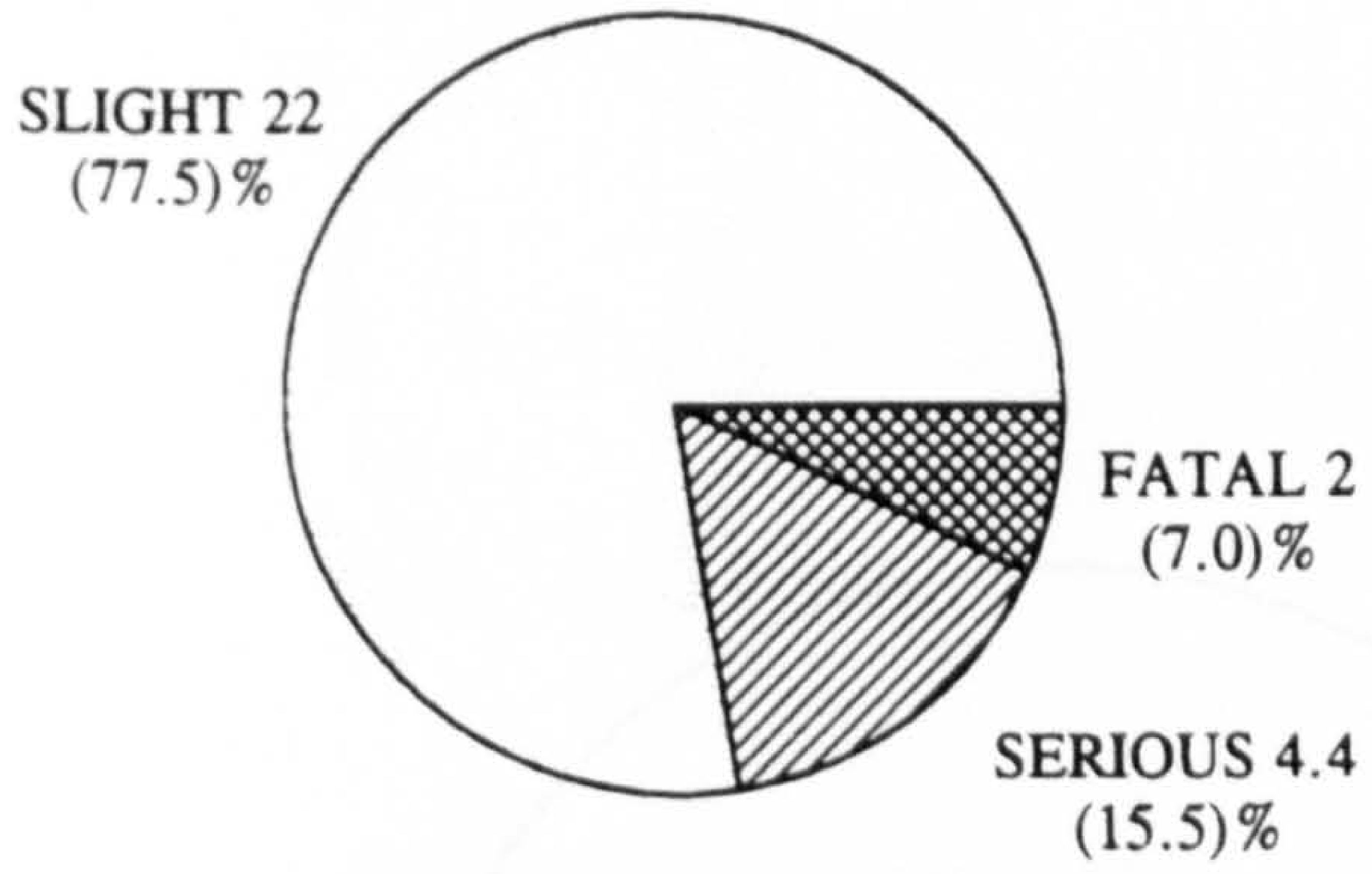
Site: EGHS
annual flow = 4.7 Mveh/annum
length of section = 0.64 km



average PIA = 0.80 per annum

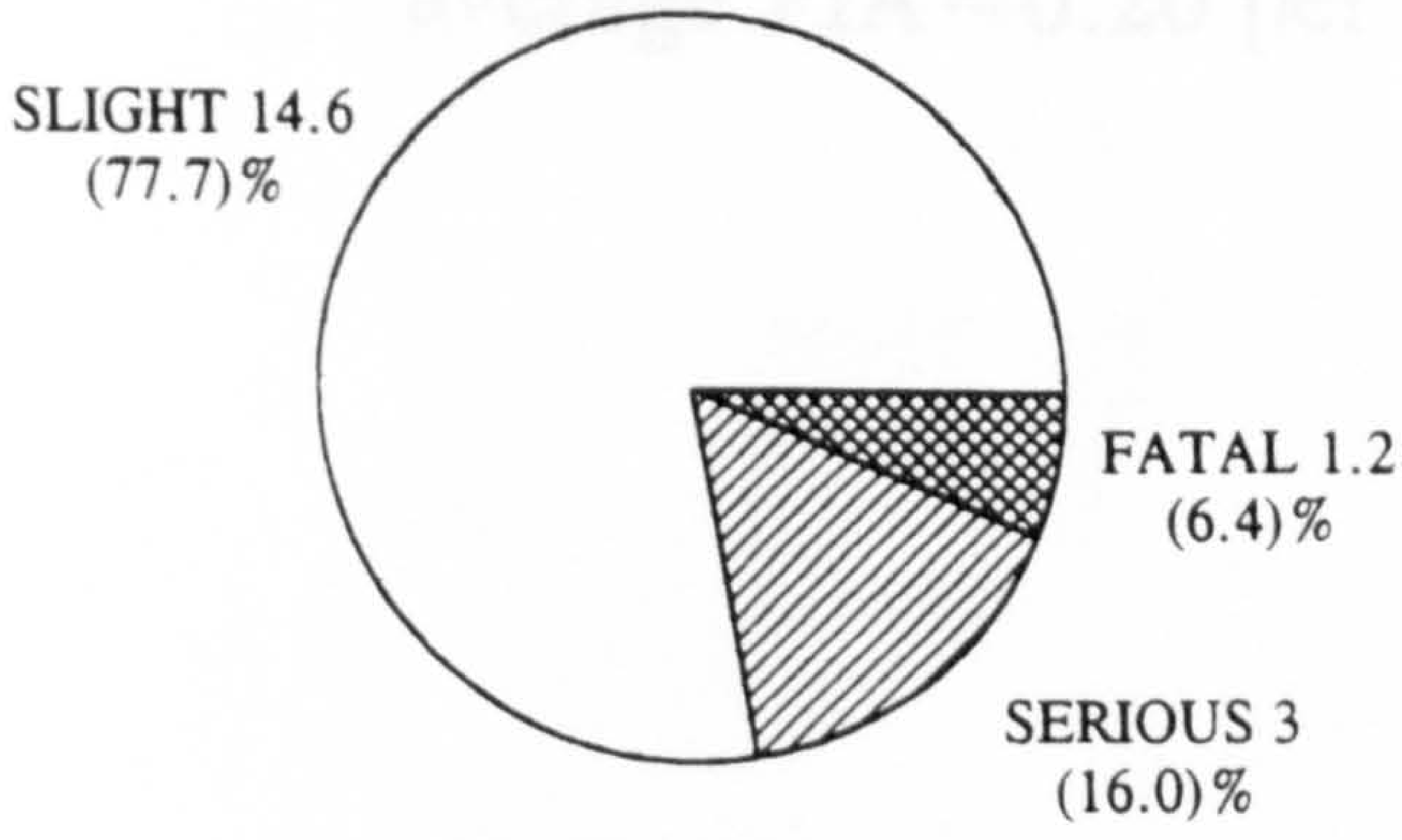
Figure 3.1a: (Continued)

Site: EA1
annual flow = 4.0 Mveh/annum
length of section = 44 km



average PIA = 28.40 per annum

Site: E19
annual flow = 5.0 Mveh/annum
length of section = 18 km



average PIA = 18.80 per annum

Figure 3.1a: (Continued)

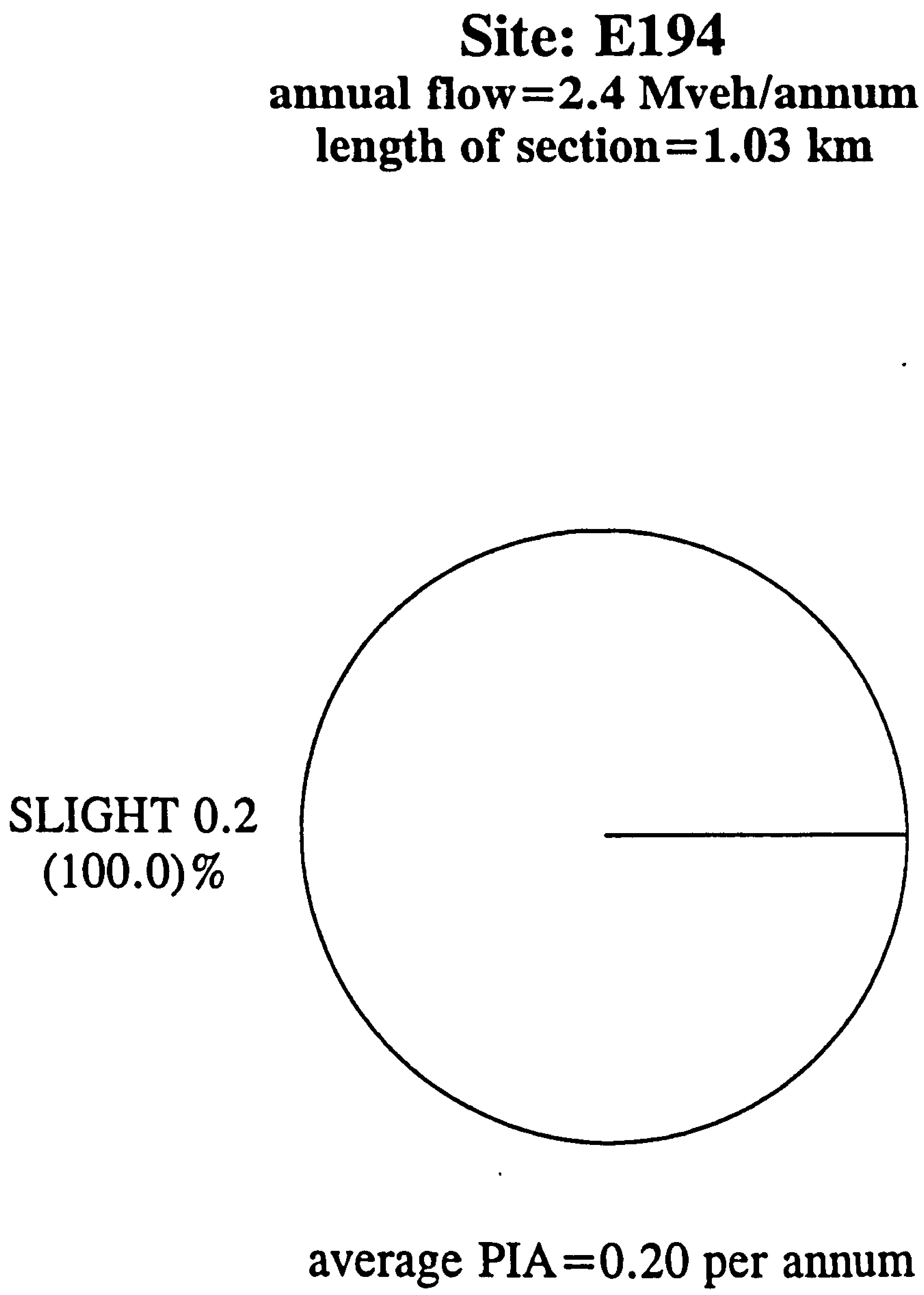


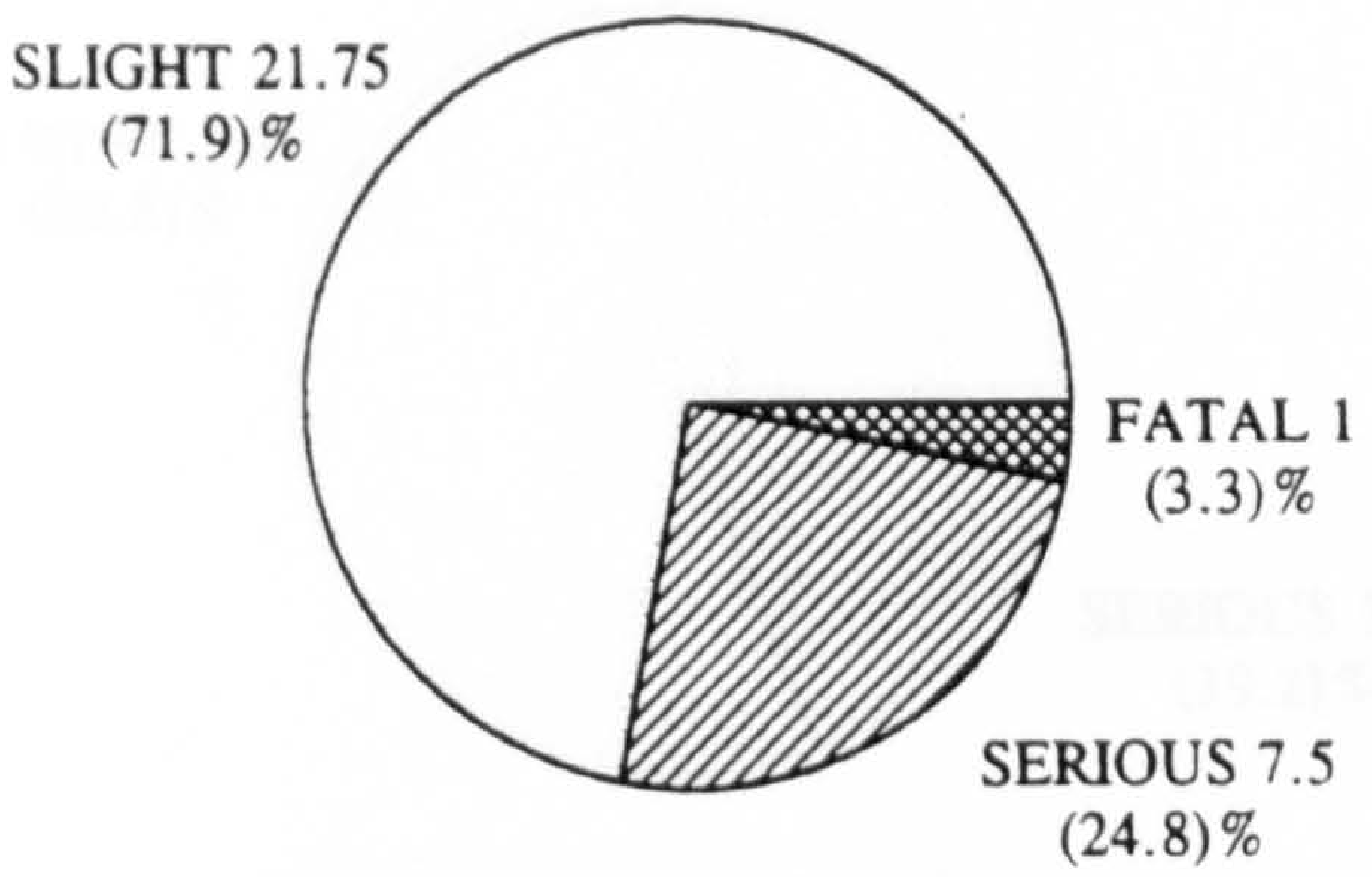
Figure 3.1b: The Frequency and Severity of Personal Injury Accidents (PIA) for the Sites Investigated (Bahrain)

(PIA records for four years)

Site: BMJ100

annual flow=6.5 Mveh/annum

length of section=10.67 km

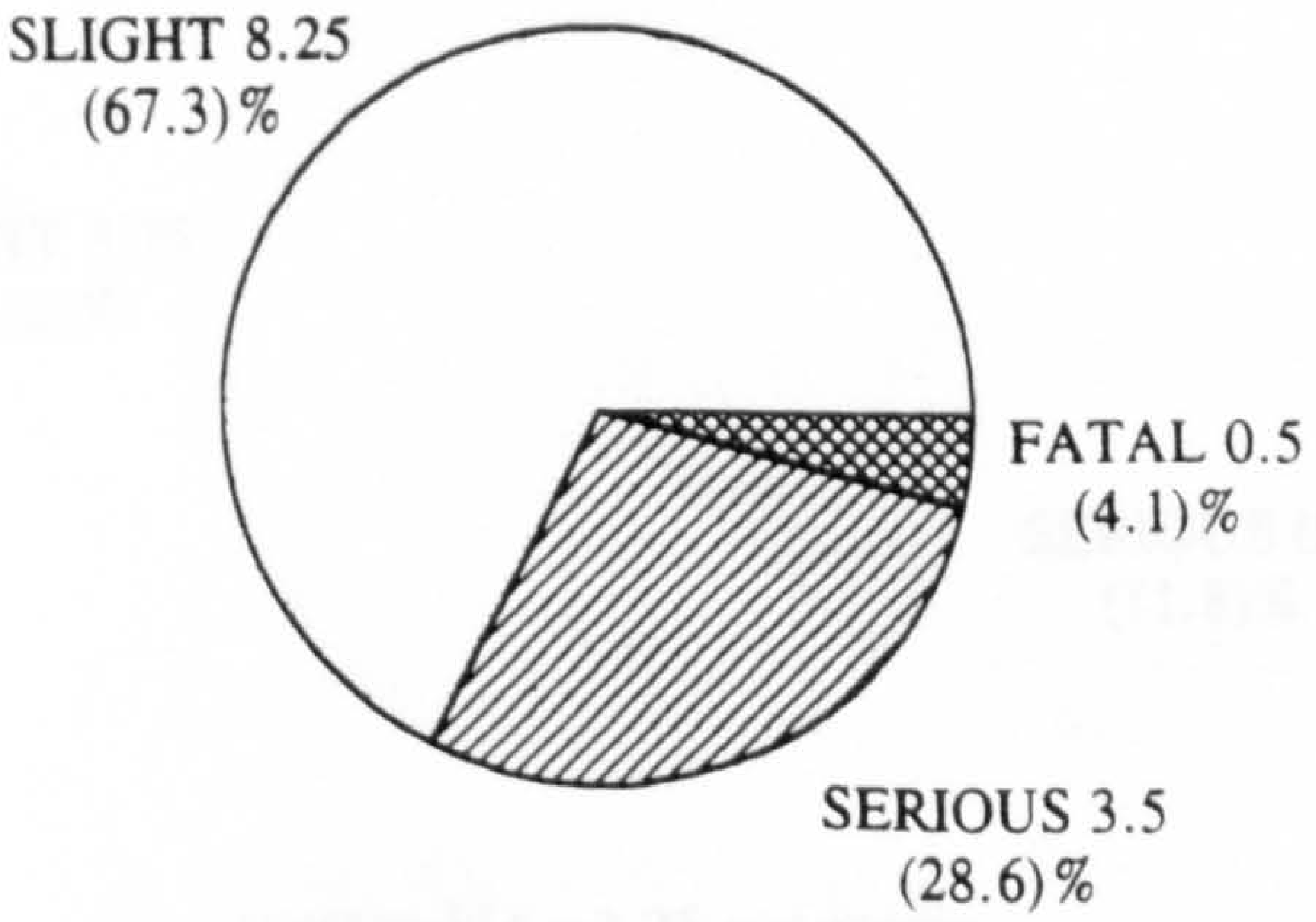


average PIA=30.25 per annum

Site: BSA100

annual flow=3.2 Mveh/annum

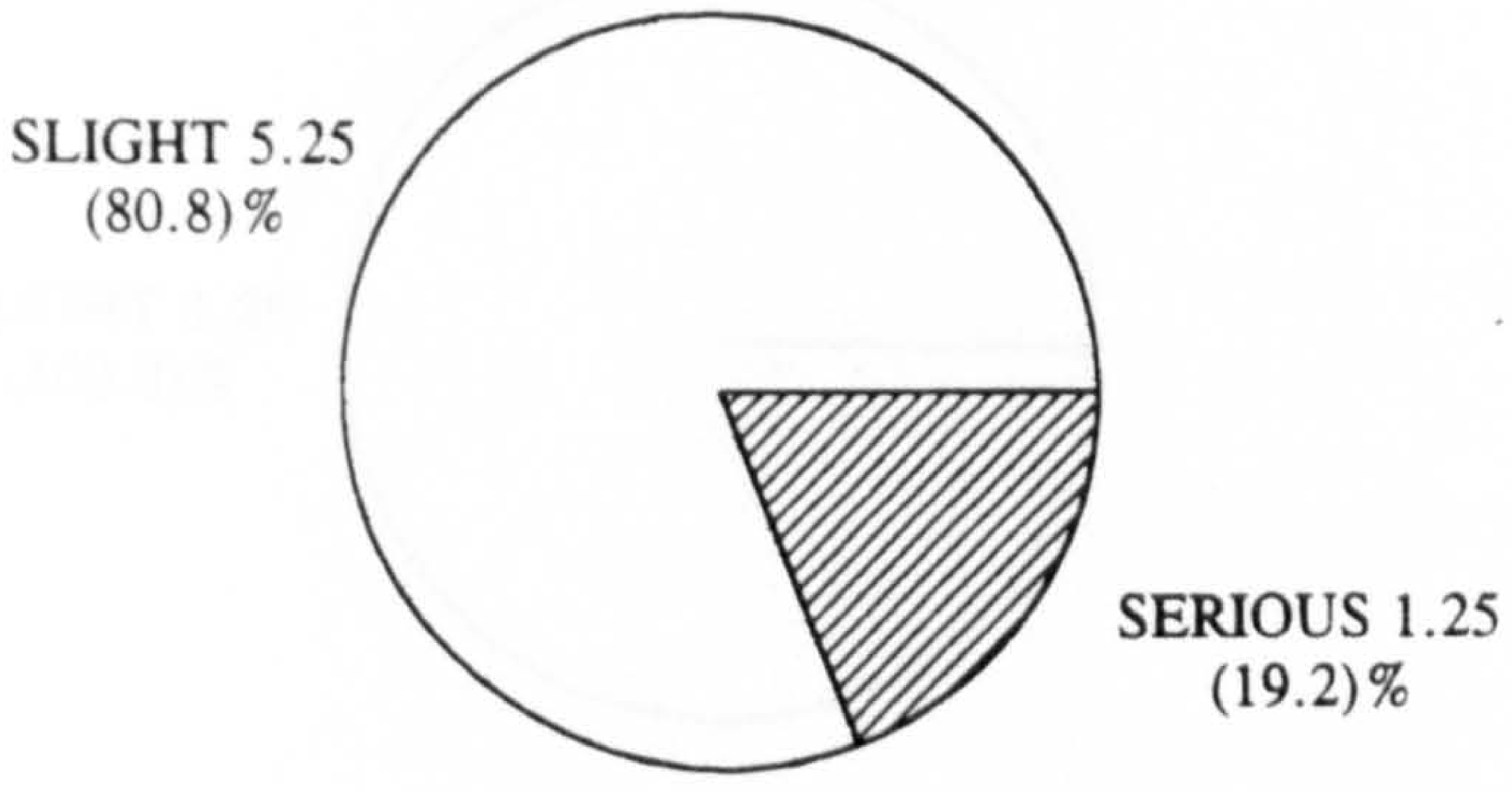
length of section=6.27 km



average PIA=12.25 per annum

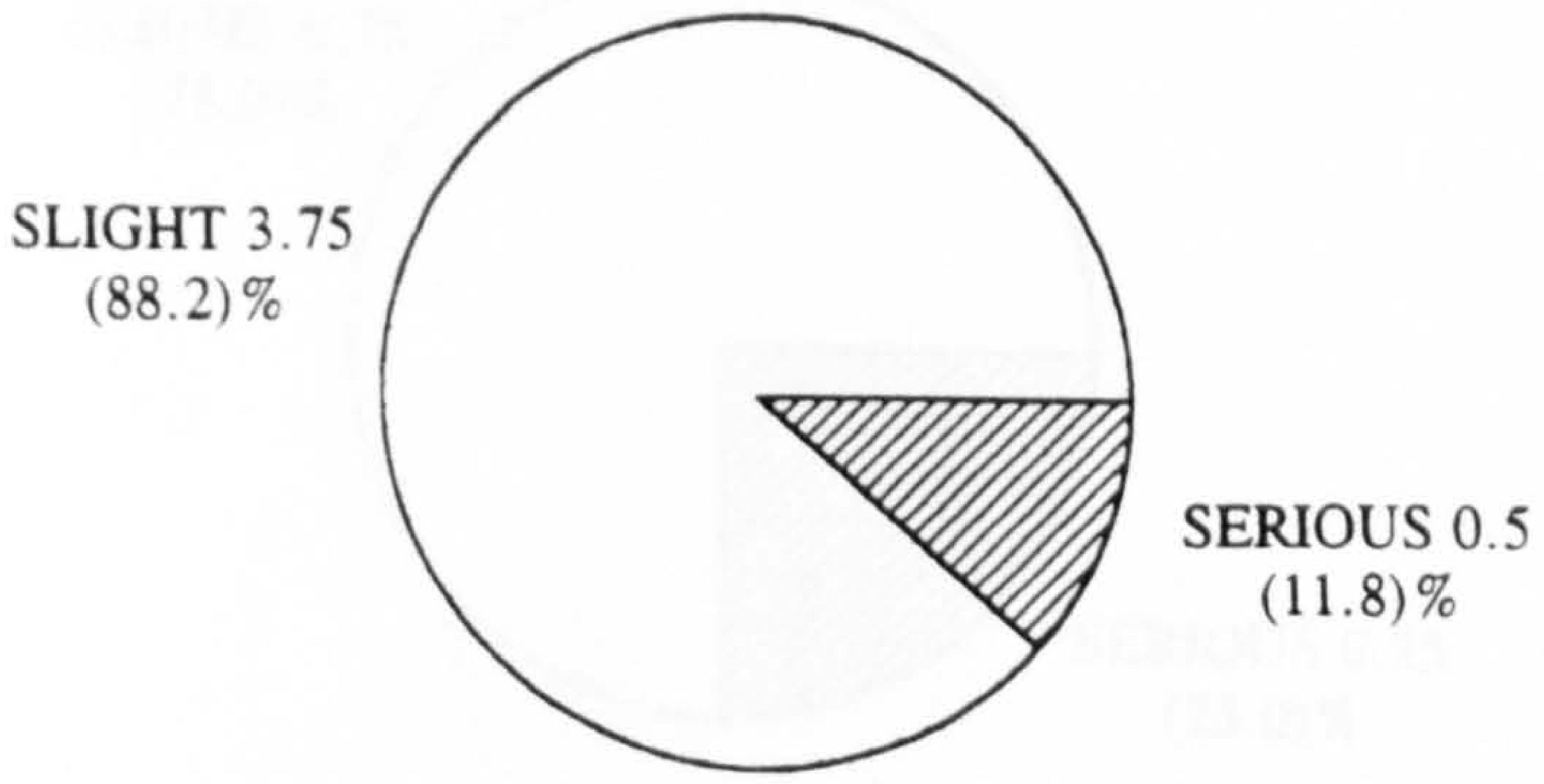
Figure 3.1b: (Continued)

Site: BIS80
annual flow=6.4 Mveh/annum
length of section=3.83 km



average PIA=6.50 per annum

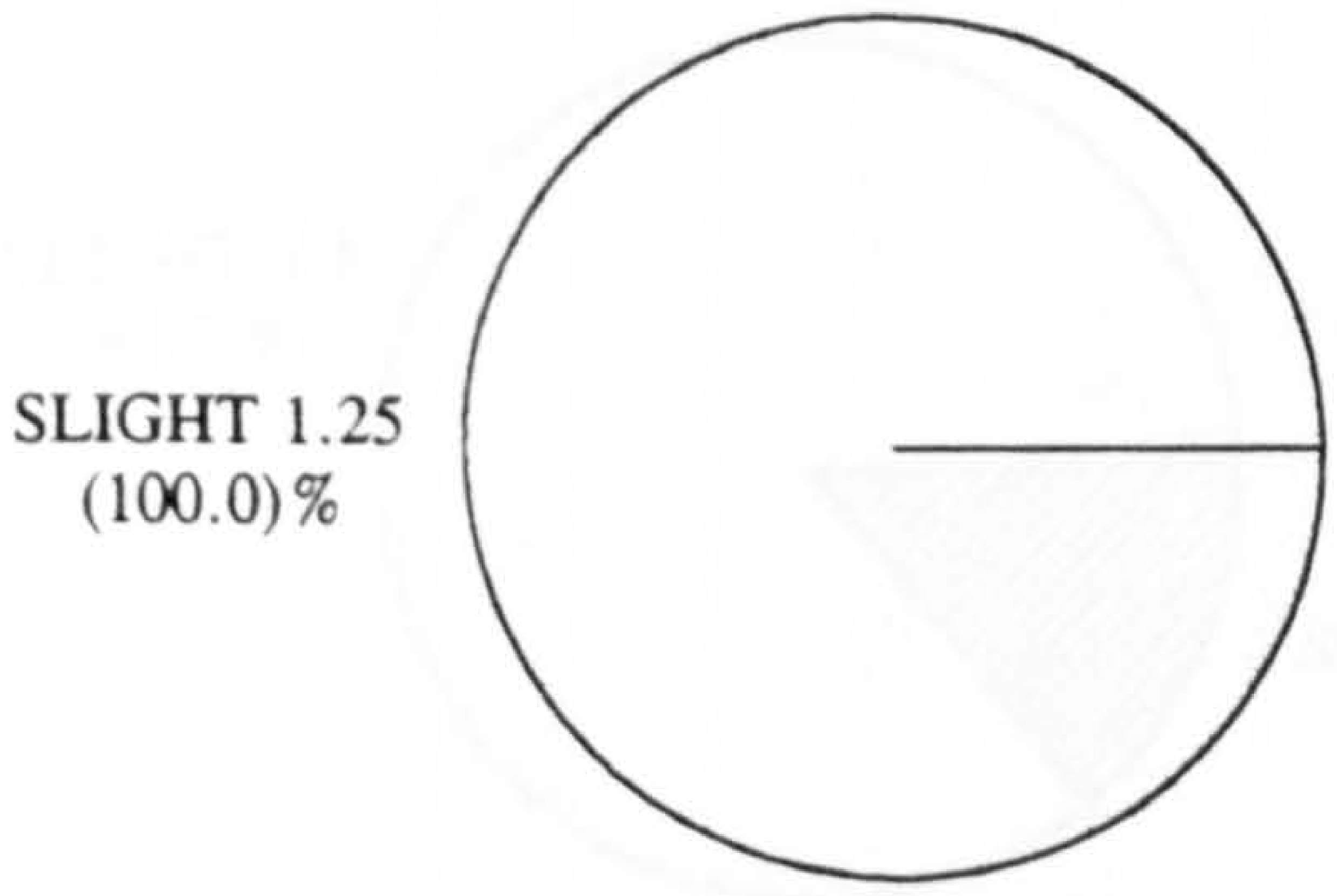
Site: BHA80
annual flow=6.9 Mveh/annum
length of section=1.52 km



average PIA=4.25 per annum

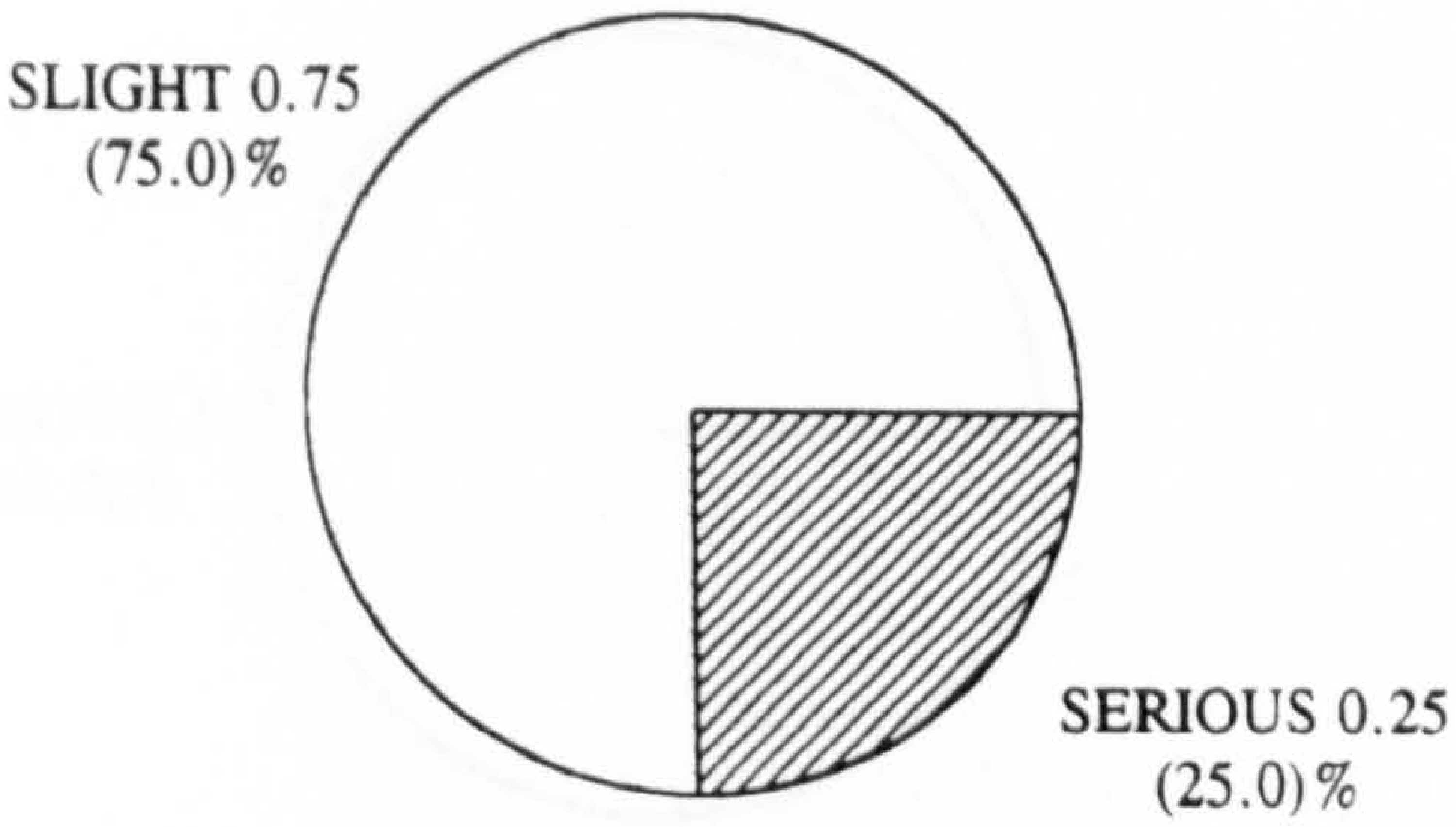
Figure 3.1b: (Continued)

Site: BFA80
annual flow=9.1 Mveh/annum
length of section=0.8 km



average PIA = 1.25 per annum

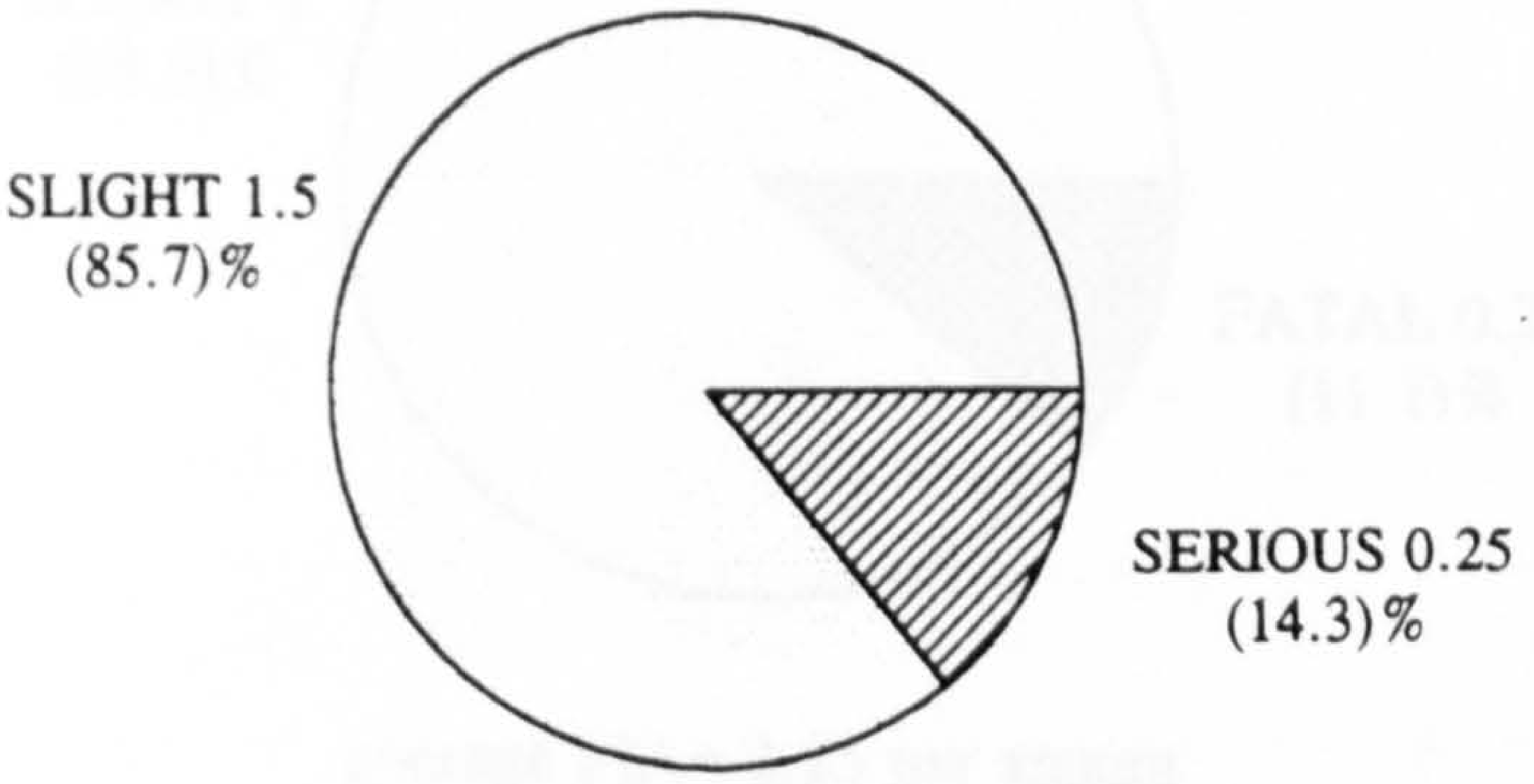
Site: BSE70
annual flow=4.2 Mveh/annum
length of section=0.55 km



average PIA = 1.00 per annum

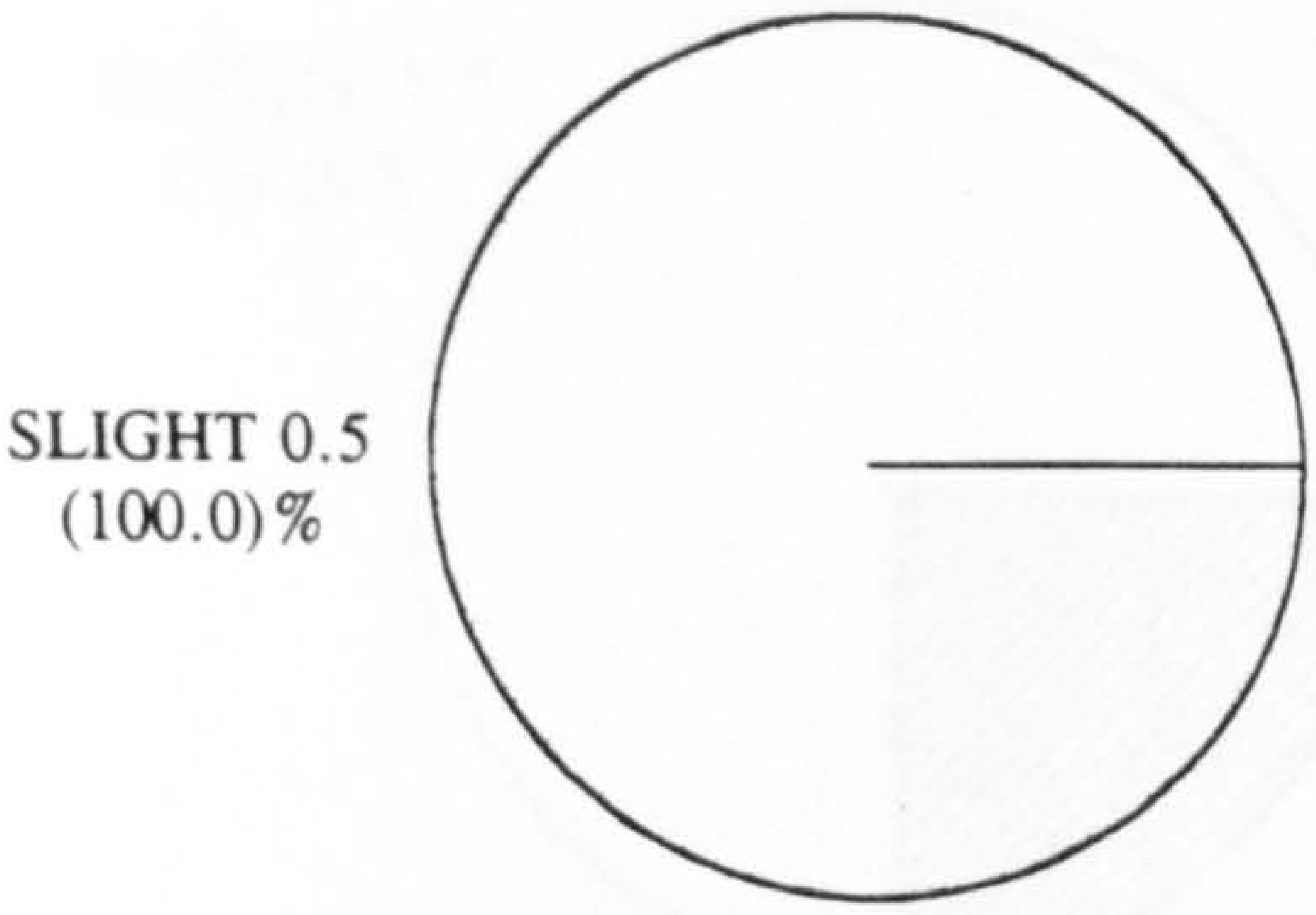
Figure 3.1b: (Continued)

Site: BKU50
annual flow=2.9 Mveh/annum
length of section=2.59 km



average PIA=1.75 per annum

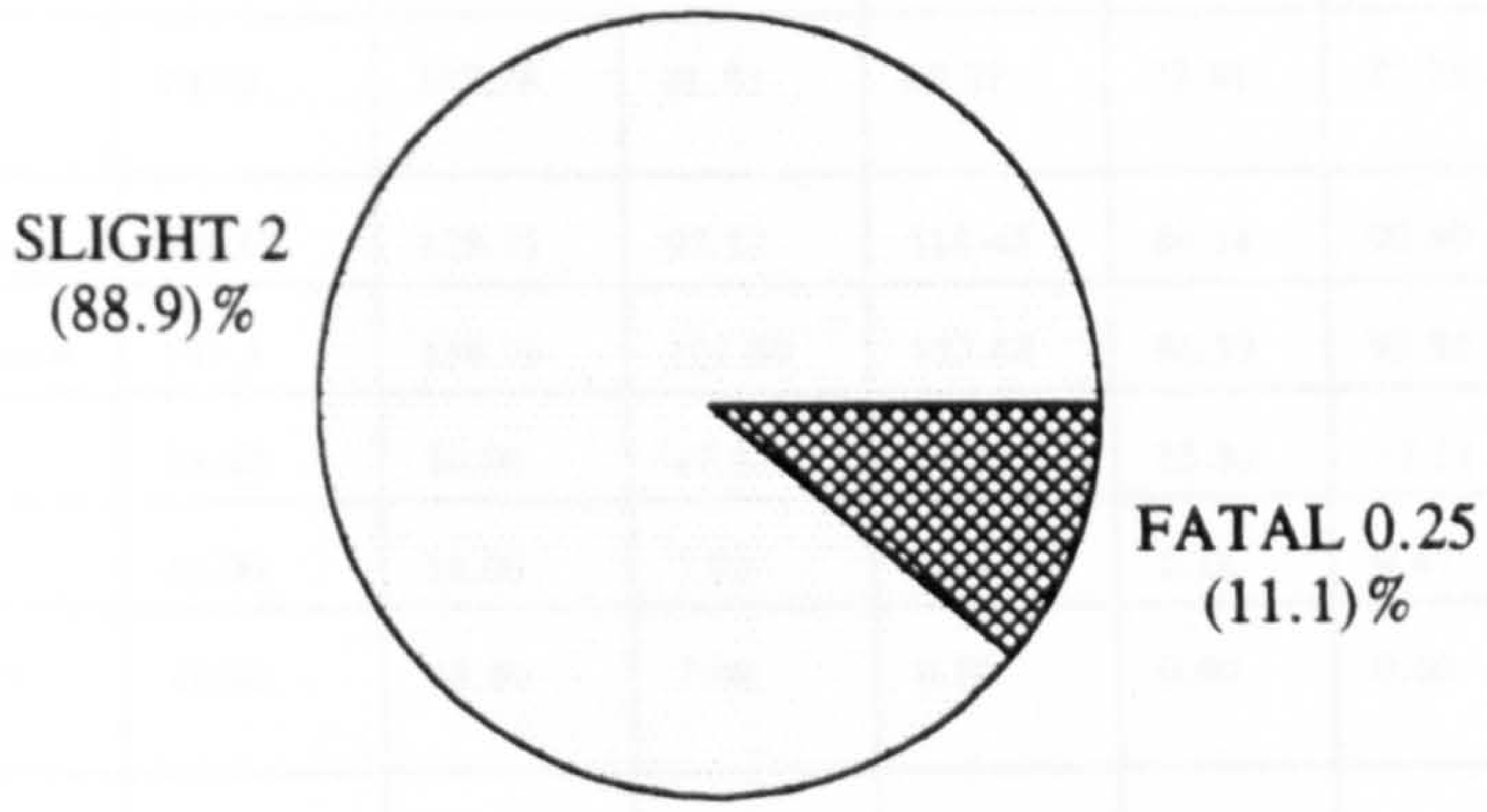
Site: BSA50
annual flow=1.2 Mveh/annum
length of section=0.82 km



average PIA=0.5 per annum

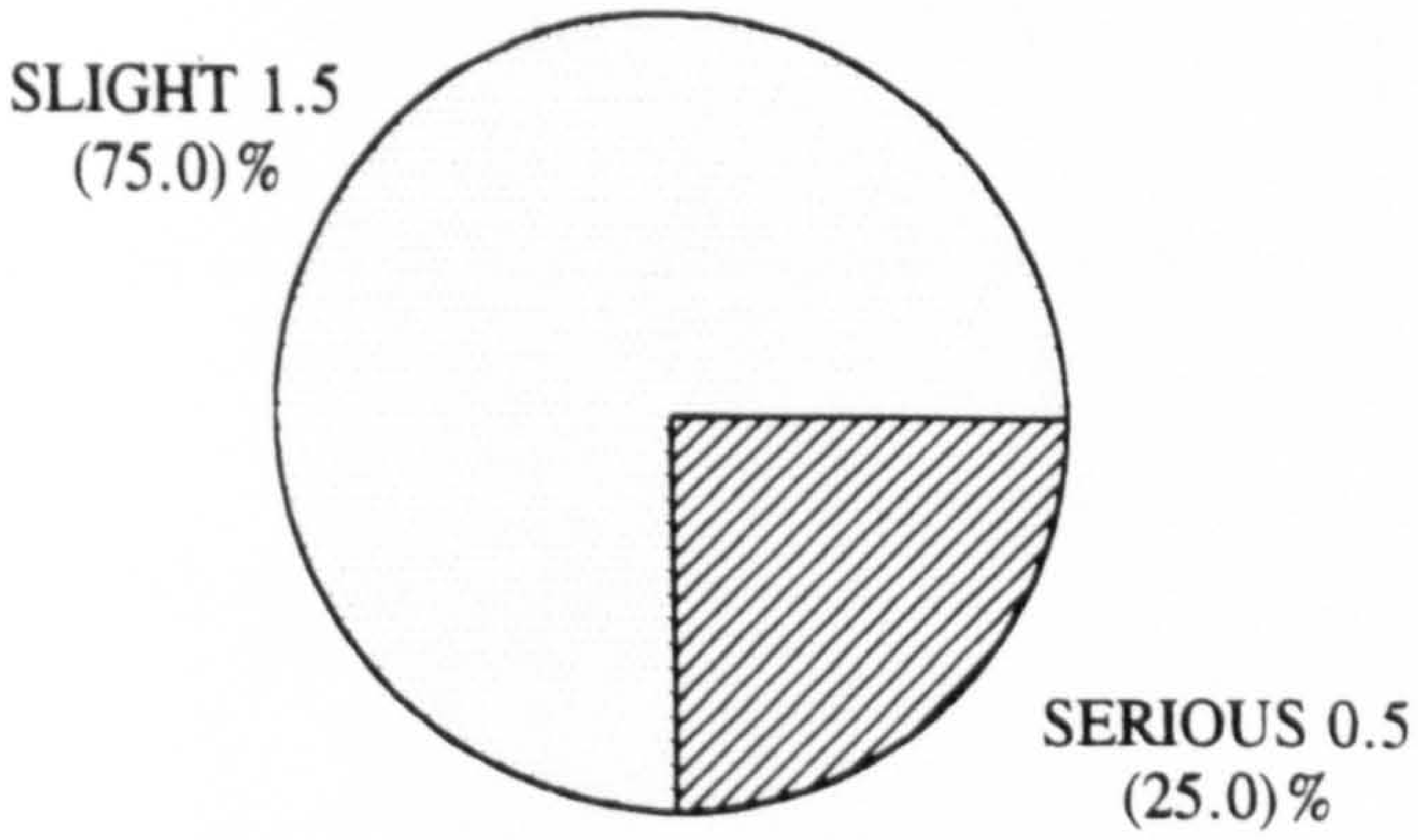
Figure 3.1b; (Continued)

Site: BSA70
annual flow = 5.4 Mveh/annum
length of section = 1.90 km



average PIA = 2.25 per annum

Site: BBU70
annual flow = 8.7 Mveh/annum
length of section = 1.05 km



average PIA = 2.00 per annum

Table 3.1a: Personal Injury Accidents (PIA) and Traffic Characteristics of the Sites Investigated (Tyne & Wear)

Sites Variables	EA1	E19	E167	EGHS	EJR	EHW	EGN	EGHN	E194
Mean speed* of traffic	110.56	107.82	83.52	93.50	78.86	77.46	72.9	72.26	63.89
Standard deviation*	14.77	18.84	13.12	17.06	10.91	13.52	10.35	11.75	6.76
Seventh* percentile speed	86.18	79.63	64.73	70.33	66.14	59.30	59.66	58.87	53.9
Fifteenth* percentile speed	91.68	87.03	69.04	75.83	68.40	63.92	62.83	61.72	58.27
Fiftieth* percentile speed	107.9	107.26	81.83	89.27	77.91	77.75	71.63	71.77	63.66
Eighty-fifth* percentile speed	125.03	129.15	97.12	114.45	89.14	90.49	83.04	84.68	71.39
Ninety-third* percentile speed	131.5	136.65	103.59	123.48	96.59	95.95	88.22	89.30	73.55
Traffic volume+	39.63	50.00	47.67	46.91	33.33	52.51	44.78	54.21	24.45
Length of the section!	44.00	18.00	7.00	0.64	1.16	0.47	0.62	1.05	1.03
Annual mean of number of PIA	28.40	18.80	7.40	0.80	0.60	0.60	0.40	0.40	0.20
Annual mean of number of slight injury accidents	22.00	14.60	6.60	0.60	0.40	0.40	0.40	0.40	0.20
annual mean of number of serious injury accidents	4.40	3.00	0.60	0.20	0.20	0.00	0.00	0.00	0.00
annual mean of number of fatal injury accidents	2.00	1.20	0.20	0.00	0.00	0.20	0.00	0.00	0.00

*: km/h
+: veh(10^5) per annum
!: km

Table 3.1b: Personal Injury Accidents (PIA) and Traffic Characteristics of the Sites Investigated (Bahrain)

Sites Variables	BMJ100	BSA100	BIS80	BHA80	BFA80	BSE70	BSA70	BBU70	BKU50	BSA50
Mean speed* of traffic	87.80	82.50	80.80	80.04	72.27	61.20	75.50	73.30	72.80	60.10
Standard deviation*	15.70	14.80	13.90	14.12	15.28	9.60	16.00	13.80	18.40	10.10
Seventh percentile speed*	64.30	61.68	60.48	58.58	52.12	46.68	52.26	52.00	43.97	45.17
Fifteenth percentile speed*	71.36	67.32	65.92	63.76	56.78	51.09	59.80	61.00	51.16	49.71
Fiftieth percentile speed*	87.21	82.08	80.99	77.08	72.43	61.3	76.16	73.97	73.77	59.57
Eighty-fifth percentile speed*	105.23	98.39	95.38	90.52	89.21	71.16	90.30	87.43	91.06	70.60
Ninety-third percentile speed*	112.17	106.04	101.09	98.36	96.85	75.31	97.80	92.07	100.04	75.61
Traffic volume+	64.49	31.72	64.53	69.20	90.54	42.54	53.75	43.13	28.79	11.82
Length of the section!	10.67	6.27	3.83	1.52	0.80	0.55	1.90	1.05	2.59	0.82
Annual mean of number of PIA	30.25	12.25	6.50	4.25	1.25	1.00	2.25	2.00	1.75	0.50
annual mean of number of slight injury accidents	21.75	8.25	5.25	3.75	1.25	0.75	2.00	1.50	1.50	0.50
Annual mean of number of serious injury accidents	7.50	3.50	1.25	0.50	0.00	0.25	0.00	0.50	0.25	0.00
Annual mean of number of fatal injury accidents	1.00	0.50	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00

*: km/h
+: veh (10^5)/annum
!: km

3.6 The Method of Analysis and the Results

3.6.1 The Speed Characteristics of the Traffic used in the Analysis

The object of this part of this study was to investigate the relationship, if any, between the speed characteristics of traffic and the frequency and severity of accidents. The speed characteristics of traffic that were used, were as follows:

(i) the mean speed (SP) (km/h),

(ii) the eighty-fifth percentile speed (EF) (km/h),

(iii) the standard deviation (STD) (km/h),

(iv) the Pearson Skewness Index (PSI):

$$PSI=\frac{3\times(mean\ speed-median)}{standard\ deviation}$$

(v) the Skewness Index (symmetry) (SI):

$$SI=\frac{2\times(93^{rd}\ percentile\ speed-50^{th}\ percentile\ speed)}{93^{rd}\ percentile\ speed-7^{th}\ percentile\ speed}$$

(vi) the Coefficient of Variation (CV):

$$CV=\frac{standard\ deviation}{mean\ speed}$$

(vii) the Speed Spread (SS) (km/h):

$$SS=the\ 85^{th}\ percentile\ speed-the\ 15^{th}\ percentile\ speed$$

(viii) the Coefficient of the Speed Spread (CSS):

$$CSS=\frac{the\ 85^{th}\ percentile\ speed-the\ 15^{th}\ percentile\ speed}{the\ 15^{th}\ percentile\ speed}$$

(ix) the Upper Speed Spread (USS) (km/h):

$$USS = \text{the } 85^{th} \text{ percentile speed} - \text{the } 50^{th} \text{ percentile speed}$$

(x) the Coefficient of Upper Speed Spread (CUSS):

$$CUSS = \frac{\text{the } 85^{th} \text{ percentile speed} - \text{the } 50^{th} \text{ percentile speed}}{\text{the } 50^{th} \text{ percentile speed}}$$

3.6.2 The Analysis of the Frequency of PIA

The relationship between the variables selected was expected to be of a multiplicative form because the frequency of PIA was expected to produce positive results. The relationship between the number of accidents (ACC) and the length of the section (LG), the traffic flow (FW) and the speed characteristics of traffic (SPD) was expected to have the following form:

$$ACC = k\ LG^{a}\ FW^{b}\ SPD^{c}$$

where k is the constant of the regression;

ACC= the annual average number of personal injury accidents (the dependent variable);

T= time span of the accident records (years) treated as an off-set (i.e. its coefficients were fixed at 1.0 assuming linear relationship with the number of accidents)

LG= the length of the section (km) (an independent variable);

FW= the traffic volume (10^5 veh/year) (i.e. an independent variable);

SPD= the speed characteristics (i.e. an independent variable); and

a,b, and c= the power coefficients of the independent variables.

Another form of the relationships was examined:

$$ACC=k\ FL^{a}\ SPD^{b}$$

where;

FL= the interaction effect of the length of the section and traffic flow (FW*LG) (10^5 veh/year km)

Another model was tested where the dependent variable was the number of accidents per unit length. The length of the section was assumed to have a linear relationship with the number of accidents (i.e. the power coefficient was assumed to be unity) . It had the following form:

$$ACCL=k\ FW^{a}\ SPD^{b}$$

where

ACCL= the annual average number of personal injury accidents per km

In the fourth model, the dependent variable was the number of accidents per vehicle unit length. This was achieved by forcing the interaction effect of the length of the section and the traffic flow (FL) into the model with its coefficient fixed at 1.0 (i.e. assuming a linear relationship with the number of accidents, as well as, with the time span of the accidents) leaving the speed character to be the, only, independent variable.

$$ACCLF=k\ SPD^{a}$$

where

ACCLF= the annual average number of personal injury accidents per 10^5 vehicle kilometre

The Poisson Probability Distribution

The total number of accidents that happened over the time span of the records was modelled using the Poisson probability distribution for the error structure. The Poisson distribution has the following form:

$$f(y|\lambda)=\frac{e^{-\lambda}\lambda^{y}}{y!},\ \lambda>0,\ y=0,1,2,\ldots$$

where y was the number of observed accidents and λ was the expected mean number of accidents which was represented by the notations ACC, ACCL, and ACCLF in the accident frequency models.

Regression Analysis

The Generalised Linear Interactive Model (GLIM) (Royal Statistical Society, 1985) was used to analyse the different forms of the proposed relationships. The package used the method of maximum likely-hood of fitting which was, almost, the same as the weighted regression of the least square method for the Normal distribution (Healy, 1988) (i.e. the input data is in Tables 3.1a and 3.1b). The Poisson distribution is a discrete distribution so the total number of accidents for all the years had to be used not the annual mean value. To overcome this problem, the 'offset' command in GLIM was used to account for the time span of accident records (i.e. years). The 'off-set' command forced the coefficient of the variable to 1.0. The 'offset' was used, also, to handle the "length of the section" variable in the third form of the relationship (i.e. moving it to the other side of the equation) and to handle the variable "vehicle distance" in the fourth form of the relationships.

Testing the Significance of the Variables

The significance of the variables depended on two conditions. Firstly, for a 95 per cent confidence level, twice the standard error of the coefficients should be less than the estimated coefficient. Secondly, it depended on the amount of change in the scaled deviance (S.D.) (i.e. which is, almost, equivalent to the sum of the square of the residuals) when the variable is added or subtracted from the model. The absolute amount of the change had to be more than 3.841 which was equivalent to one degree of freedom at 95 per cent confidence level in the Chi-Square Distribution (Healy, 1988). For the model describing the relationships between the speed characteristics of the traffic and the accidents the scaled deviance of the model, in general, has to be equal or less than the number of degrees of freedom.

The Results of the Analysis

The most significant relationship between accident frequency and the speed characteristics of the traffic were the following (i.e. for abbreviations see Sections 3.6.1 and 3.6.2):

Tyne & Wear

$$ACC=0.10\ FL^{1.02}\ CUSS^{1.09}$$

$$ACCLF=.11\ CUSS^{1.03}$$

Bahrain

$$ACCL=3.3x10^{-7}\ FW^{.31}\ SP^{3.3}$$

$$ACC=.16\ LG^{1.16}\ FW^{.56}\ SI^{3.21}$$

(See Tables 3.2a and 3.2b for a summary of the significant results, Figures 3.2a and 3.2b for the validation of the models and Appendix II: Exhibits 3.1a and 3.1b for the results of all speed characteristics tested)

Figure 3.2a: The Validation of the Accident Frequency Model:
$ACCLF = 0.11\ CUSS^{1.03}$ (Tyne & Wear)

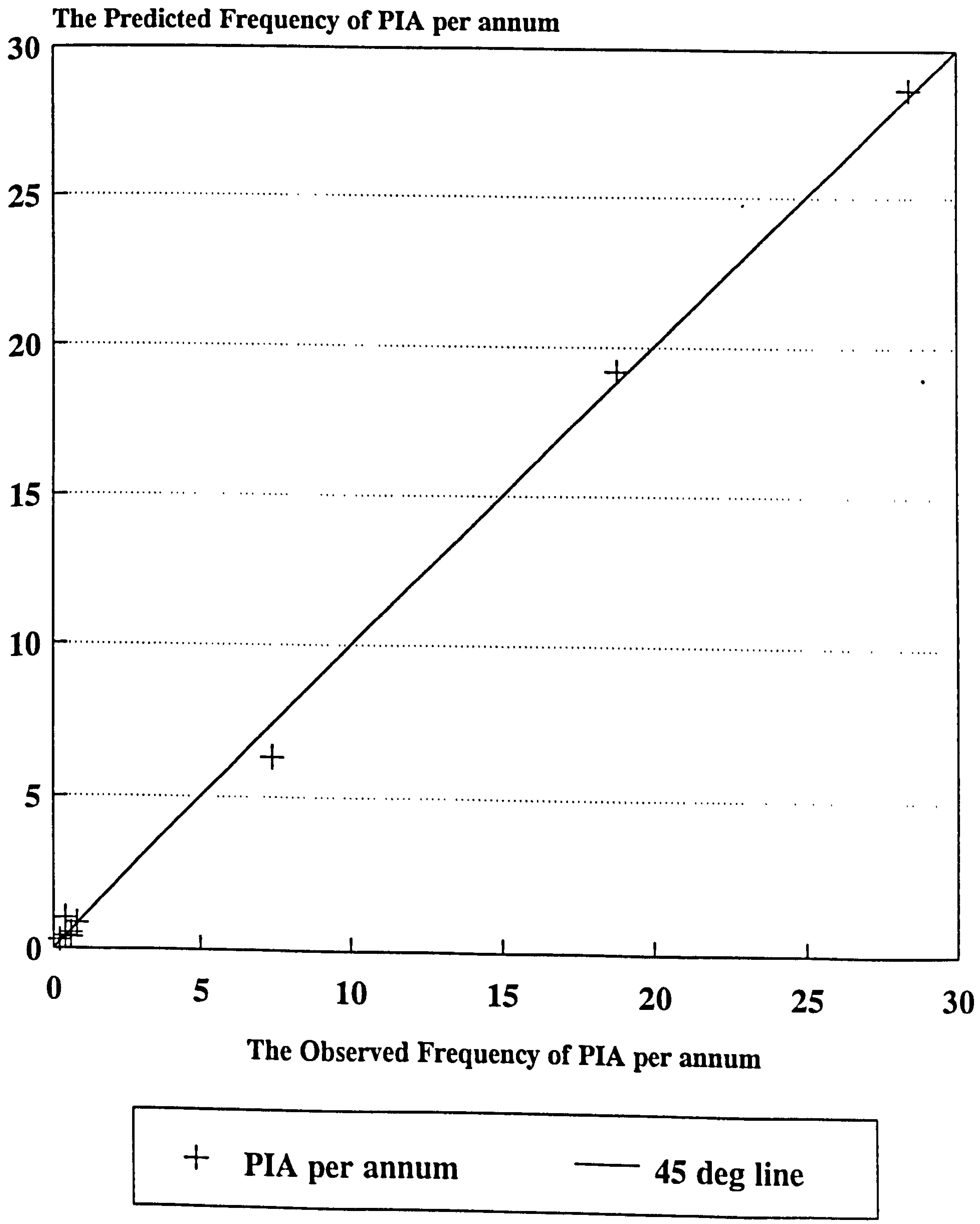


Figure 3.2b: The Validation of the Accident Frequency Models

$ACCL= 4.35x10^{-16}\ FW^{.31}\ SP^{3.28}$ (Bahrain)

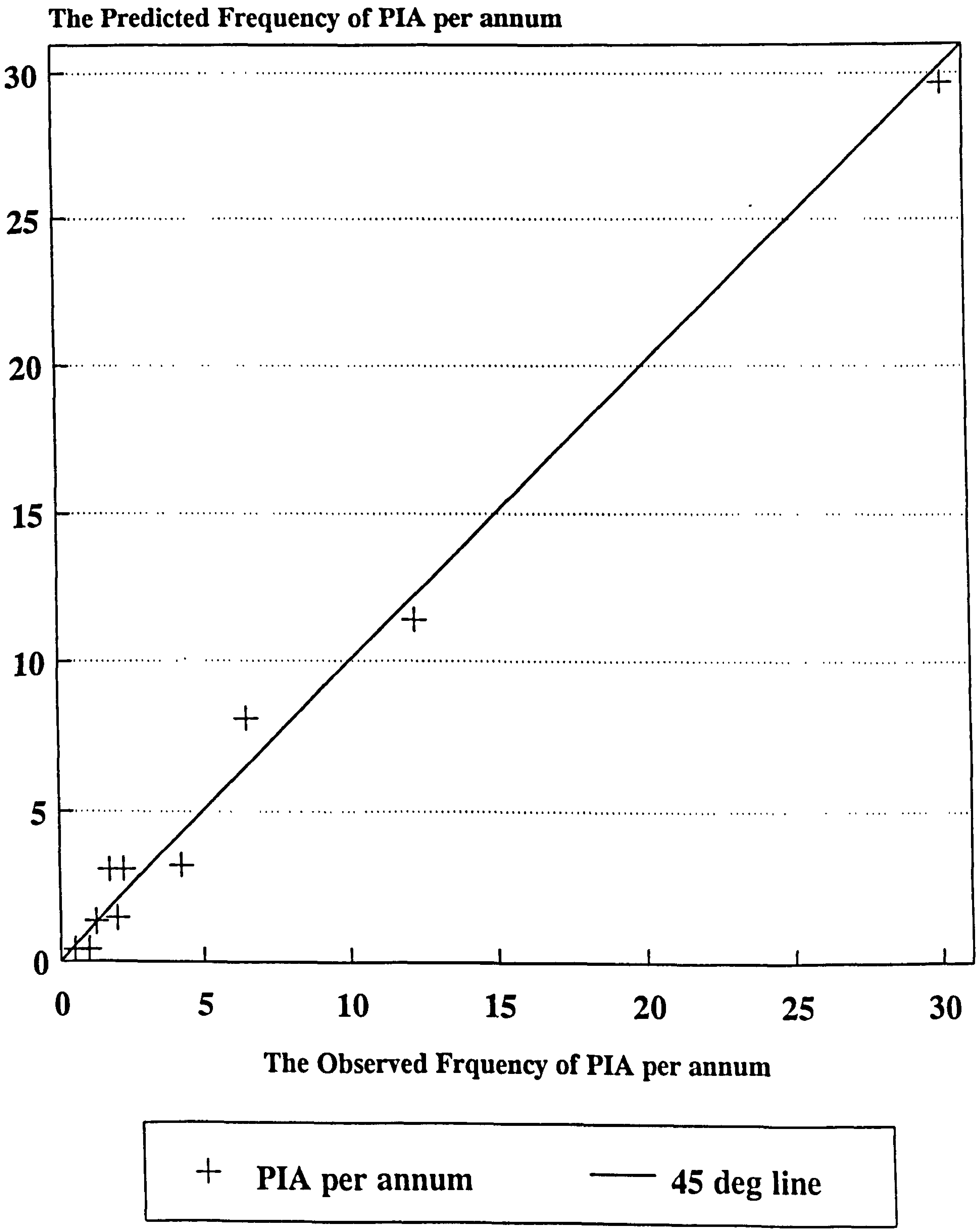


Table 3.2a: The Accident Frequency Models (Tyne & Wear)

Relationship*	Offset variable	Stand. error	ΔS.D.	S.D (deg. of freedom)
$ACC=.003\ FL^{.93}\ STD^{.79}$	years	0.06 0.40	-3.91	5.19 (6)
$ACC=.12\ FL^{1.03}\ CV^{1.10}$	years	0.06 0.50	-4.78	4.31 (6)
$ACC=.002\ FL^{.91}\ SS^{.76}$	years	0.07 0.37	-4.09	5.00 (6)
$ACC=.05\ FL^{.99}\ CSS^{.96}$	years	0.06 0.42	-5.26	3.83 (6)
$ACC=.004\ FL^{.93}\ USS^{.74}$	years	0.06 0.36	-4.06	5.03 (6)
$ACC=.10\ FL^{1.02}\ CUSS^{1.09}$	years	0.06 0.48	-5.14	3.95 (6)
$ACCLF=.13\ CV^{1.02}$	years*LG *FW	0.46	-4.82	4.47 (7)
$ACCLF=.04\ CSS^{.97}$	years*LG *FW	0.42	-5.40	3.89 (7)
$ACCLF=.11\ CUSS^{1.03}$	years*LG *FW	0.44	-5.24	4.05 (7)

*for the abbreviations see Sections 3.6.1 and 3.6.2

Table 3.2b: The Significant Accident Frequency Models (Bahrain)

Relationship*	Offset	Stand. error	ΔS.D.	S.D. (deg. of freedom)
$ACC=.16\ LG^{1.16}\ FW^{.56}\ SI^{3.21}$	years	0.08 0.18 1.54	-4.34	8.23 (6)
$ACCL=4.35x10^{-16}\ FW^{.31}\ SP^{3.28}$	years*LG	0.21 1.01	-11.72	9.76 (7)

*for the abbreviations see Sections 3.6.1 and 3.6.2

3.6.3 The Analysis of the Severity of PIA

Serious and fatal injury accidents were combined to form a new class which was called the 'hazard' category to overcome the problem of having too few observations in the serious and fatal categories. The relationship between the severity of injury accidents (i.e. slight, serious fatal, and hazard) with the speed characteristics of traffic was analysed in two ways. First, the frequency of each class of severity was treated separately using the Poisson distribution to model the data in a similar way to that used for the total accident frequency analysis in Section 3.6.2. Secondly, the Binomial distribution was used, treating the severity frequency of each class of severity as a number of 'successes' out of so many 'attempts' (i.e. accidents).

The Results

(i) The Poisson Probability Distribution

The most significant results were associated with slight injury accidents. The speed characteristics and other accident categories, did not show a definite relationship, at the 95 per cent confidence level, even though, the mean and the eighty-fifth percentile speed of the traffic had a, relatively, more significant effect on the severity of personal injury accidents than on the frequency of personal injury accidents.

The most significant results were:

Tyne & Wear

$$SLLF=.09\ CUSS^{1.08}$$

where SLLF= the annual average number of slight injury accidents per 10^5 vehicle km

Bahrain

$$SLL=.10\ FW^{.67}\ SI^{3.34}$$

where SLL= the annual average number of slight injury accidents per km

For a summary of the other significant results see Table 3.3a for Tyne & Wear and Table 3.3b for Bahrain. For the results of all the speed characteristics see Appendix II: Exhibits 3.2a and 3.2b.

Table 3.3a: The Personal Injury Accident Severity Model using the Poisson Distribution (Tyne & Wear)

Relationship*	Offset	Stand. error	ΔS.D.	S.D. (deg. of freedom)
$SLLF=0.09\ CUSS^{1.08}$	YEARS* LG*FW	0.50	-4.53	3.81 (7)

*for the abbreviations see Sections 3.6.1 and 3.6.2

Table 3.3b: The Personal Injury Accident Severity Model using the Poisson Distribution (Bahrain)

Relationship*	Offset	Stand. error	ΔS.D.	S.D. (deg. of freedom)
$SLL=.10\ FW^{.67}\ SI^{3.34}$	YEARS* LG	.20 1.60	-4.60	5.16 (7)

*for abbreviations see Sections 3.6.1 and 3.6.2

(ii) The Binomial Distribution

It is a discrete distribution which has the following form:

$$Pr(x)=\binom{n}{x}p^{x}(1-p)^{n-x}$$

$$\text{where,}$$

$$(x=0,1,\ldots,n-1,n)$$

$$n \text{ (a poistive integer) and } p\ (0\leq p\leq 1) \text{ are parameters}$$

The equation which described the relationship between the severity of the accidents and the speed characteristics of the traffic, had the following form:

$$\frac{accident\ severity}{total\ accidents}=a\ speed\ charact.^{b}$$

where
a,b parameters

No significant results were obtained from this analysis. For the results of all the speed characteristics see the Appendix II: Exhibits 3.4a and 3.4b.

3.7 Discussion

3.7.1 The Data

A survey was carried out using detailed maps together with a personal inspection of each possible site. The opinions of the local highway authorities were sought when selecting suitable sites. The criteria for the selection of injury accidents was outlined in Section 3.4. Nevertheless, some shortcomings were encountered due to the limitations of some of the 'suitable' sites such as the lack of precision in identifying the exact locations of some accidents, the lack of suitable distributions of traffic speed and traffic volumes from previous years (i.e. as was the case in Bahrain), not having the precise traffic conditions at the time of the accidents, and the absence of documented reports about any changes in road conditions that might have occurred during previous years.

3.7.2 The Analysis

Various characteristics of the speed distributions were used to test against the frequency and severity of personal injury accidents. Some of these definitions were obtained from the literature, whereas the others were developed for this particular study. The multiplicative relationship was found to be particularly suitable for this kind of analysis. The accident frequency distribution was positive and discrete with the probability of accidents decreasing as the frequency increased. The Poisson probability distribution modelled such a relationship. The severity of accidents were analysed in two ways. First, each category of severity was treated in a similar way to the frequency of the total accident analysis. Secondly, it was analysed as an outcome probability of an attempt (i.e. the attempt was the personal injury accident and the outcome could be three possibilities: slight injury, serious injury, or fatal injury). The Binomial probability distribution was suitable to describe the relationship (e.g. the number of accidents in the particular severity class was the numerator and the total number of accidents was the denominator).

3.7.3 The Results

In analysing the frequency of personal injury accidents for Tyne & Wear, the Coefficient of the Upper Speed Spread (CUSS) was the most influential speed characteristic in determining the number of accidents (i.e. the length of the section and the traffic flow were assumed to be linearly related to the number of accidents). The validation of the results revealed good agreement between the observed and the number of accidents predicted by the model. This result implied that as the difference between the eighty-fifth percentile speed of traffic and the median speed of traffic increased, more vehicles exhibited excessive speeds which led to more accidents. Such differences had a more severe effect if the median speed was 'low', which meant the difference would be high when it was considered relative to the median speed. Some of the speed differential characteristics had a significant effect on the frequency of injury accidents but these were less significant than CUSS. This could be explained by the fact that the speed differentials of the upper half of the speed distribution, where the absolute speeds of vehicles were high and the control of vehicles was more difficult, had a more severe influence on accidents than a similar speed spread at lower parts of the speed distribution. The mean speed and the eighty-fifth percentile speed did not show any significant results. This result was supported by studies which were inclined to the opinion that the speed differentials between vehicles (i.e. and excessive vehicle speeds) was the cause of accidents not the mean speed of traffic, Solomon (1964), Garber and Gadiraju (1990), Middleton and Kenyon (1981), Indiana University (1970), ITE Metropolitan section of New York and New Jersey Sub-Committee (1977) and ITE Special Technical Council Task Force (1987). The length of the section had, an almost, linear relationship with the number of accidents which was anticipated. This relationship meant that if the length of the section was doubled, for example, double the number of accidents were expected. The traffic flow, and the interaction effect of the length of the section and the traffic flow had a less good linear relationship with the number of accidents than the length of the section. This meant that doubling the flow of traffic, for example, did not mean that the number of accidents would double, as was suggested by some studies (see Section 3.2.5).

The Bahrain data revealed that the speed characteristic which was most related to the number of accidents (i.e. the length of the section was assumed to have a linear relationship with number of accidents) was the mean speed (SP) of traffic. The validation of the results revealed good agreement between the observed data and the number of accidents predicted by the model. This agreed with the experiences in different countries where changing the speed limit led to a change in the mean speed of traffic which was associated with a change in the number of accidents (see Section 3.2.1). The other influential speed characteristic was the Skewness Index (SI) which agreed with the opinion that the speed differential was related to the number of accidents. Here, also, the relationship between the length of the section, the traffic flow, and the interaction effect of the length of the section and the traffic flow with the frequency of injury accidents had similar characteristics to those found in Tyne & Wear.

The results of the two sets of data agreed, partially. The speed differential of vehicles was an influential factor when determining the number of accidents in both places (i.e. CUSS and SI), even though, the speed differential in Tyne & Wear was for the upper part of the speed distribution and the speed differential for Bahrain was for the whole distribution. The role of the mean speed of traffic remained the main difference between the results of the two sets of data. The difference could be associated with different environmental conditions prevailing in the two places such as road conditions, vehicles, traffic laws, weather, drivers' education and the cultural background, in general. Each of these factors could have contributed individually or collectively in producing the dissimilarity of the results of the two sets of the data. It would be hard to associate the exact reason of the variation in the results.

In the analysis of accident severity, for Tyne & Wear, and Bahrain, no significant results were revealed for the first method of analysis (i.e. Poisson distribution) except for the slight injury accident category which was similar to the total accident-frequency analysis. For more severe accidents, no solid relationships were found, even though, the mean speed showed more significant results than in the analysis of the total injury accidents which were expected. In the second method of analysis (i.e. the Binomial probability distribution), no significant relationships were found.

Generally, the limited data could have affected the results. More sites were needed to test the relationships more rigorously. For example, sites of similar lengths but with significantly different speed characteristics would have enhanced the results but, usually, the vehicles attained higher speeds on the longer sections of road with 'higher' speed limits displayed. Ideally, longer sections of road were needed as the shorter lengths exhibited very few accidents and, after the selection procedure, the number of accidents decreased, even further, which made the significance of the analysis less reliable. In the case of the severity of accidents, many sites exhibited no serious or fatal injury accidents which led to small variations in the severity of injury accidents for different sites. This was reflected in the results from the regression analysis, which explained the variation in the severity of the accidents by the variation in the length of the sections (i.e. in the data collected, most of the severe injury accidents happened on the 'longer' sections of roads) and the traffic volume and, in some other cases, the variation in the accidents was explained by a constant of regression, only, which produced satisfactory statistical results. This was true for both methods of analysis. The random occurrence of accidents could have effected the results, especially, for the serious and fatal accidents on the 'shorter' sections. The accuracy of reporting the accidents could have been another source of error. The assumptions that have been made such as the typical traffic speeds and traffic volumes could have been a source of error and affected the results.

3.8 Conclusion

In this Chapter, an attempt was made to explore the relationship between the speed characteristics of traffic, which is the main consequence associated with speed limits, and the frequency and severity of personal injury accidents. The results were intended to be used in the economic analysis of the effect of changing speed limits. The literature on this subject has been reviewed. Some opinions associated the changes that happened in the number of personal injury accidents following changes in speed limits with the changes in the mean speed of traffic, others were inclined to conclude that the speed differentials (speed spread) were a cause of accidents and not the mean speed of traffic but no quantifiable relationship was found in the literature. A hypothesis was proposed. A methodology consisted of data collection criteria and methods of analysis were outlined to examine the hypothesis. Two sets of data were collected from Tyne & Wear, England and the State of Bahrain. The results, for Tyne & Wear, showed that the speed differentials, especially, in the coefficient of the upper part of the speed distribution (CUSS) was related to the frequency of personal injury accidents. The results for Bahrain were similar to those for Tyne & Wear where the skewness index of speed distributions (SI) was related to the number of personal injury accidents, and the mean speed of traffic was related strongly to the frequency of personal injury accidents. Unfortunately, the analysis produced no firm results on the relationship between the speed of traffic and the severity of injury accidents, even though, the mean speed of traffic demonstrated a weak relationship with the severity of injury accidents.

Chapter Four

Cost-Benefit Analysis

4.1 Introduction

This chapter discusses the cost-benefit analysis method and, particularly, the method adopted by the Department of Transport in U.K. which is detailed in the COBA9 Manual (Department of Transport U.K., 1982) and the COBA10 Manual (Department of Transport U.K., 1994a). The components of the total cost were reviewed with special emphasis on their relationships with the mean speed of traffic. The assumptions and shortcomings of the method in relation to the objectives set for this study are discussed in detail.

4.2 Cost-Benefit Analysis

4.2.1 General

"Cost benefit analysis is a practical way of assessing the desirability of projects, where it is important to take a long view (i.e. in the sense of looking at repercussions in the future, as well as the nearer, future) and a wide view (i.e. in the sense of allowing for side-effects of many kinds on many persons, industries, regions, etc.), i.e, it implies the enumeration and evaluation of all the relevant costs and benefits. This involves drawing on a variety of traditional sections of economic study- welfare economics, public finance, resource economics- and trying to weld these components into a coherent whole" (Prest and Turvey, 1965). Cost-benefit analysis was first used in France, then it was used in the U.S.A. by the Army Corps of Engineers when they tried to value tangibles. In the 1930s, the social justification was brought into the concept and by the end of the Second World War the idea of bringing in secondary benefits into the calculation was introduced. In 1950, 'welfare economics' had been introduced to cost-benefit analysis.

4.2.2 Cost-Benefit Analysis (COBA) Method (Department of Transport U.K., 1982)

The cost-benefit technique has been used to evaluate public sector investment (i.e. government projects) in order to allocate budgets to individual projects in order of priority. Outcomes of road projects have no market value (i.e. the savings, are usually, in time, operating cost, and accidents where the costs, usually, include capital and maintenance cost). In theory, cost-benefit analysis has been developed for such a situation where the cost or benefit has been measured to society as a whole (i.e. social cost-benefit analysis). Practically, the analysis has failed to consider the whole of society and, instead, has been more confined to road users. Changes in travel-time and vehicle operating costs were confined to road users and changes in accident costs accrued to road users including pedestrians, central and local government, relatives and friends of those at risk. As there is no market value for the savings, their values have been estimated on the 'willingness to pay' principle using, therefore, the 'consumer surplus' approach. The valuations were 'resource costs' where 'transferred payments' (e.g taxes and subsidies) were not included. The user costs are defined as "physical units of time, vehicle operating and accident numbers in terms of hours etc. multiplied by the money values per physical unit e.g. £ per hour". Consumer surplus is defined as "the difference between what people are prepared to pay for a given quantity of goods or services and what people actually pay". COBA adopted a 'fixed-trip' matrix and assumed that vehicle type and journey purpose proportions would be constant in future years. Usually, benefits and costs of projects do not happen simultaneously. Both individuals and governments prefer costs occurring 'later' and benefits occurring 'sooner'. A reference point (i.e. a base year) had to be assigned where all different costs and benefits could be referred for comparison. This point was called the 'present value year'. Also, prices had to be referred to a 'price base year' which could be the same as the former year or a different year using price indices . A discount rate has been used in transforming the future values to the 'present value year' in order to account for the fact that £1 today, if it was invested at an interest rate 'r', would be worth £(1+r) in one year and £$(1+r)^2$ in the second year and so on (i.e. it was assumed that £1 has the same real value in the future without accounting for the inflation). Inflation needed to be accounted for quite separately. The formula that was used to determine the net present value (NPV) had the following form:

$$NPV = \frac{S}{(1+r)^n}$$

PV= the present value

S= the sum

r= the discount rate, expressed as a fraction (The Government decides the discount rate)

n= the year in which the sum was received (n=0 for the 'present value year')

$$NPV= PBV-PVC$$

NPV= net present value

PBV= present value of stream of benefits

PVC= present value of stream of costs

To take into consideration different economic growth scenarios, two economic growth forecasts were applied in the COBA method (i.e. low and high economic growth) to the streams of benefits and costs during the project life.

There were some other limitations with the COBA method. The environmental considerations have not been included in the financial analysis because all attempts to price them failed but their importance could not be ignored. This problem was echoed by some other researchers (Maxwell-Stewart, 1974), (Rees and Gwilliam, 1974), (Margason and Corcoran, 1978), (Gamble and Davinroy, 1978). The COBA9 Manual has stated three possible sources of error in the results obtained which were: the incorrect formulation of the model, measurement errors due to the use of sampling technique, and prediction errors in the forecast inputs. The COBA9 recommended that sensitivity tests should be carried out on variables used in the cost-benefit analysis.

4.3 Travel-Time

4.3.1 General

It has been agreed that imposing speed limits would lead to longer journey times (European Conference of Ministers of Transport, 1977). Travel-time cost was one of the main consequences of changing speed limits (Hall et al., 1970) and especially for business trips (McLean, 1980). Even the public, who behaved in a cost conscious manner according to Bevis et al. (1965), considered shortening their journey times was more important, for example, than saving fuel (Sawhill et al., 1970). The travel-time was directly related to the speed of traffic. The amount of daily travel-time depended on socio-economic and demographic variables (e.g. household income, car ownership, employment status, sex, and age) (Prendergast and Williams, 1980). The travel-time cost included money expenditures and the opportunity cost of time (Gronau, 1976). The cost of travel-time varied according to traffic composition, time of the day, car occupants, gross domestic product, vehicle type (Department of Transport, 1994), (Dawson, 1972), (Dawson and Vass, 1974), and soci-economic factors (Thomas and Thompson, 1970), (Wardman, 1986). Inaccuracies in estimating travel-time cost might arise because of the assumptions that were made (Stopher, 1976). Tanner (1979) showed that the generalised expenditure was similar in rural and urban areas and the expenditure per person has increased between 1953 and 1976.

4.3.2 Travel-Time in the Cost-Benefit Analysis Method (COBA)

Working time was valued at the cost to the employer of the travelling employee and was at least equal to the cost to the employer for hiring the labour for that time. The gross wage of the employee, was considered which included National Insurance, pension contributions, and overheads because it reflected the importance that the employer placed on the working travel-time. To evaluate the value of non-working travel-time, which included all travel purposes except travel in the course of work, an estimate was made of how much people were ready to sacrifice in terms of payment, which could be used otherwise in purchasing other goods and services, in order to save one hour of their non-working travel-time . The net of that amount after deducting taxes was the 'resource cost' (see Appendix iii, Table 1). The travel-time values were then related to the Gross Domestic Product (GDP), to enable a forecast to be made for low and high economic growth in future (see Appendix iii, Table 2). An argument often occurs about the significance of 'small' savings in travel-time (e.g. a saving of one minute compared to 30 minutes). It has been argued that such small savings should be included for the following reasons:

(i) it was admitted that 'small' savings of a group of road users might be worthless, but the proposed saving time value was an average of different amounts of savings (i.e. large and small savings);

(ii) the addition of these 'small' savings would accumulate to 'large' savings. Ignoring a project because of its individual 'small' savings and choosing another with 'larger' individual savings without considering the sums would be misleading and form bias; and

(iii) some studies showed that people place positive values on 'small' savings.

There were implicit assumptions in calculating working time, for example, using average not marginal pay, the employers would tend to adjust to a saving of working time by increasing output with the same level of employment, the employee acted in the best interest of his employer, the travel was done in the 'employer time' , and except for the transport workers, no productive work was done during the travel.

4.4 Vehicle Operating Cost (VOC)

4.4.1 General

(i) Fuel Consumption of Vehicles

The role of speed limits in cutting down the fuel consumption of vehicles was considered, seriously, during the energy crisis in 1973 (Sawhill et al., 1970). Since that time many researchers have focused their attention on the fuel consumption of vehicles and its relationship with the speed of traffic and speed limits realising facts such as: cars, in the U.K., consumed 60 per cent of road transport fuel (Waters and Laker, 1978).

The fuel consumption of heavy vehicles did not vary, significantly, with speeds less than 70 km/h (Dawson, 1972), (Dawson and Vass, 1974). A number of fuel consumption models were developed to simulate various conditions, the one adopted in the COBA manual will be reviewed later:

(i) the Energy-Related Model of Instantaneous Fuel Consumption: which was related to the speed, acceleration, and grade of the road (Biggs and Akcelik, 1986). The model was suitable for evaluating changes in traffic management;

(ii) and (iii) PKE (Positive Kinetic Energy) and PIP (Positive Inertial Power): were found to be the best predictive models but the variables used in the models were difficult to obtain by traffic engineers (Pitt et al., 1987);

(iv) the Simple Average Travel Speed Model of Fuel Consumption: this has been used previously in urban conditions (Biggs and Akcelik, 1985), (Biggs and Akcelik, 1986);

(v) a computer simulation model was developed by Al-Omishy (1989) to find the fuel consumption of petrol and diesel vehicles for free-flow conditions. The results of the model agreed with the other models mentioned here; and

(vi) the UTPS fuel consumption model was investigated and has been shown to be suitable for running speed on freeways (Bowyer et al., 1986), (Biggs and Akcelik, 1986).

The predictions from these models provided more accurate representation of fuel consumption for vehicles at 'high' speeds and in free-flow conditions rather than 'low' speed and non-free-flow conditions (Watson, 1989), (Lewis and Tillotson, 1982), (Rice, 1985).

The fuel consumption of vehicles tended to drop as the speed increased from zero, passing through a minimum value until it started to increase but at a slower rate than the previous rate of decrease (Biggs and Akcelik, 1986), (Waters and Laker, 1978). It has been observed that vehicles at 'high' speeds (70 km/h) have been shown to consume double the fuel of vehicles at 'low' speeds (40 km/h). Generally, travelling at "moderate" speed produced fuel savings (Ministry of Transport, 1967). Everall (1968) and Claffey (1965) found that the optimum speed was between 48 to 68 km/h. Underwood (1979) found that the speed of vehicles to provide a minimum fuel consumption was around 50 km/h but he warned that this fact should not be the only factor for setting the speed limit. A similar cautious conclusion was stated by Waters (1980) as he stated that there were other factors to consider in setting speed limits, for example; productivity and efficiency of the operation. It was estimated that fuel consumption reduced by about 6.1 per cent when free-flow was compared to congested conditions for speeds around 50 km/h (Gyenes, 1980). Chang and Horowitz (1979) found that any attempt to increase the speed of traffic in urban situations would lead to a reduction in the fuel consumption. It was concluded that a speed limit enforced more strictly would lead to savings in the fuel consumption of vehicles but it was argued that by comparing these savings to the national fuel consumption, the savings would not be significant (Leake, 1980). In the U.S.A., it was estimated that if a 100 per cent compliance rate was observed for 55 mile/h, the savings in fuel would not be more than 2.5 per cent (Waters and Laker, 1978); some other sources determined that the savings in fuel was not more than 1 per cent (Copulos, 1986). In Queensland, Australia, it was determined that if an 80 km/h speed limit was imposed on its road network, a reduction of 1.2 per cent would be expected in fuel consumption (Middleton and Kenyon, 1981). Lower speeds for heavy goods vehicles has been shown to lead to lower fuel consumption except on motorways. This was simulated by a computer model which gave a good agreement between the predicted and the observed data (Renouf,. 1979), (Renouf, 1981). Langdon (1984) investigated the relationship between the mean speed of vehicles, the acceleration and deceleration of vehicles and the fuel consumption from which emerged a better correlation between the predicted results and the observed data. Other factors contributed to the fuel consumption of vehicles such as the type of vehicle, the engine efficiency (Easingwood-Wilson et al., 1977), the gradients, the horizontal bends (Cawthorne, 1978), the behaviour of the driver (e.g. aggressive driving) (Hooper and Mullen, 1974), the petrol price (Chang and Herman, 1980), the traffic conditions (Bowyer et al., 1984), the type of surface (Underwood, 1979), the design speed of the road (i.e. the fuel consumption, especially for heavy goods vehicles, decreased as the design speed of the road increased) (Mclean, 1980), and the number of passengers in the vehicle (Al-Omishy, 1989). The fuel consumption of heavy goods vehicles was affected by the loads that were being carried by those vehicles (Williams, 1977). Diesel engines (i.e. in volumetric terms) saved about 25 per cent compared to gasoline engines but with lower performance; the equivalent energy savings were 14 per cent in average traffic (Bashford, 1978) but in dense traffic the savings might reach to 40 per cent (Weeks, 1981).

(ii) The Non-Fuel Element of VOC

As the speed of vehicles increased, the non-fuel element cost decreased (Dawson and Vass, 1974), (Dawson, 1972). The oil and tyre costs were not considered as a major cost. Maintenance included: lubricants, the engine, the chassis, the body, the electrical system, and the braking system (Winfrey, 1965).

4.4.2 Vehicle Operating Cost in COBA

(i) The Fuel Consumption Element of VOC

The change in total vehicle operating cost (VOC) depended on the changes in the distance travelled, the changes in the travelling speed on the link, and the hilliness on the link. VOC consisted of six items: fuel, oil, tyres, maintenance, depreciation, and size of fleet. The fuel consumption element of VOC had the following form:

$$(a+b/v+cv^2)(1+mH+nH^2)$$

where v was the speed of the vehicle (km/h), H was the average link hilliness metre/km, a, b, c, m, and n were coefficients depending on the vehicle type (see Appendix III, Table 3). High and low growth rates were considered to accommodate for different economic growths, which were expected to affect the price of petrol and the efficiency of consumption (see Appendix III, Table 4). A high fuel cost was forecasted in the low economic growth scenario whereas a low fuel cost was anticipated in the high economic growth scenario. It was believed that in high economic growth the cost of fuel would increase less than the fuel price because in response to the high fuel price more efficient engines would be designed and small vehicles would be manufactured. The opposite trend was anticipated for low economic growth.

(ii) The Non-Fuel Element of VOC

The non-fuel element of VOC had the following form:

$$a+b/V$$

the term 'a' describes the elements related to the distance covered by the vehicles like: oil, tyres, mileage and maintenance related depreciation. The term 'b' describes the changes in the productivity of commercial vehicles and cars in working time, and other goods vehicles and public service vehicles. The term 'b' is related to the mean speed of traffic. Items that did not change with the use of vehicle were not included (e.g. excise duty and insurance). Depreciation depended on time, mileage, and speed. The depreciation rate would be higher in the earlier years of owning a new vehicle. Depreciation for other goods vehicles (OGVs), light goods vehicles (LGVs), and public service vehicles (PSVs) was assumed to be entirely time related according to the COBA10 whereas with COBA9 Manual it was assumed to be related totally to mileage. The depreciation of cars and light goods vehicles depended, partially, on the passage of time. Only the part of depreciation that related to the mileage was considered as a marginal resource cost when determining VOC. It was assumed that no change in real terms would occur to the non-fuel element cost in future years.

4.5 The Valuation of Accidents in COBA

The savings resulting from the reduction in the frequency and severity of accidents forms a vital part in cost-benefit analysis. It is important to place monetary values on accidents in order to include them in cost-benefit analysis. In COBA 9 (Department of Transport U.K., 1982) the valuation of injury accidents included the following which depended on the Human Capital approach:

(i) the direct financial cost (e.g. damage of vehicles);

(ii) the loss of output of those killed or injured. Their wages and non-wage payments were considered to be an appropriate measure to evaluate the loss to society; it was assumed that employment in future years would have been full or nearly full; and

(iii) an additional allowance for 'pain, grief, and suffering' resulting from personal injury or death. It was based on the assumption that the minimum cost society was willing to pay, was the future discounted consumption of a non-productive member of society. COBA 10 (Department of Transport U.K., 1994a) adopted the Willingness to Pay (WTP) approach. WTP includes the human costs and the direct economic costs. The cost of accidents given in Appendix III, Table 5 has been based on COBA 10; this includes (i) and (ii) but for (iii) COBA 10 has included the human cost, based on WTP values, which represented pain, grief and suffering to the casualty, relatives and friends, and, for fatal casualties, the intrinsic loss of enjoyment of life over and above the consumption of goods and services. Human costs as calculated by the WTP method represents the ex-ante benefit of avoidance of risk of a road accident, rather than ex post values of the consequences of an accident as was done in COBA 9.

The cost of an injury accident is usually higher than the aggregate cost of each of the casualties because the accident is usually classified according to the most severe casualty and, usually, there would be more than one casualty of similar and/or different seriousness and also the cost of damage to vehicles and properties and costs of police and the administrative costs of accident insurance would be included. The cost of an accident differed according to the casualties and the type of road being considered. In COBA, the severity split for the average personal injury accident (i.e. the number of fatal, serious, and slight casualties per accident) (see Appendix III, Table 6) was used to determine the average cost of personal injury accidents. It was anticipated that the cost of accidents would change in the future because the value of an accident was related to GDP. The growth rates that were applied to travel-time cost were considered to be suitable for accidents. The number of accidents on a given length of road and the traffic flow was expressed as an accident rate which was defined as the number of 'Personal Injury Accidents per million vehicle kilometres' (see Appendix III, Table 7). The implicit assumption was that by doubling either the length or the traffic flow on the road, would double the number of accidents. The other two factors that determine the number of accidents were: the number and type of junctions and the type of links.

Chapter Five

Analysis of Cost and Benefits of Changing Speed Limits

5.1 Introduction

Cost-benefit analysis (COBA) is used by the Department of Transport in U.K. to evaluate road projects. In this study, cost-benefit analysis has been used to evaluate the economic consequences of changing the posted speed limits on roads. The main difference in applying this method in this case was the fact that the project did not include a capital cost for construction. The cost consisted , mainly, of the operating cost of traffic which included the travel-time cost, the vehicle operating cost, and the cost of accidents. The application of cost-benefit analysis for non-construction project has been shown to be successful in some other cases (Hibbard and Miller, 1974). The cost-benefit analysis that has been used in this chapter was discussed in Chapter Four.

When a national maximum speed limit of 70 mile/h was imposed on roads in the U.K. in 1965, an assessment was made to evaluate the economic impact of imposing the new speed limit. It was estimated that there was a reduction in the operating cost of traffic by 20 per cent but there was a note of caution due to the amount of uncertainty that existed in the components of the cost, especially, the cost of accidents which made the outcome less reliable (Ministry of Transport, 1967). The difficulty of assessing the economic impact of imposing speed limits was shared by ITE Technical Council Committee 4M-2 (1977) in their attempt to evaluate the impact of imposing 55 mile/h speed limit in 1974 in the U.S.A. The European Conference of Ministers of Transport (1977) evaluated some cases of imposing speed limits in some European countries using cost benefit-analysis. The uncertainty of the components of the total cost was the main obstacle when they attempted to draw firm conclusions on the economic advantages and disadvantages but they were inclined to adopt the opinion that reductions in speed limits led to reductions in the operating cost of traffic.

In this chapter, an illustration of the cost-benefit analysis calculation has been presented with a discussion of the results obtained. The following items have been discussed: the characteristics of the base case, the calculation of the total annual cost of the road traffic for the base case in the year 1994, the calculation of the total annual cost and the annual net benefits of changing the mean speed of traffic for the base case to various mean speeds of traffic for the year 1994, the calculation of the net present value (NPV) of the total cost for the base case for the economic assessment period 1994-2003 (low and high economic growth), the calculation of the NPV of both the total cost and the benefits of changing the speed limit of the base case to various speed limits for the economic assessment period 1994-2003 (low and high economic growth), an analysis of the uncertainty of accident cost, a discussion of the methods of calculation and the results and, finally, a conclusion of the outcome of the chapter.

5.2 The Base Case: Characteristics and Assumptions

The base case was considered to be a hypothetical section of a road. It described the road alignment and cross-section, characteristics of the road traffic, the economic parameters, and the assumptions made in the cost-benefit analysis. The characteristics of the base case were chosen to represent the objective and the scope of the study in general. The values used related to the U.K.

5.2.1 Road Characteristics

The hypothetical section of the road for the base case was assigned the following geometric characteristics:

(i) motorway standards;
(ii) 1 kilometre in length;
(ii) dual-carriageway, two-lanes (in each direction);
(iii) controlled access (no junctions);
(iv) relatively flat vertical alignment;
(v) relatively straight horizontal alignment; and
(vi) the design speed of the road section was suitable for the range of mean speeds of traffic investigated.

5.2.2 Traffic Characteristics

The traffic characteristics for the base case were:

(i) only, free-flow traffic was considered (i.e. according to the definition of free-flow in Chapter Two);
(ii) the daily free-flow traffic was considered to be 15,000 vehicle/day in the base year;

(iii) the free-flow hours of the day were assumed to maintain their status throughout the life of the economic assessment;

(iv) the low and high compound rates of traffic growth were 1.80% and 1.94% per annum respectively (Department of Transport U.K., 1993a);

(v) the growth of free-flow traffic was assumed to be the same as the general growth of traffic;

(vi) it was assumed that no trip re-distribution would occur due to changes in the speed limit of the base case (i.e. no shift in traffic from or to the section of road for the base case, especially, if the change happened throughout the road network);

(vii) the national motorway traffic composition was adopted (i.e. 77.3% cars, 8.2% light goods vehicles (LGV), 13.8% other goods vehicles (OGV) (6.3% OGV1, 7.6% OGV2), and 0.8% public service vehicles (PSV)) (Department of Transport U.K., 1993a) which was assumed to be applicable to free-flow traffic;

(viii) the mean speed of free-flow traffic was assumed to be 108.6 km/h (Department of Transport U.K., 1994b);

(ix) no growth was assumed in the speed of traffic during the economic assessment period (Department of Transport U.K., 1994b);

(x) the posted speed limit was 70 mile/h (i.e. the current national maximum speed limit for motorways);

(xi) the effect of speed limits on the mean speed of traffic was obtained by applying the 'Speed Limit Effect Model SPLA' which was developed in Chapter Two;

(xii) five speed limits were chosen for examination; these were: 50 mile/h, 60 mile/h, 80 mile/h, 90 mile/h, and 100 mile/h;

(xiii) the frequency and severity of personal injury accident was assumed to be constant for various mean speeds of traffic; and

(xiv) it was assumed that no annual growth in the frequency and severity of personal injury accidents would happen during the economic assessment period.

5.2.3 Economic Parameters

The base case had the following economic parameters:

(i) the relationships, assumptions, prices, costs, that were used in the study, were taken from the COBA9 manual (Department of Transport U.K., 1982) and for updated values COBA10 manual (draft) (Department of Transport U.K., 1994a) was used (i.e. the costs were in 1992 prices);

(ii) the values of cost were assumed to be valid for the free-flow traffic conditions;

(iii) the prices were converted to 1994 prices using price indices. Index for 1992 prices was 138.5 and for the first quarter of 1994 was 142.0 (Central Statistical Office, 1994):

$$Retail\ price\ index(RPI) = \frac{1^{st}\ quarter\ of\ 1994\ price\ index}{1992\ price\ index}$$

$$1994\ prices = RPI\ (1992\ prices)$$

(iv) the 'present value year' was 1994;

(v) the economic assessment period was for ten years (1994-2003);

(vi) the discount rate was 8 per cent per annum; and

(vii) it was assumed that the cost of speed enforcement would not change with either time or changes in the speed limits.

5.3 The Calculation of the Annual Cost of Road Traffic for the Base Case for the Year 1994

The cost-benefit analysis was used to determine the total annual cost of road traffic for the base case for the year 1994. To determine the total annual cost, the costs of each of the components of the total cost were determined.

5.3.1 The Cost of Travel-Time

The annual cost of travel-time was calculated according to the following formula:

$$ATTC_i = 365\ \frac{TTC_i\ (\frac{LN}{MS})\ DF\ P_i}{100}$$

where;

$ATTC_i$= annual travel-time cost of vehicle type i (£)

TTC_i= travel-time cost of vehicle type i (pence/hour) (appendix iii, Table 1)

LN= length of the section (km)

MS= mean speed of traffic (km/h)

DF= daily free-flow traffic (vehicle/day)

P_i= proportion of vehicle type i in the traffic stream

i= vehicle type (1= average car, 2= light goods vehicle (LGV), 3= other goods vehicle (OGV), and 4= public service vehicles (PSV), for detailed definitions of type of vehicles see (Department of Transport, 1982))

365 was used to convert the daily cost to annual cost

$$ATTC_{BC}=\Sigma\ (ATTC_1+ATTC_2+ATTC_3+ATTC_4)$$

where;

$ATTC_{BC}$= the annual travel-time cost of all vehicle types (£M) for the base case (see Table 5.1 and Figure 5.1a).

5.3.2 The Vehicle Operating Cost (VOC)

VOC consisted of two elements: the fuel consumption element and the non-fuel element.

(i) The Fuel Consumption Element of VOC

The annual fuel consumption cost of road traffic was determined by the following relationship:

$$AFCC_i=\frac{365\ DF\ P_i\,(a_i+\frac{b_i}{MS}+c_i MS^2)}{100}$$

where;

$AFCC_i$= annual fuel consumption cost for vehicle type i (£)

a_i, b_i, and c_i were parameters for vehicle type i (appendix iii, Table 3)

i= vehicle type (1=car, 2=LGV, 3=OGV1, 4= OGV2, and 5= PSV)

Others as they were defined previously.

$$AFCC_{BC}=\sum\ (AFCC_1+AFCC_2+\ldots.+AFCC_5)$$

where;

$AFFC_{BC}$= annual fuel consumption cost (£M) for all vehicle types for the base case (see Table 5.1 and Figure 5.1b).

(ii) The Non-Fuel Element of VOC

The non-fuel element of cost was determined by the following equation:

$$ANFEC_i=\frac{365\ DF_i\ P_i(a_i+\frac{b_i}{MS})}{100}$$

where;

$ANFEC_i$= annual non-fuel element cost of vehicle type i (£)

a_i and b_i were parameters for vehicle type i (appendix iii, table 3)

Others as they were defined previously.

$$ANFEC_{BC}=\sum (ANFEC_1+ANFEC_2+\ldots.+ANFEC_5)$$

where;

$ANFEC_{BC}$= the annual non-fuel element cost (£M) of all types of vehicles for the base case (see Table 5.1 and Figure 5.1b).

(iii) VOC

$$VOC_{BC}= AFCC_{BC}+ANFEC_{BC}$$

where

VOC_{BC}= the annual vehicle operating cost (£M) for the base case (see Table 5.1, and Figure 5.1a and 5.1b).

5.3.3 The Accident Cost

The annual cost of an average personal injury accident (PIA) was calculated using the following equation:

$$APIA=\frac{365\ AR\ DF\ LN}{10^6}$$

where;

APIA= the annual number of PIA for the base case

AR= the rate of PIA for the base case (i.e. the number of injury accidents per million vehicle km) (Appendix iii: Table 7)

$$PIAC=ACC_{FATAL}\ AC_{FATAL}+ACC_{SERIOUS}\ AC_{SERIOUS}+ACC_{SLIGHT}\ AC_{SLIGHT}+PAC+DPC$$

where;

PIAC= the average PIA cost (£)

ACC= the average casualty cost according to severity (£) (i.e. fatal, serious, and slight) (£) (Appendix iii: Table 5)

AC= the average number of a specified type of casualty per average PIA according to the type of casualty (Appendix iii: Table 6)

PAC= the average cost of police and administration per average PIA (£) (Appendix iii: Table 5)

DPC= the average cost of damage to property per average PIA (£) (Appendix iii: Table 5)

$$APIAC_{BC}=(APIA)\ \ (PIAC)$$

$APIAC_{BC}$= the annual personal injury accident cost (£M) for the base case (see Table 5.1 and Figure 5.1a).

Other variables were assumed to be as they were defined previously.

5.3.4 The Total Annual Cost

The total annual cost of road traffic for the base case for the year 1994 was:

$$ATC_{BC}=ATTC_{BC}+AVOC_{BC}+APIAC_{BC}$$

where

TAC_{BC}= the total annual cost of traffic for the base case (£M) (see Table 5.1 and Figure 5.1a) and with the other variables as they were defined previously.

5.4 The Calculation of the Total Annual Cost of Road Traffic for the Base Case at Various Mean Speeds of Traffic for the Year 1994

The calculation procedure that was carried out for the base case in Section 5.3 above was repeated for various mean speeds of traffic. The total annual costs at various speed limits were illustrated in Table 5.1 and Figure 5.2a. The relative changes in the total annual cost at various mean speeds of traffic to the total annual cost for the base case were illustrated in Figure 5.2b. The costs of the components of total annual cost for the base case at various mean speeds of traffic were illustrated in Table 5.1 and Figure 5.3a. For the costs of the components of the annual VOC for the base case (i.e. the fuel-element and the non-fuel element) at various mean speeds of traffic were displayed in Table 5.1 and Figure 5.3b.

5.5 The Calculation of the Annual Net Benefits of Changing the Mean Speed of Traffic for the Base Case to Various Mean Speeds of Traffic for the Year 1994

The net benefit was determined according to the following formula:

$$ANB_{\Delta MS}=TAC_{BC}-TAC_{MS}$$

$ANB_{\Delta MS}$= the annual net benefit of changing the mean speed of traffic for the base case to various mean speeds of traffic (MS) (£M) (see Table 5.1 and Figure 5.4)

TAC_{BC}= the total annual cost for the base case (£M)

TAC_{MS}= the total annual cost of the mean speed of traffic at various speed limits (MS) (£M)

Table 5.1: The Results of the Calculations of the Annual Costs for the Year 1994 for the Base Case for Various Mean Speeds of Traffic

Mean speed of traffic km/h	Annual travel-time cost (£M)	Annual fuel elem. of VOC (£M)	Annual non-fuel elem. of VOC cost (£M)	Annual VOC (£M) (fuel & non-fuel)	Annual accd. cost (£M)	Total annual cost (£M)	Ratio of total costs to the total cost for the base case (%)	Annual net benefits of Δ the mean speed of traffic of the base case (£M)
30	1.41	0.11	0.31	0.42	0.04	1.87	232.8	-1.07
40	1.06	0.10	0.29	0.39	0.04	1.49	185.1	-0.68
50	0.85	0.10	0.28	0.37	0.04	1.26	156.7	-0.46
60	0.70	0.09	0.27	0.36	0.04	1.11	138.1	-0.31
70	0.60	0.10	0.26	0.36	0.04	1.00	125.2	-0.20
80	0.53	0.10	0.26	0.36	0.04	0.93	115.7	-0.13
90	0.47	0.11	0.25	0.36	0.04	0.87	108.7	-0.07
100	0.42	0.11	0.25	0.37	0.04	0.83	103.5	-0.03
108.6 (base case)	0.39	0.12	0.25	0.37	0.04	0.80	100	0.00 no change
110	0.38	0.12	0.25	0.37	0.04	0.80	99.5	0.00
120	0.35	0.13	0.25	0.38	0.04	0.77	96.5	0.03
130	0.33	0.14	0.25	0.39	0.04	0.76	94.3	0.05
140	0.30	0.15	0.25	0.40	0.04	0.74	92.8	0.06
150	0.28	0.17	0.24	0.41	0.04	0.74	91.8	0.07
160	0.26	0.18	0.24	0.43	0.04	0.73	91.3	0.07
170	0.25	0.20	0.24	0.44	0.04	0.73	91.2	0.07
180	0.23	0.21	0.24	0.46	0.04	0.73	91.4	0.07
190	0.22	0.23	0.24	0.47	0.04	0.74	91.9	0.06
200	0.21	0.25	0.24	0.49	0.04	0.74	92.8	0.06

Figure 5.1a: The Total Annual Cost and Annual Costs of the Components of the Total Cost for the Base Case for the Year 1994

(costs are in million pounds per annum)
the total annual cost=£0.80 million per annum

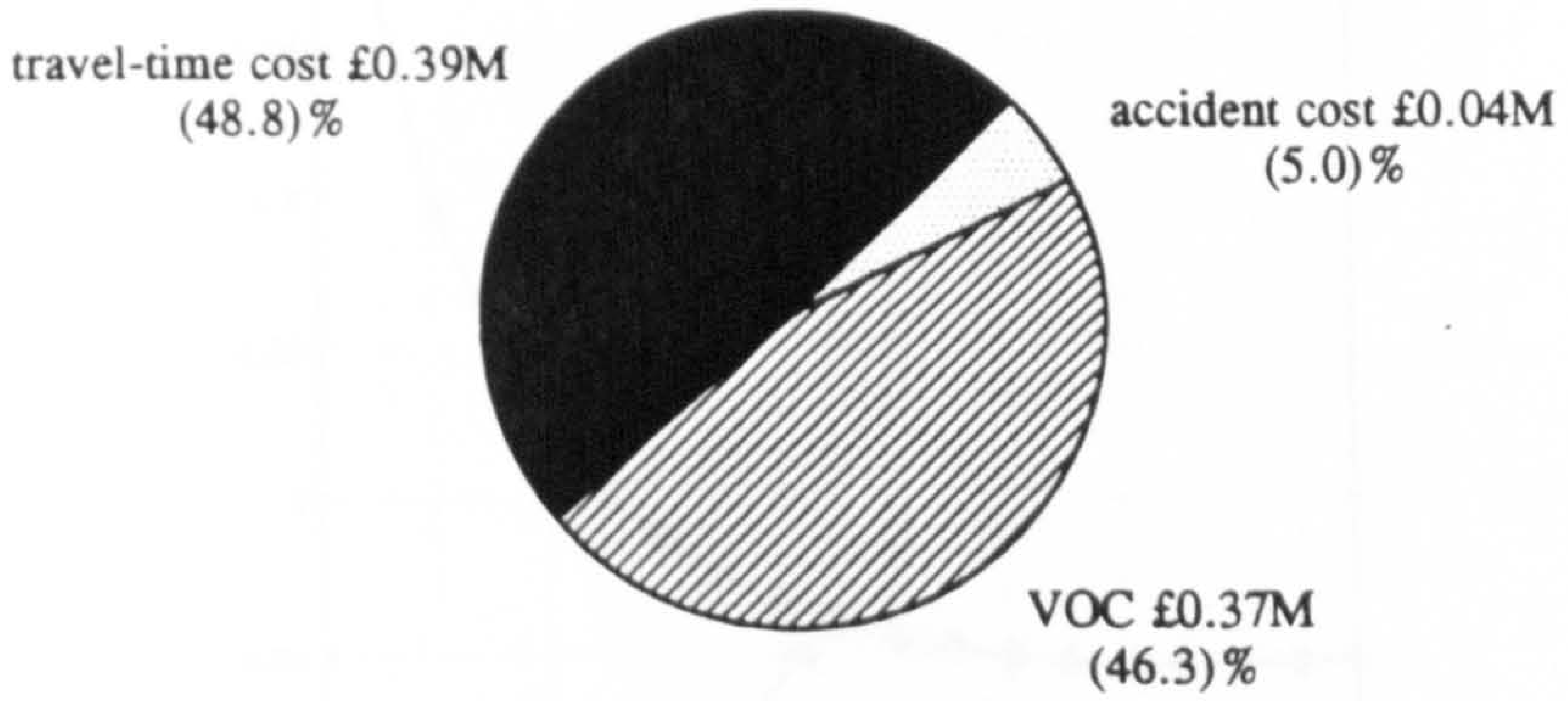


Figure 5.1b: The Annual Costs of the Components of VOC for the Base Case for the Year 1994

(costs are in million pounds per annum)
VOC= £0.37 million per annum

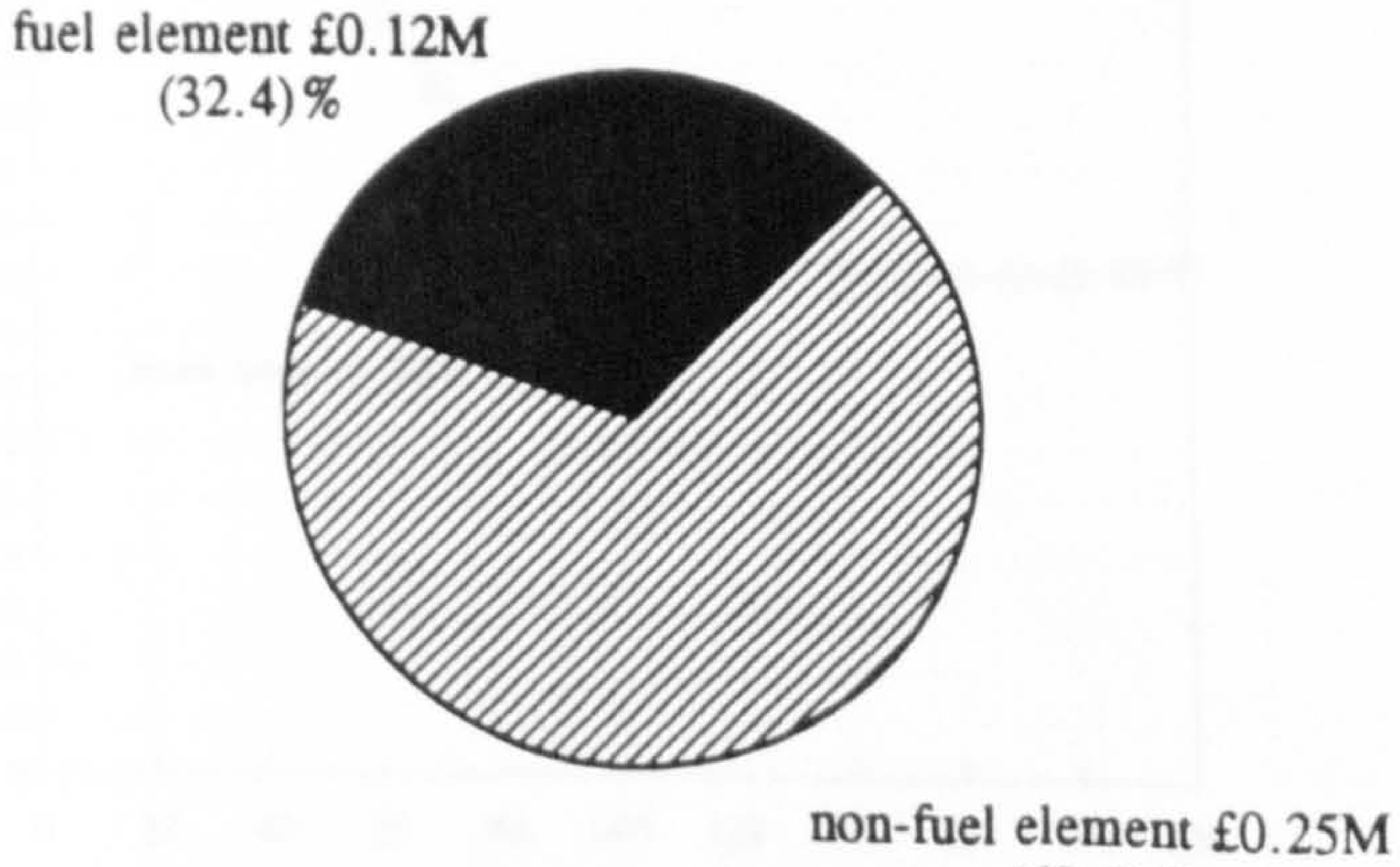


Figure 5.2a: The Total Annual Cost for the Base Case for the Year 1994 at Various Mean Speeds of Traffic
(note: the frequency and the severity of PIA were assumed to be constant)

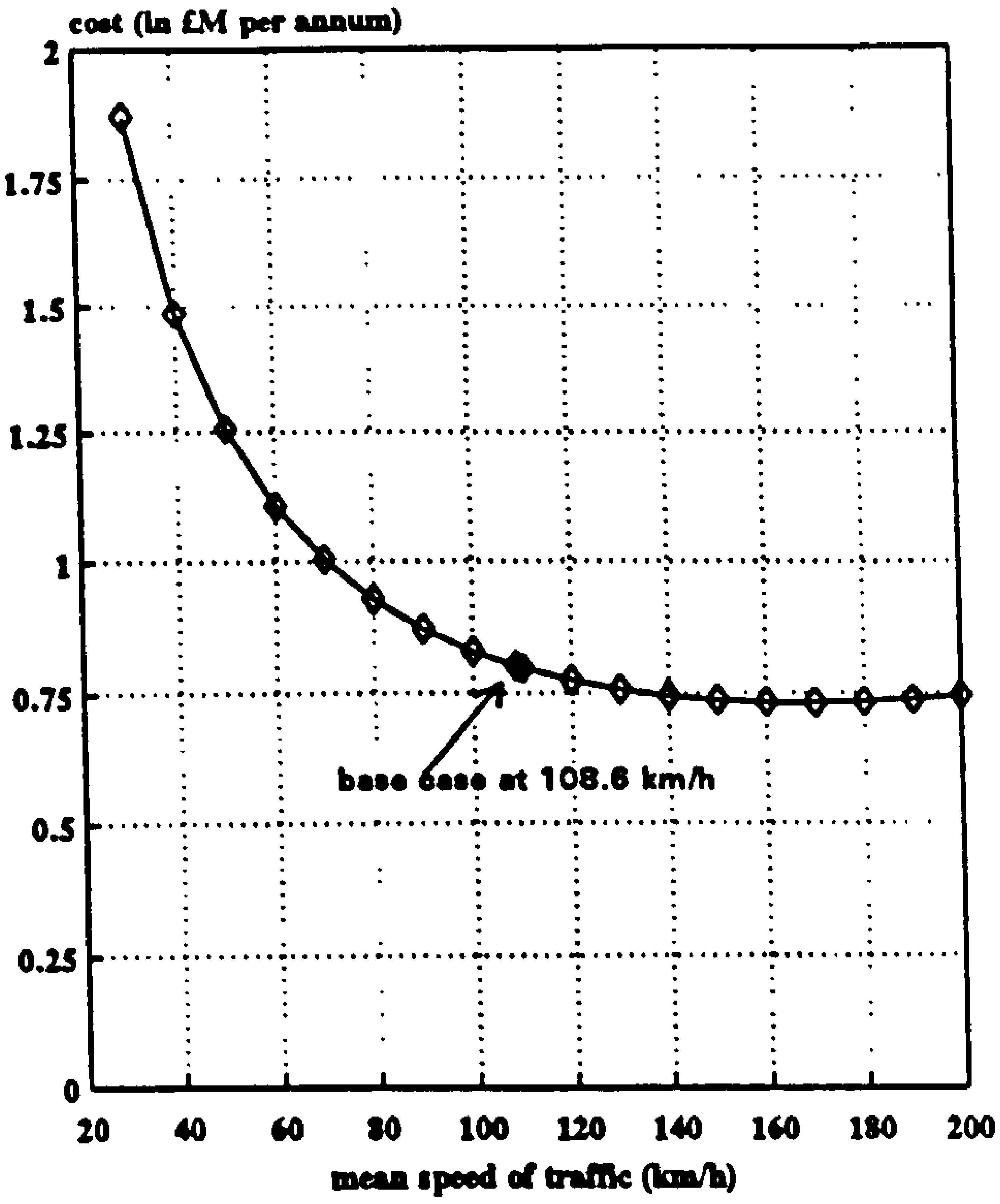


Figure 5.2b: The Ratio (%) in the Total Annual Cost at Various Mean Speeds of Traffic to the Total Annual Cost for the Base Case for the Year 1994
(note: the frequency and the severity of PIA were assumed to be constant)

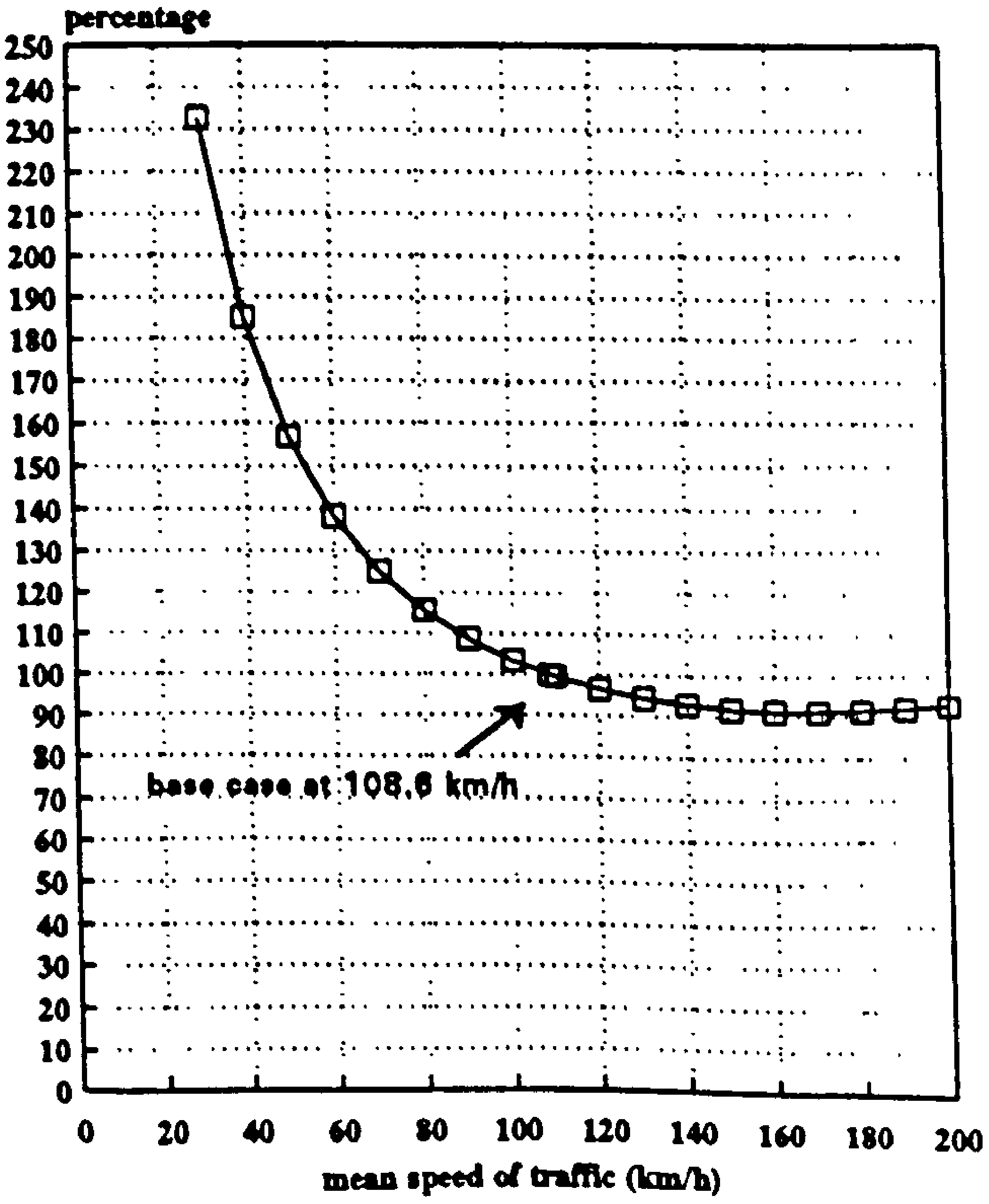


Figure 5.3a: The Annual Costs of the Components of the Total Cost for the Base Case at Various Mean Speeds of Traffic for the Year 1994

(the frequency and the severity of PIA were assumed to be constant)

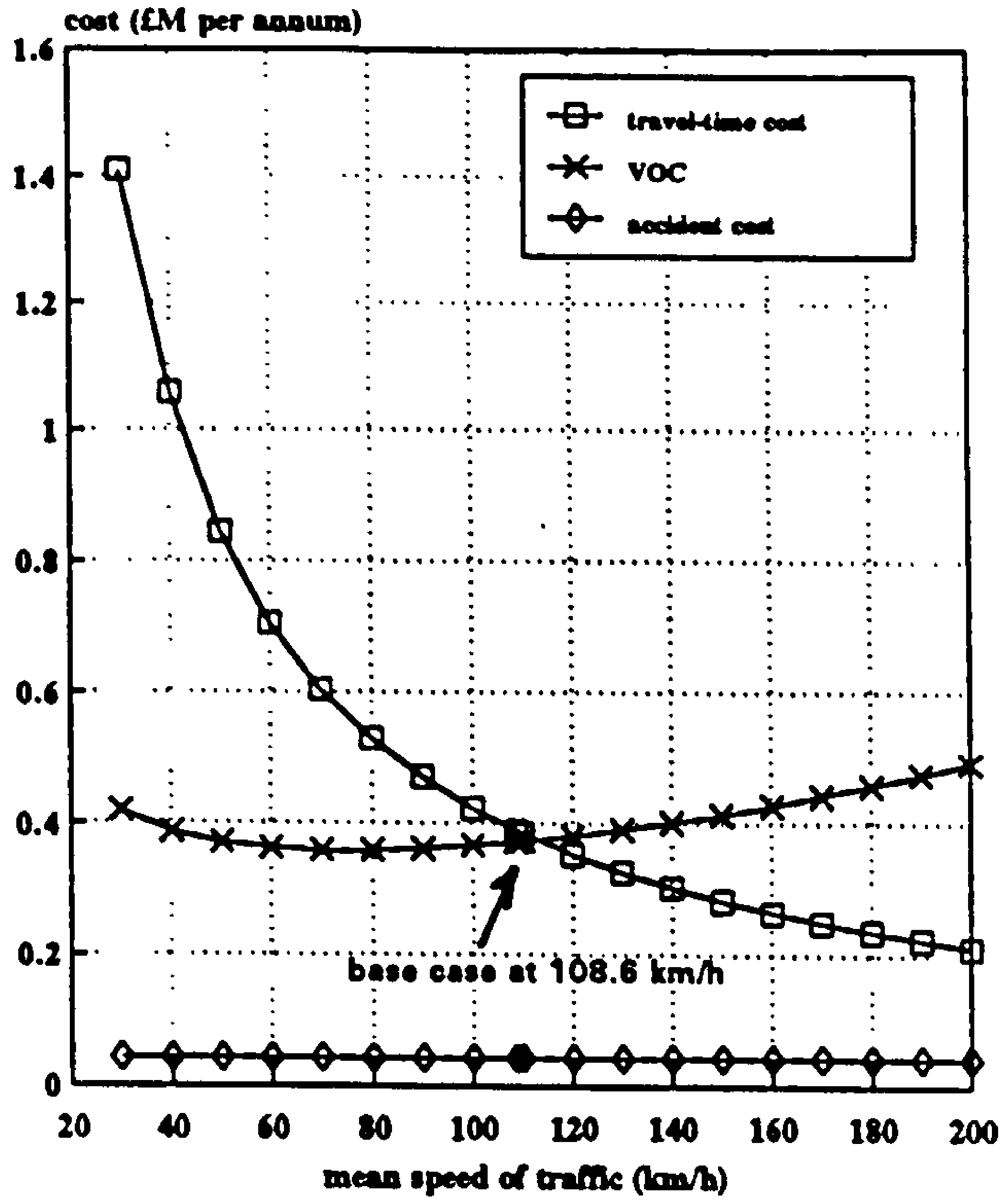


Figure 5.3b: The Annual Costs of the Components of the VOC for the Base Case at Various Mean Speeds of Traffic for the Year 1994

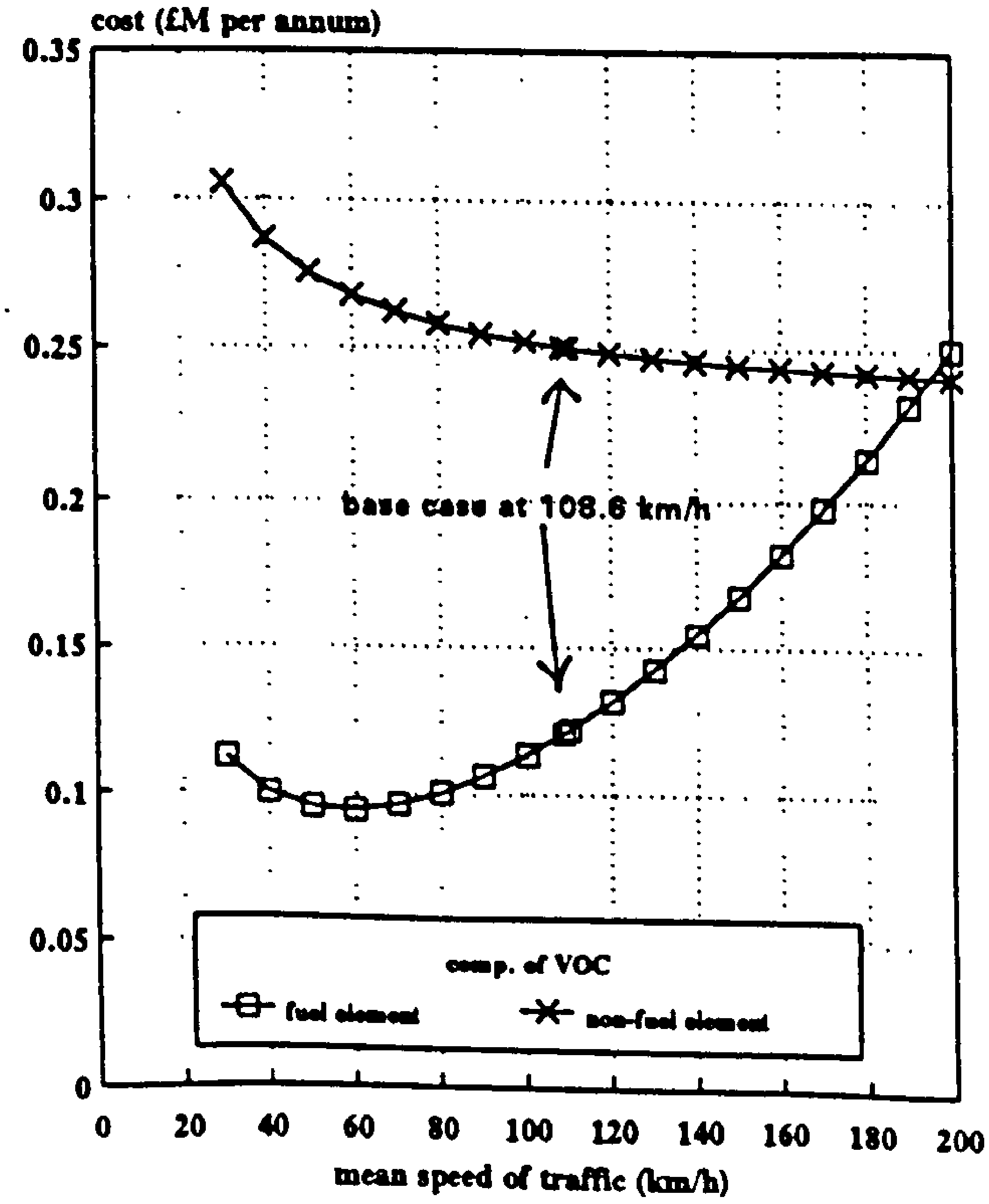
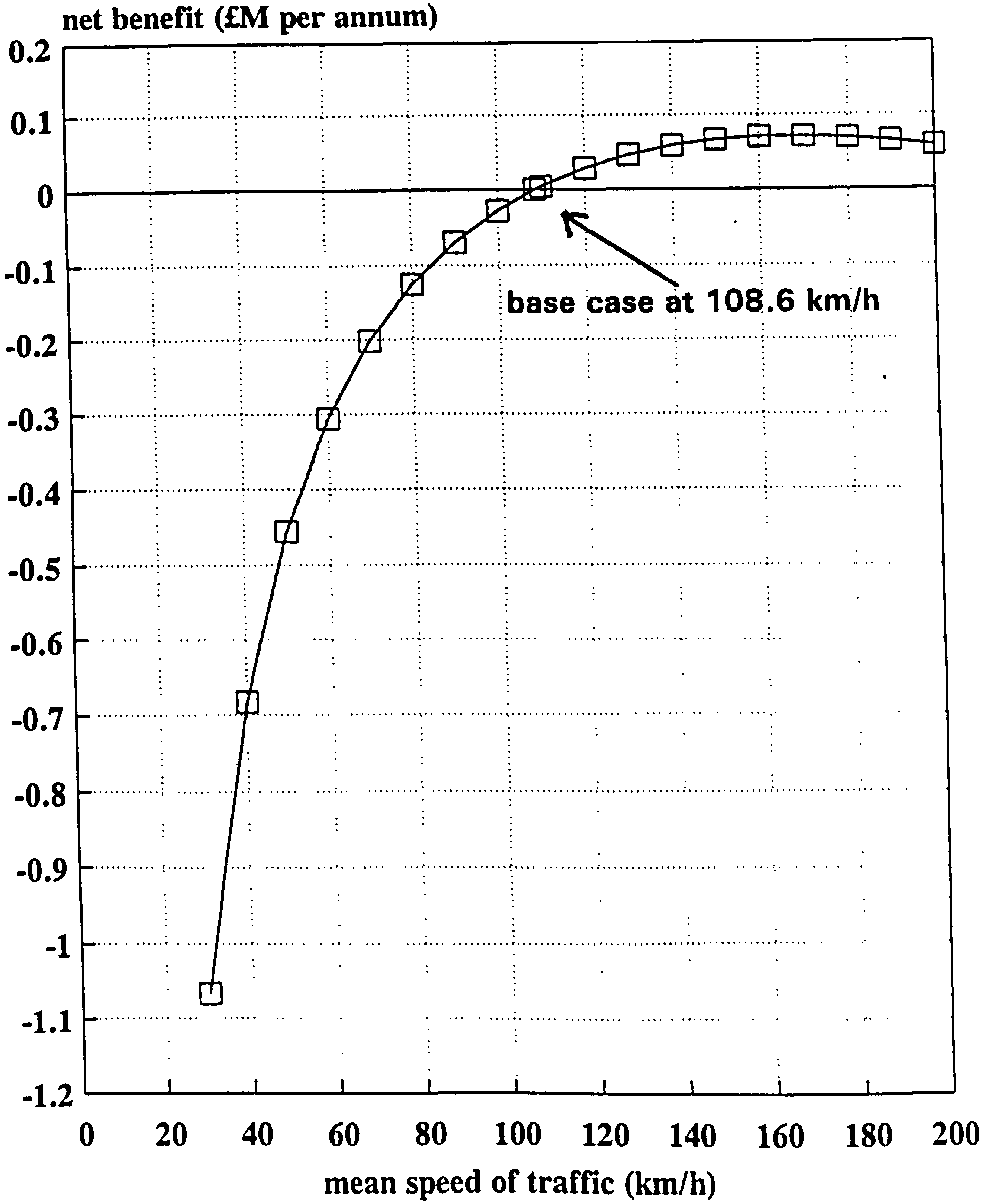


Figure 5.4: The Annual Net Benefits of Changing the Mean Speed of Traffic for the Base Case to Various Mean Speeds of Traffic for the Year 1994
(note: the frequency and the severity of PIA were assumed to be constant)



5.6 The Calculation of the NPV of the Total Cost for the Base Case for the Period 1994-2003 (low economic growth)

5.6.1 Introduction

The NPV of the total cost for the base case was determined by finding the NPV of each of the components of the total cost. Low economic growth was applied through out the economic assessment period.

5.6.2 Travel-Time Cost

Travel-time cost for any particular type of vehicle and any particular year in the economic assessment period was found using the following equation:

$$TTC_{i,n}=\frac{365\ (TTC_i\ (1+GVT_n)^n)\ (\frac{LN}{MS})\ [DF\ (1+TG)^n]\ P_i}{100}\ .$$

where

$TTC_{i,n}$= the total travel-time cost for vehicle type i in year n of the assessment

i= the vehicle type (1, 2, 3, and 4 as were defined before) (£)

n= the year of assessment (0,1,2,.....9) (base year 1944 was considered to be equal 0)

GVT_n= the compound annual rate of growth of the real value of travel-time cost for year n (i.e. another rate was used for year 2002 and 2003) (Appendix III: Table 2)

TG= the compound annual rate of growth of traffic (i.e. as stated in the base case)

Other variables as they were defined before.

$$TTC_n=\Sigma\ (TTC_{1,n}+TTC_{2,n}+TTC_{3,n}+TTC_{4,n})$$

TTC_n= the travel-time cost of all vehicle types in year n

$$NPV(TTTC_{BC})=\sum\ [\frac{TTC_0}{(1+r)^0}+\frac{TTC_1}{(1+r)^1}+...+\frac{TTC_9}{(1+r)^9}]$$

where

$TTTC_{BC}$= NPV of the total travel-time cost for the economic assessment period for the base case (£M) (see Table 5.2a and Figure 5.5a)

r= discount rate per annum (i.e. as stated in the base case)

The other factors remained as they were defined before.

5.6.3 VOC

(i) Fuel Consumption Cost

The fuel cost for any particular type of vehicle and any particular year in the economic assessment period was found using the following equation:

$$FCC_{i,n}=\frac{365\ [DF\ (1+TG)^{n}]\ P_{i}[(a_{i}+b_{i}+c_{i}MS^{2})\ (1+GFC_{i,n})^{n}]}{100}$$

where:

$FCC_{i,n}$= the fuel consumption cost for vehicle type i in year number n of the assessment period (£)

GFC= the compound annual growth rate (%) in the cost of fuel resources for vehicle type i in year number n for the assessment period (i.e. there was a growth rate for cars and LGVs, and another rate for OGVs and PSVs which, both, changed in year 2001 and onwards) (Appendix iii: Table 4)

$$FCC_{n}=\sum\ (FCC_{1,n}+FCC_{2,n}+\ldots+FCC_{5,n})$$

where

FCC_n= the fuel consumption cost for all vehicle types in year n

$$NPV(TFCC_{BC})=\sum\ [\frac{FCC_{0}}{(1+r)^{0}}+\frac{FCC_{1}}{(1+r)^{1}}+\ldots+\frac{FCC_{9}}{(1+r)^{9}}]$$

where

$NPV(TFCC_{BC})$= NPV of the total fuel consumption cost for the base case (£M) (see Table 5.2a and Figure 5.5b).

All other factors remained as they were defined before.

(ii) Non-Fuel Cost

The non-fuel element was calculated in the following way:

$$NFEC_{i,n}=\frac{365\ [DF_i\ (1+TG)^n]\ P_i(a_i+\frac{b_i}{MS})}{100}$$

where

$NFEC_{i,n}$= the cost of the non-fuel element for vehicle type i in year n of the economic assessment

All other factors remained as they were defined before.

$$NFEC_n=\sum\ (NFEC_{1,n}+NFEC_{2,n}+\ldots+NFEC_{5,n})$$

where

$NFEC_n$= the cost of the non-fuel element for all vehicle types in year n of the economic assessment period (£)

All other factors remained as they were defined before.

$$NPV(TNFEC_{BC})=\sum\ [\frac{NFEC_0}{(1+r)^0}+\frac{NFEC_1}{(1+r)^1}+\ldots+\frac{NFEC_9}{(1+r)^9}]$$

where

$NPV(TNFEC_{BC})$= the NPV of the total cost of the non-fuel element for the base case (£M) (see Table 5.2a and Figure 5.5b).

All other factors remained as they were defined before.

(iii) VOC

$$NPV(TVOC_{BC})=NPV(TFCC_{BC})+NPV(TNFEC_{BC})$$

$NPV(TVOC_{BC})$= the NPV of the total vehicle operating cost for the base case (£M) (see Table 5.2a and Figures 5.5a and 5.5b)

5.6.4 Accident Cost

For any year of the economic assessment period, the accident costs were determined using the following formula:

$$PIA_n = \frac{365\ AR\ [DF\ (1+TG)^n]\ LN}{10^6}$$

where

PIA_n= the personal injury accidents in year n of the economic assessment period.

All the other factors have been defined previously.

$$PIAC_n = (1+GVA)^n (ACC_{FATAL}\ AC_{FATAL} + ACC_{SERIOUS}\ AC_{SERIOUS} + ACC_{SLIGHT}\ AC_{SLI}$$

where;

$PIAC_n$= average personal injury accident cost in year n of the economic assessment period (£)

All other factors have been defined previously.

$$APIAC_n = PIA_n\ PIAC_n$$

where;

$APIAC_n$= the annual personal injury accidents cost in year n of the economic assessment period (£)

All other factors have been defined previously.

$$NPV(TPIAC_{BC}) = \sum \left[\frac{PIAC_0}{(1+r)^0} + \frac{PIAC_1}{(1+r)^1} + \ldots + \frac{PIAC_9}{(1+r)^9}\right]$$

where;

$NPV(TPIAC_{BC})$= the NPV of the total cost of personal injury accidents for the base case (£M) (see Table 5.2a and Figure 5.5a).

All other factors have been defined previously.

5.6.5 The Total Cost

$$NPV(TC_{BC})=NPV(TTTC_{BC})+NPV(TVOC_{BC})+NPV(TPIAC_{BC})$$

$NPV(TC_{BC})$= the NPV of the total cost for the base case (£M) (see Table 5.2a and Figure 5.5a).

All other factors have been defined previously.

5.7 The Calculation of the NPV of the Total Cost for the Base Case for the Period 1994-2003 (high economic growth)

A similar calculation procedure that was applied for the low economic growth was adopted for high economic growth (see Table 5.2b and Figures 5.6a and 5.6b).

5.8 The Effect of the Speed Limit on the Mean Speed of Traffic

The mean speed of traffic was estimated for various speed limits using the Speed Limit Effect Model SPLA that was developed in Chapter Two which had the following form:

$$MST = 6.74\ SPL^{.43}\ LSEC^{.09}\ TRPLN^{.23}$$

where;

MST= the mean speed of traffic (km/h) (adjusted to the mean speed for the base case and converted to km/h)

SPL= the speed limit (mile/h)

LSEC= the length of section category

TRPLN= the trip length category

(see Figure 5.7)

5.9 Calculation of the NPV of the Total Cost of Traffic for the Economic Assessment Period 1994-2003 for Various Speed Limits

5.9.1 Low Economic Growth

The calculation procedure that was carried out in Section 5.6 was repeated for various speed limits. The NPV of the total cost for various speed limits were illustrated in Table 5.2a and Figure 5.8a. The changes in the NPV of the total cost for various speed limits relative to the NPV of the total cost for the base case were shown in Table 5.2a and Figure 5.8b. The NPV of each of the components of total cost for various speed limits were demonstrated in Table 5.2a and Figure 5.9a where the NPV of the components of VOC for various speed limits were displayed in Table 5.2a and Figure 5.9b.

5.9.2 High Economic Growth

The calculation procedure that was carried out in Section 5.7 was repeated for various speed limits. The results can be found in Table 5.2b and Figures 5.10a, 5.10b, 5.11a, and 5.11b.

5.10 The Calculation of the NPV of the Net Benefits of Changing the Speed Limit of the Base Case

5.10.1 Low Economic Growth

The NPV of the net benefits resulting from changes in the speed limit of the base case was calculated using the following equation:

$$NPV(NB_{\Delta SPL}) = NPV(TC_{BC}) - NPV(TC_{SPL})$$

where

$NPV(NB_{\Delta SPL})$ = the NPV of the net benefits derived from changing the speed limit of the base case to another speed limit (see Table 5.2a and Figure 5.12a)

$NPV(TC_{BC})$ = the NPV of the total cost for the base case (i.e. low economic growth)

$NPV(TC_{SPL})$ = the NPV of the total cost of the proposed speed limit under investigation (i.e. low economic growth)

5.10.2 High Economic Growth

A similar equation to the one referred to in Section 5.10.1 was used except that the values used were for high economic growth (see Table 5.2b and Figure 5.12b).

Table 5.2a: The Results of the Calculation of the NPV of the of Road Traffic Operating Costs for the Base Case for Various Speed Limits (low economic growth)

Speed limit (mile/h)	Travel-time cost (£M)	Fuel elem. cost (£M)	Non-fuel elem. cost (£M)	VOC (£M) (fuel & non-fuel elem.)	Accd. cost (£M)	Total cost (£M)	Net benefits of changing the speed limit of the base case (£M)	Relative total cost to the base case (%)
50	3.63	1.08	1.97	3.04	0.35	7.02	-0.32	104.7
60	3.42	1.12	1.96	3.08	0.35	6.85	-0.14	102.2
70	3.23	1.17	1.95	3.12	0.35	6.70	0.00	100.0
80	3.07	1.22	1.94	3.16	0.35	6.58	0.12	98.2
90	2.92	1.28	1.93	3.21	0.35	6.48	0.22	96.7
100	2.78	1.34	1.92	3.27	0.35	6.40	0.30	95.5

Table 5.2b: The Results of the Calculation of the NPV of the Road Traffic Operating Cost for the Base Case for Various Speed limits (high economic growth)

Speed limit (mile/h)	Travel-time cost (£M)	Fuel elem. cost (£M)	Non-fuel elem. cost (£M)	VOC (£M) (fuel & non-fuel elem.)	Accd. cost (£M)	Total cost (£M)	Net benefits (£M) of changing the speed limit of the base case	Relative total cost to total cost of the base case (%)
50	3.84	9.23	1.97	2.89	0.37	7.10	-0.35	105.3
60	3.62	9.61	1.96	2.92	0.37	6.91	-0.17	102.4
70	3.42	10.03	1.95	2.95	0.37	6.75	0.00	100.0
80	3.25	10.49	1.94	2.99	0.37	6.61	0.14	98.0
90	3.09	10.99	1.93	3.03	0.37	6.49	0.26	96.2
100	2.95	11.51	1.92	3.08	0.37	6.39	0.35	94.8

Figure 5.5a: The NPV of the Total Cost Including the Costs of each of the Components for the Base Case (low economic growth)
(costs are in million pounds)
the NPV of total cost= £6.70 million

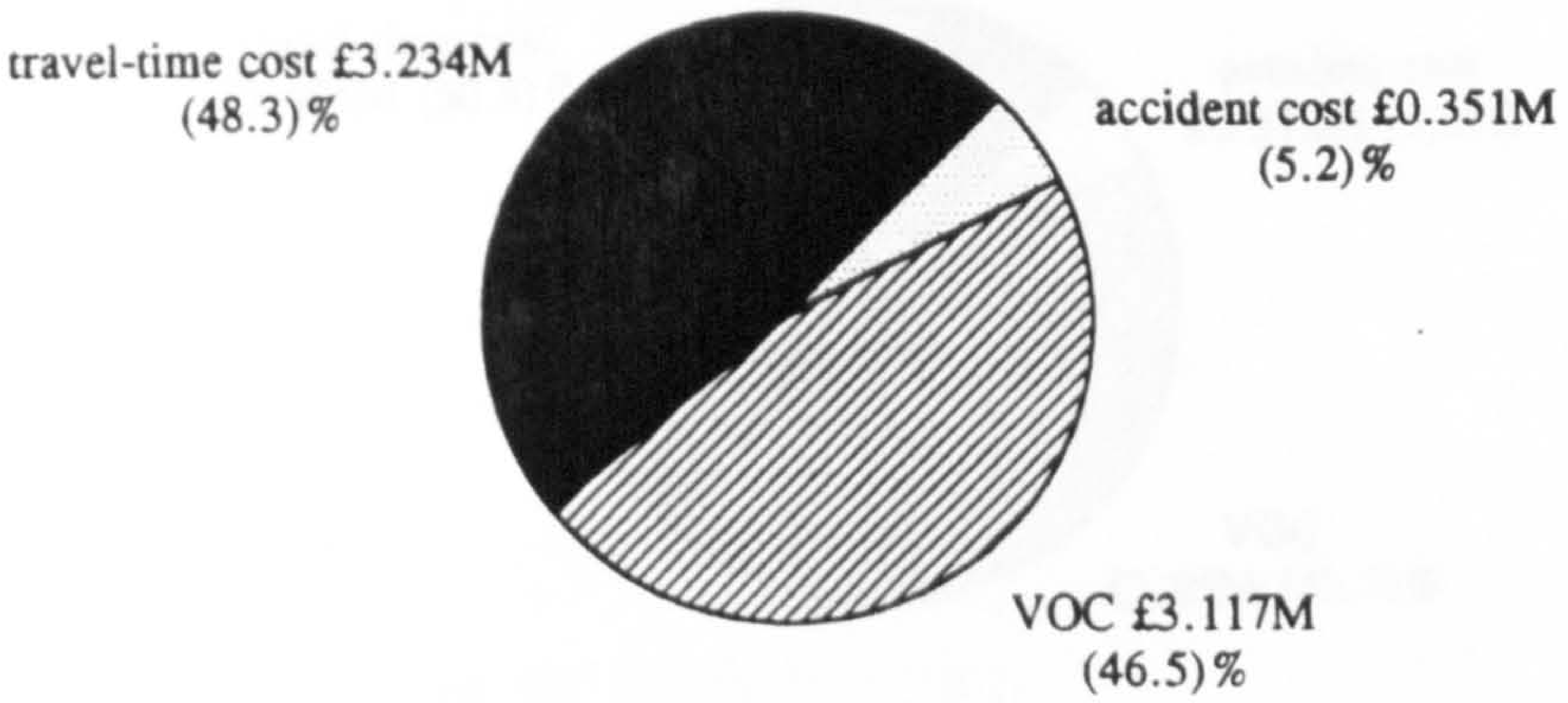


Figure 5.5b: The NPV of the Costs of each of the Components of VOC for the Base Case (low economic growth)
(costs are in million pounds)
the NPV of VOC= £3.12 million

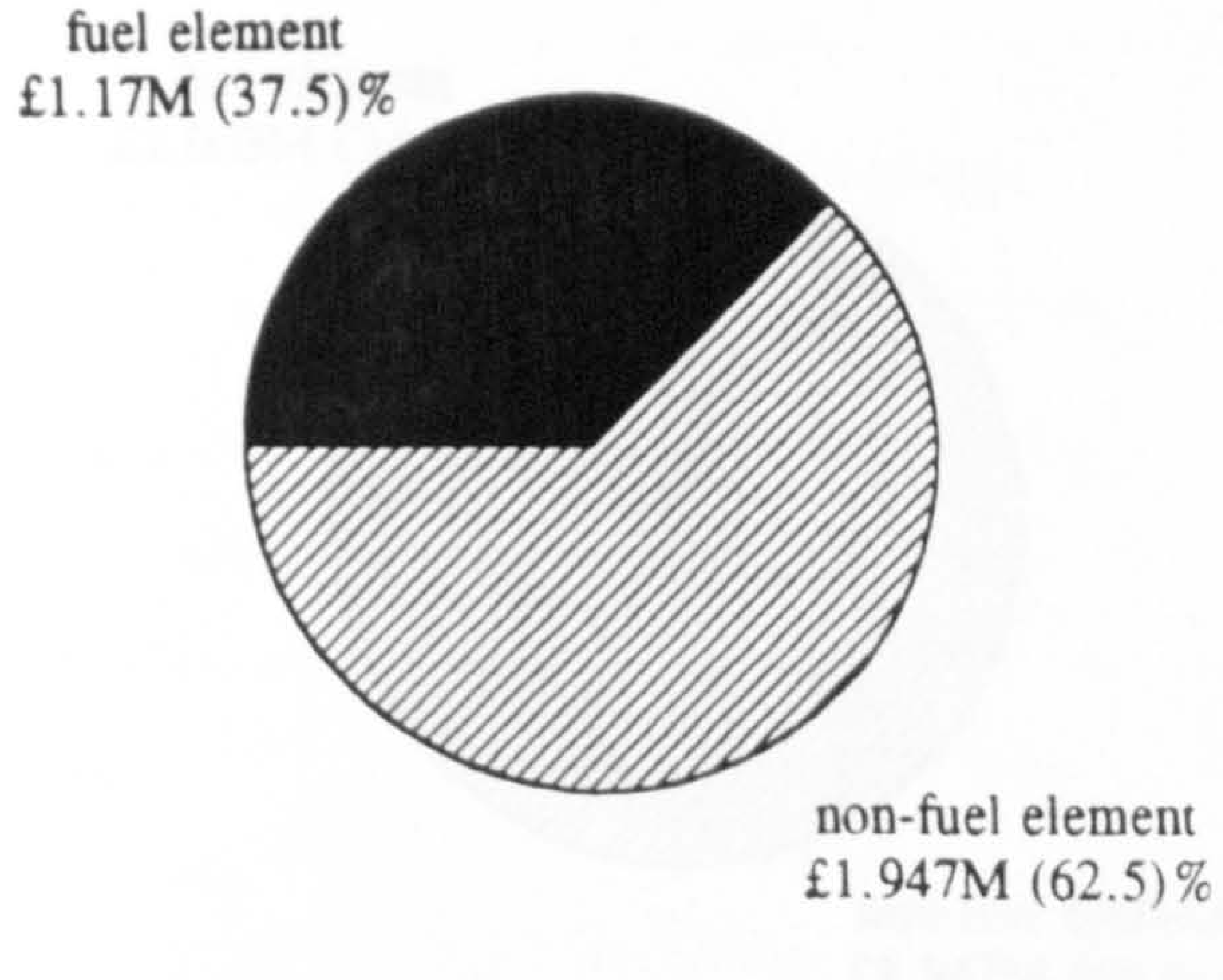


Figure 5.6a: The NPV of the Total Cost Including the Costs of each of the Components for the Base Case (high economic growth)

(costs are in million pounds)
the NPV of total cost= £6.75 million

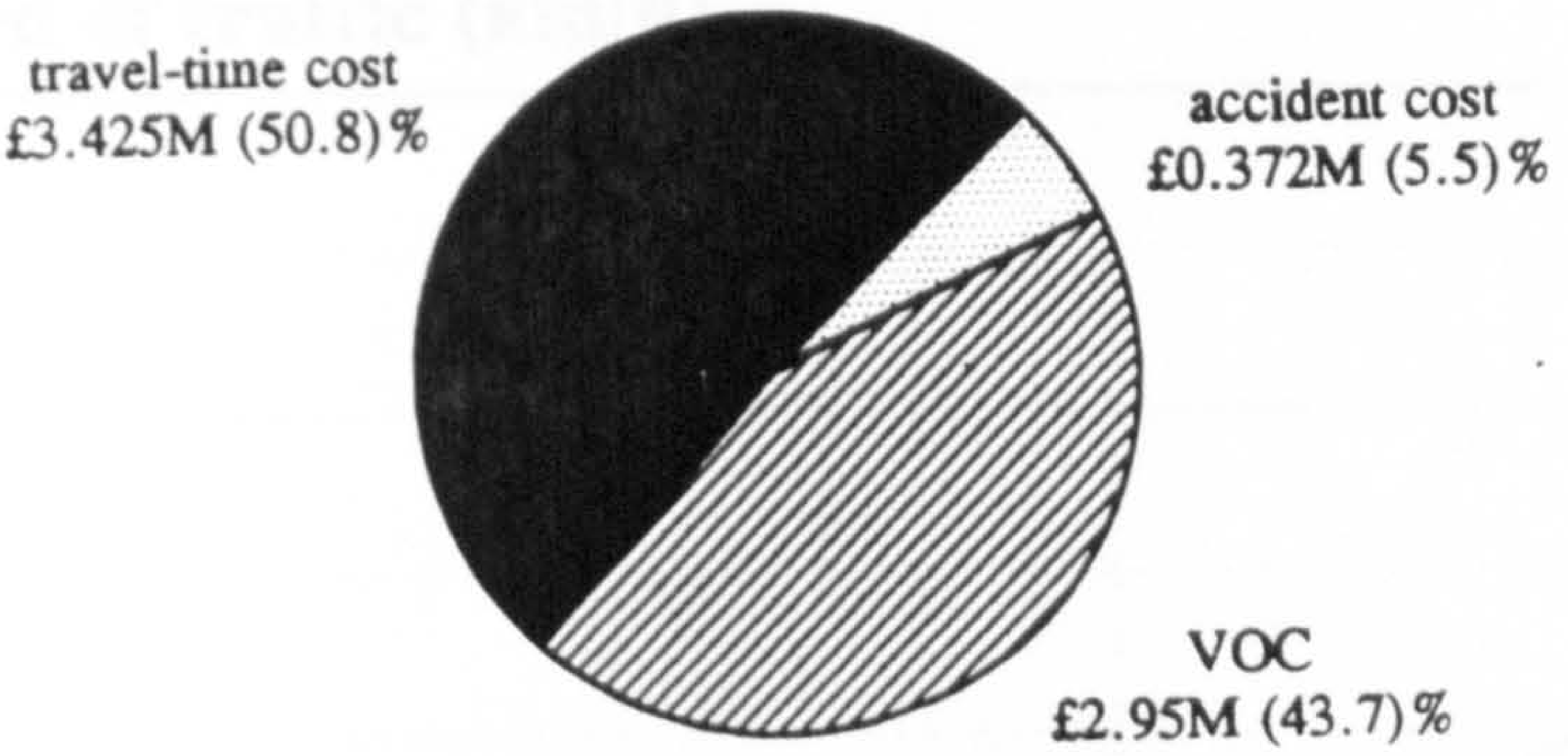


Figure 5.6b: The NPVs of the Costs of each of the Components of VOC for the Base Case (high economic growth)

(costs are in million pounds)
the NPV of VOC= £2.95 million

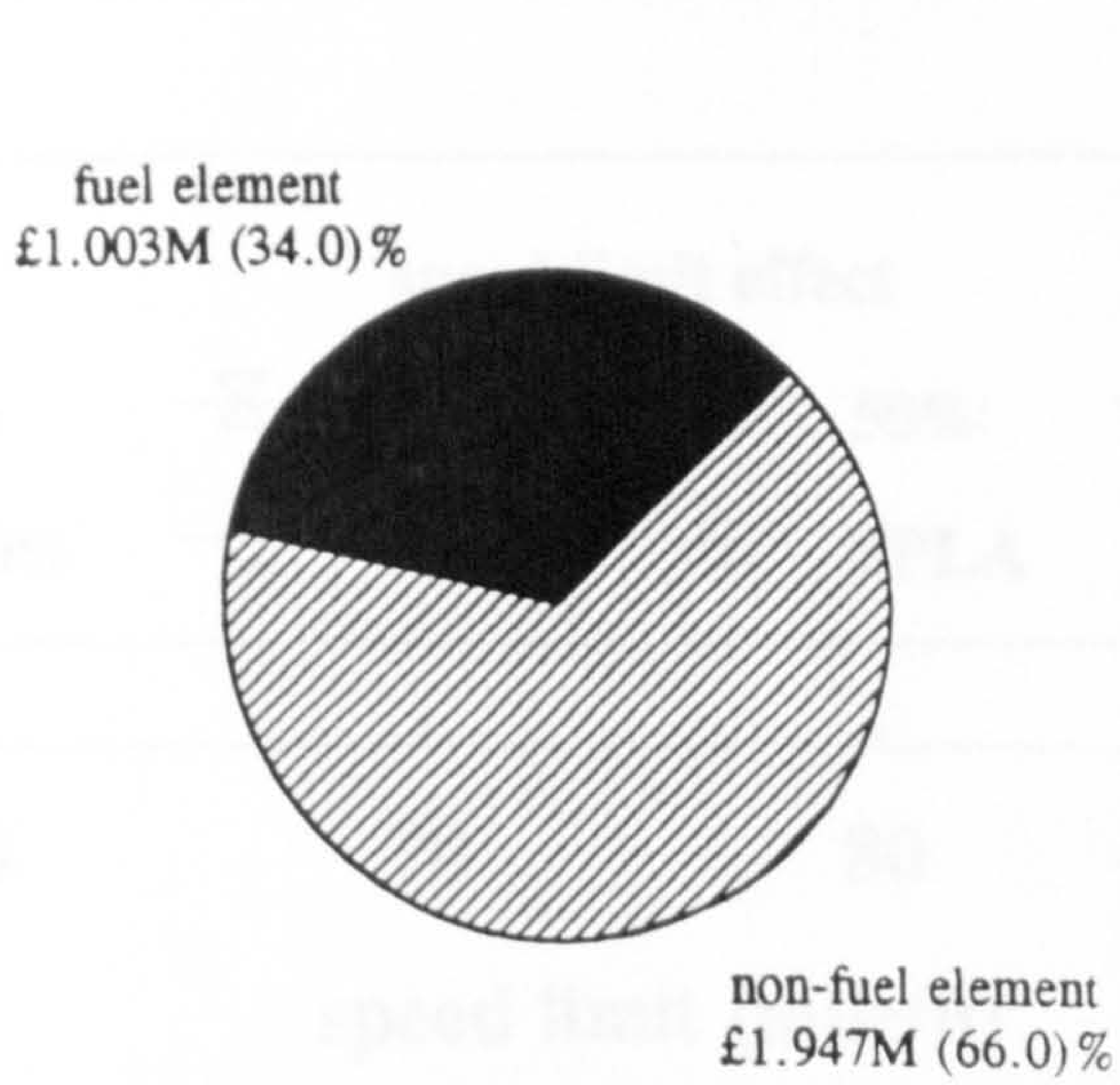


Figure 5.7: The Effect of Speed Limits on the Mean Speed of Traffic
(*the effect of the speed limit= the ratio of the expected change in the mean speed of traffic (km/h) to the proposed change in the speed limit (mile/h). SPLA and SPLM are models obtained from the speed limit effect calculation in Chapter Two)

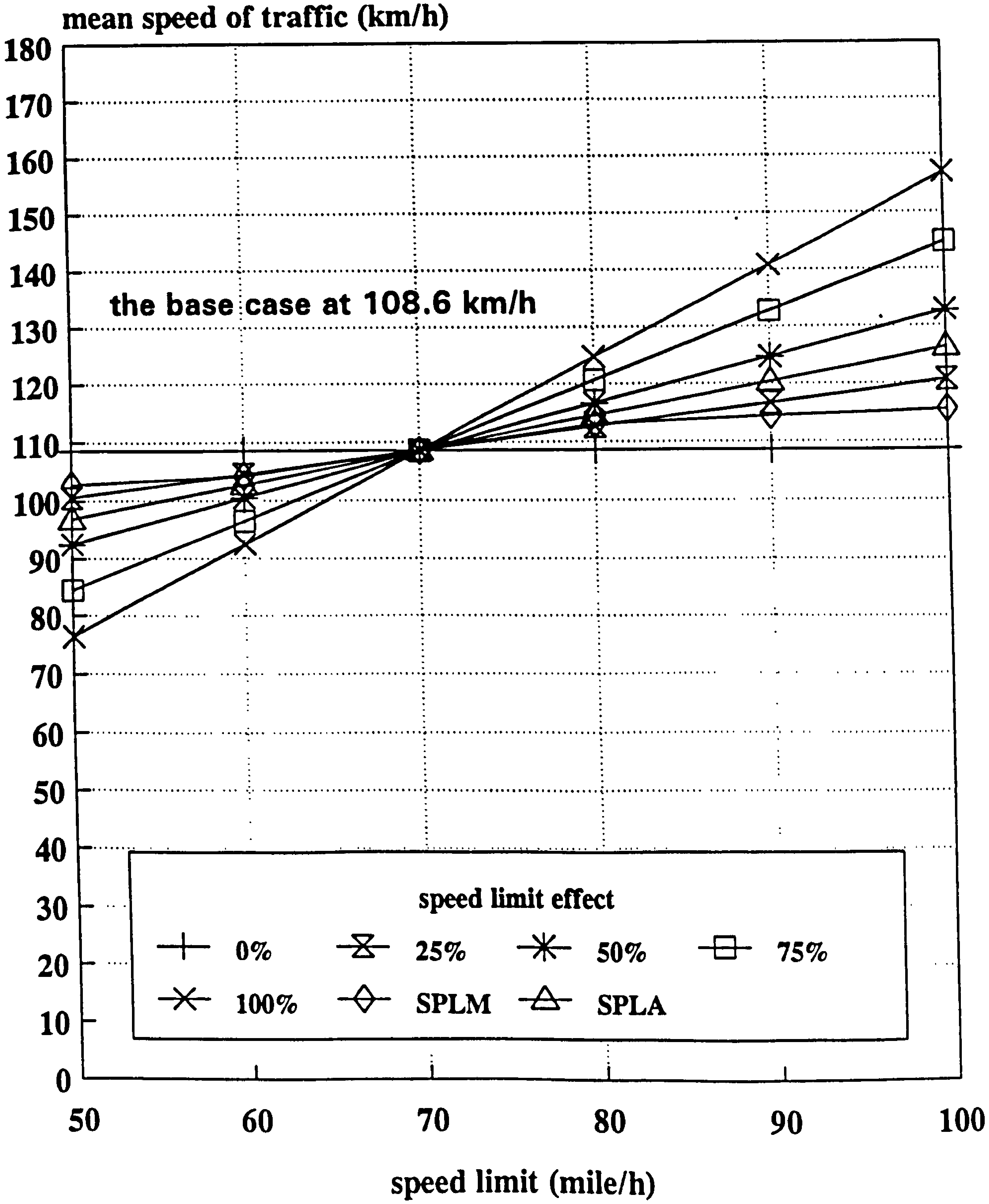


Figure 5.8a: The NPV of the Total Cost for the Base Case at Various Speed Limits (low economic growth)
(note: the frequency and the severity of PIA were assumed to be constant)

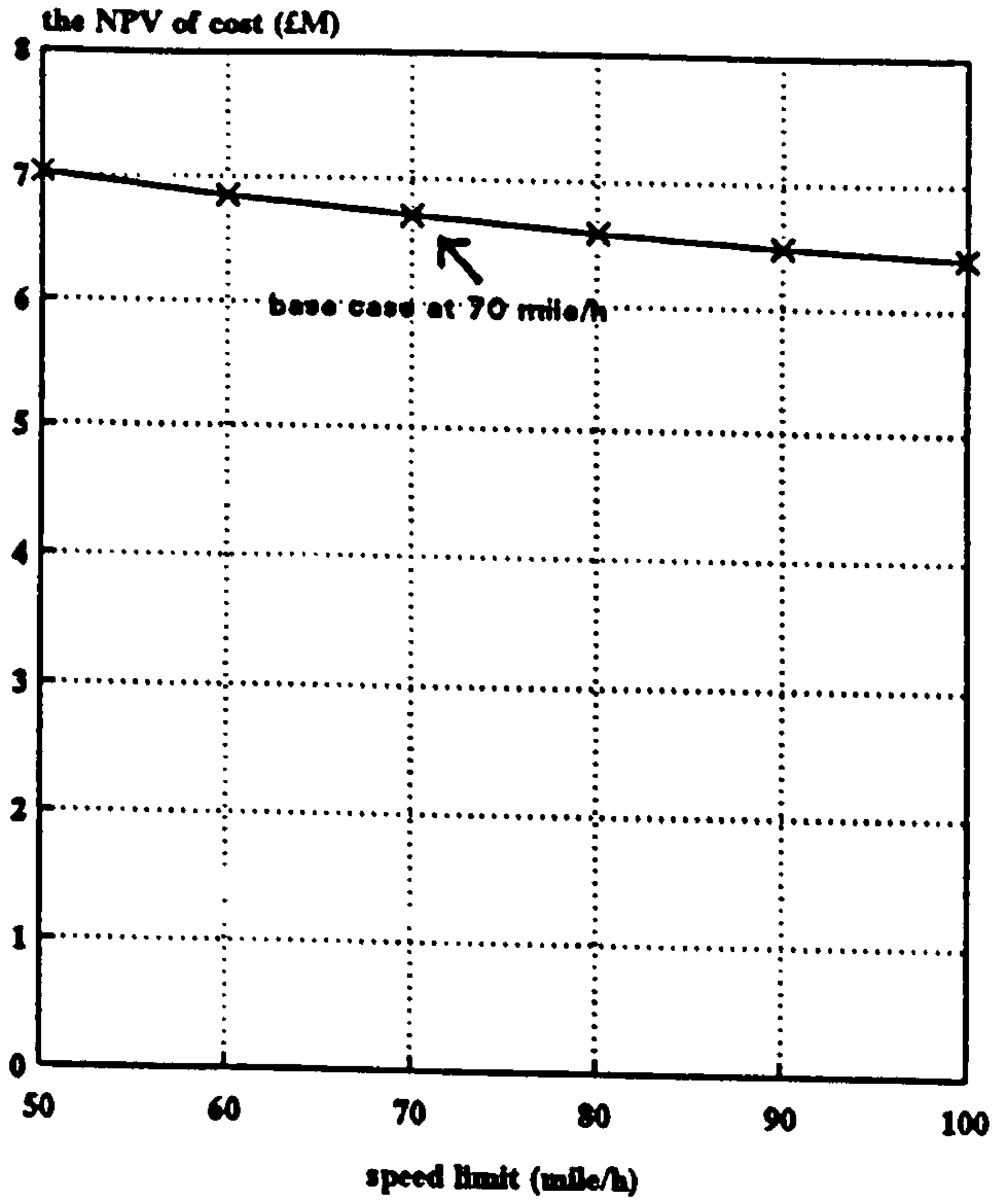


Figure 5.8b: The Ratio (%) of the NPV of the Total Cost at Various Speed Limits to the Total Cost for the Base Case (low economic growth)
(note: the frequency and the severity of PIA were assumed to be constant)

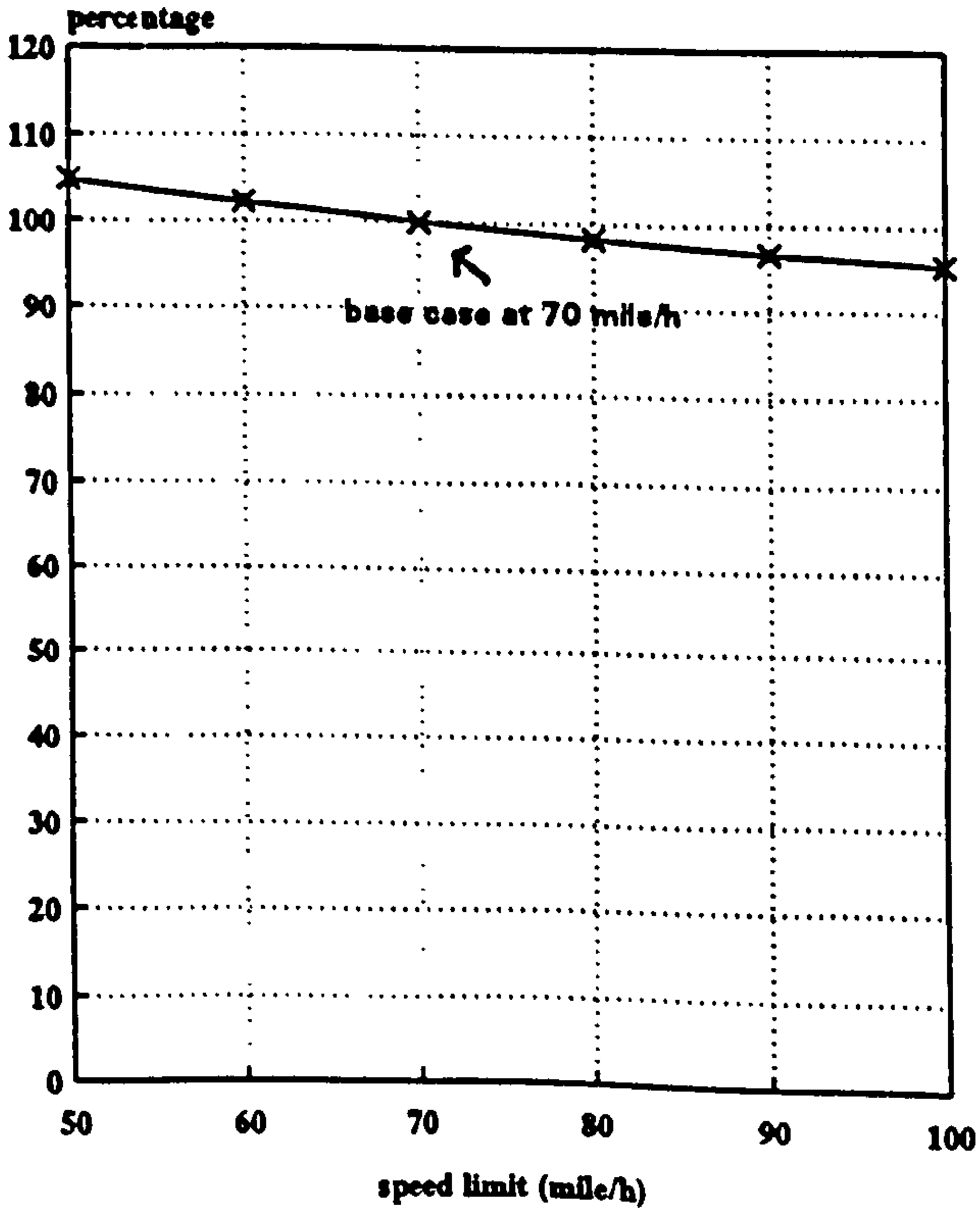


Figure 5.9a: The NPV of the Components of the Total Cost for the Base Case at Various Speed Limits (low economic growth)
(note: the frequency and the severity of PIA were assumed to be constant)

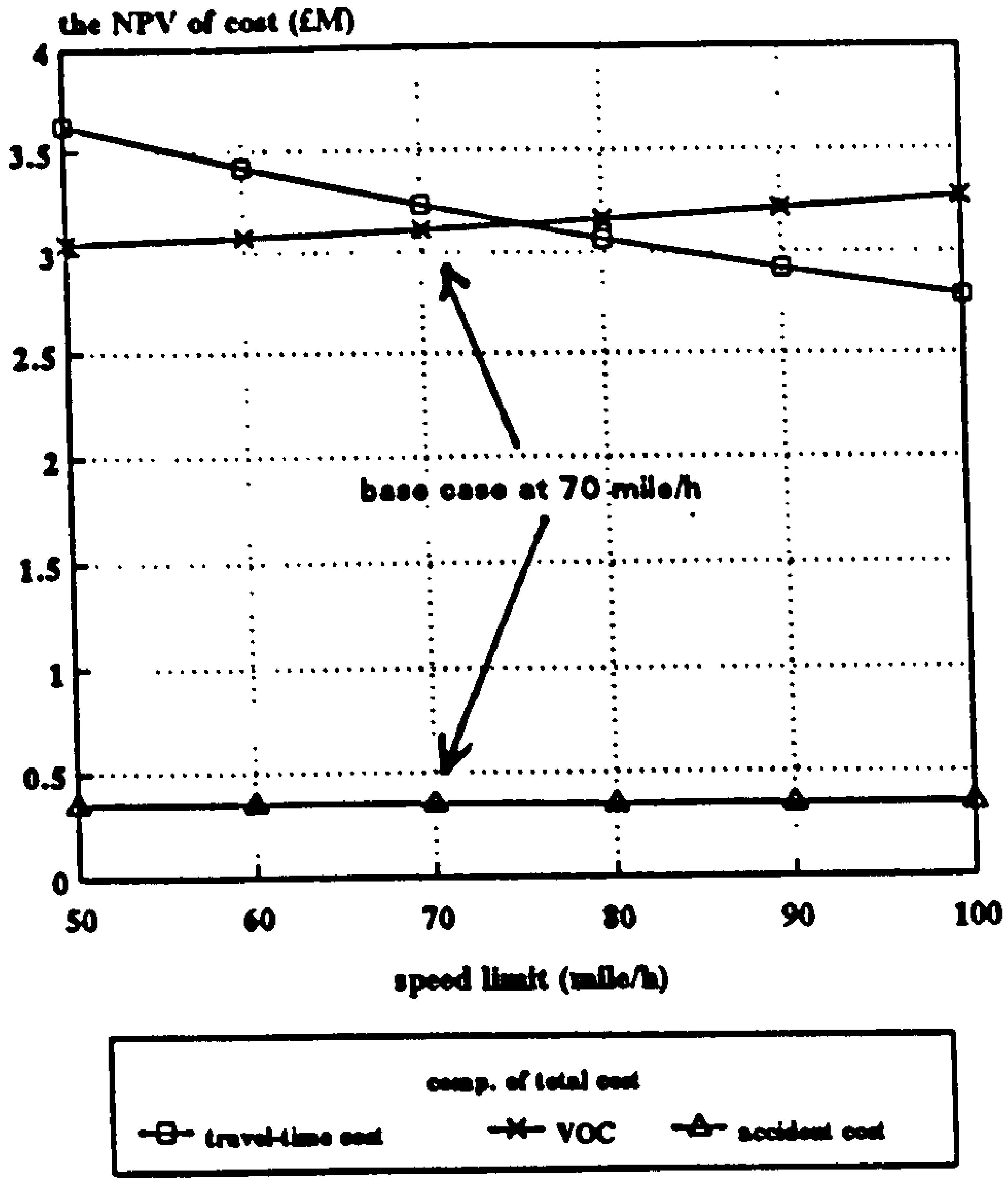


Figure 5.9b: The NPV of the Components of VOC for the base case at Various Speed Limits (low economic Growth)

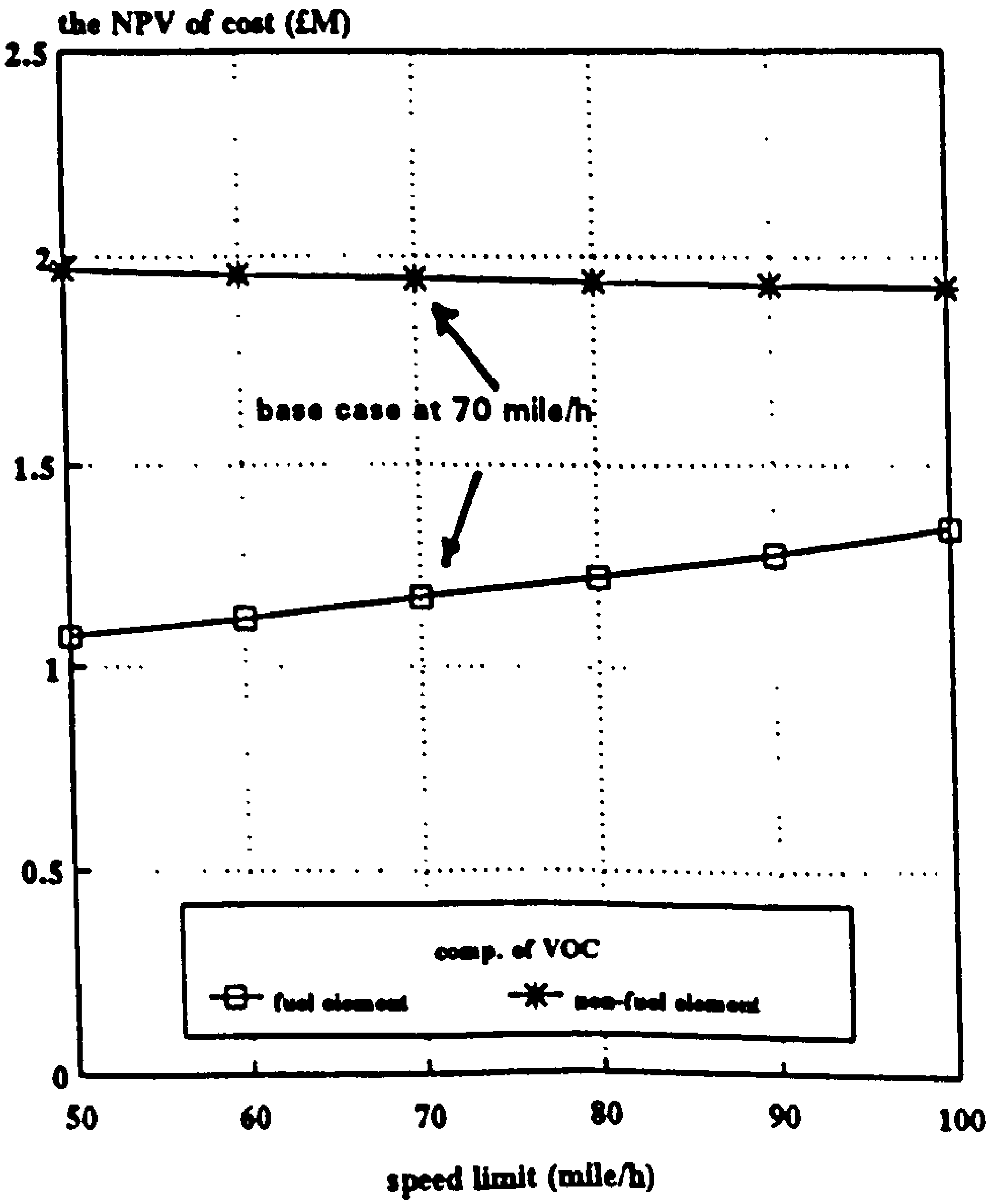


Figure 5.10a: The NPV of the Total Costs for the Base Case at Various Speed Limits (high economic growth)

(note: the frequency and the severity of PIA were assumed to be constant)

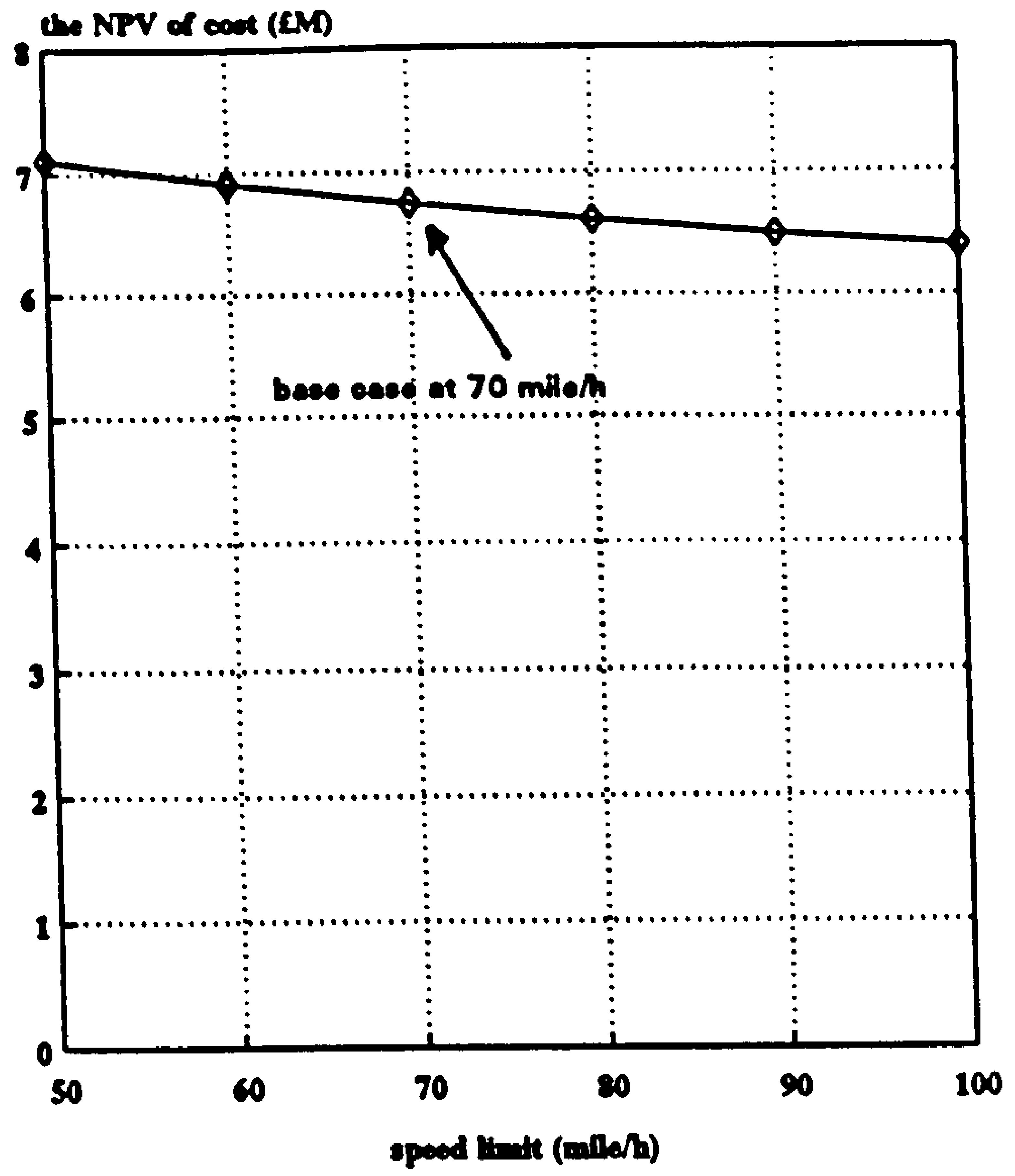


Figure 5.10b: The Ratio (%) of the NPV of the Total Costs at Various Speed Limits to the Total Cost for the Base Case (high economic growth)

(note: the frequency and the severity of PIA were assumed to be constant)

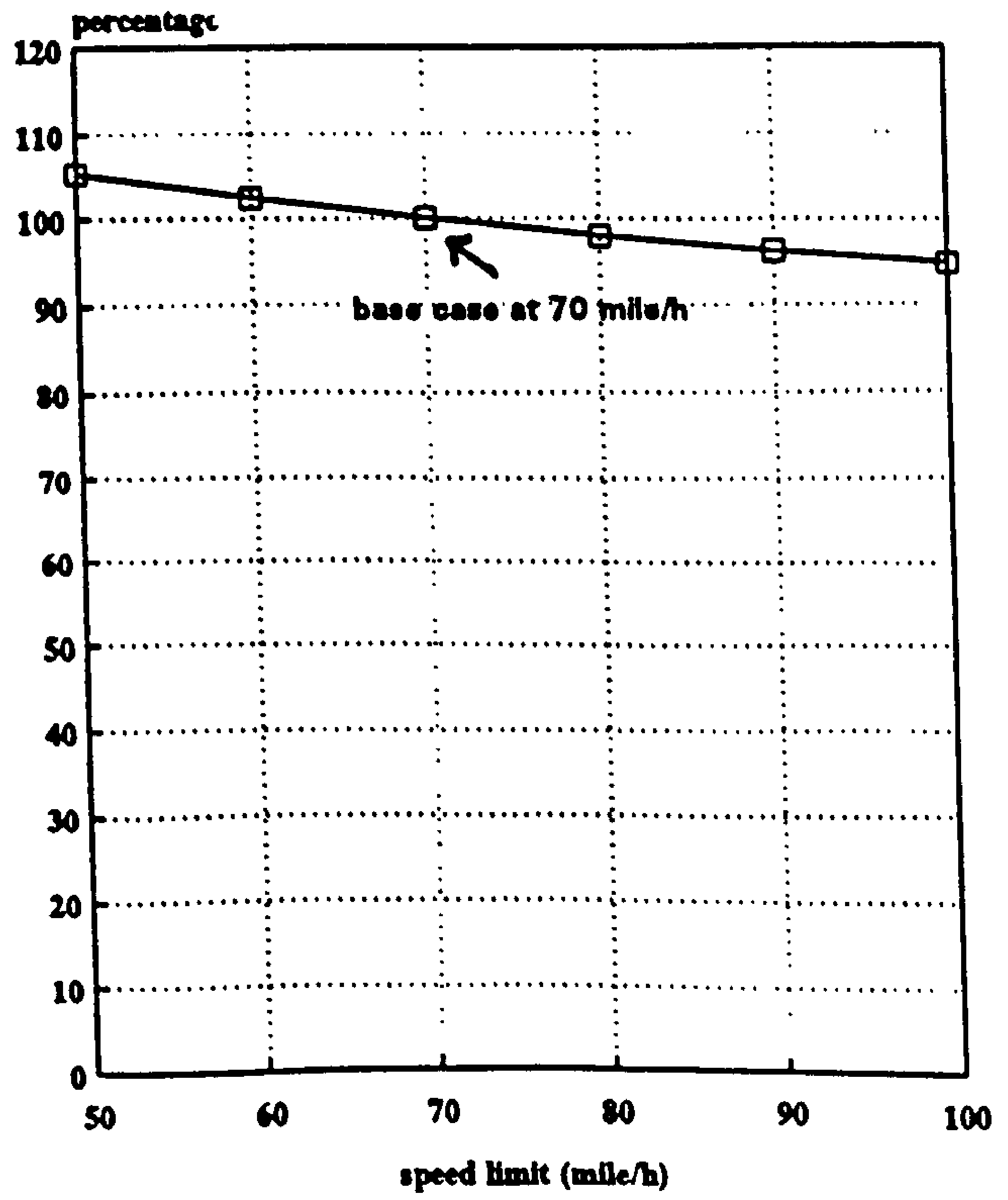


Figure 5.11a : The NPV of the Components of the Total Cost for the Base Case at Various Speed Limits (high economic growth)

(note: the frequency and the severity of PIA were assumed to be constant)

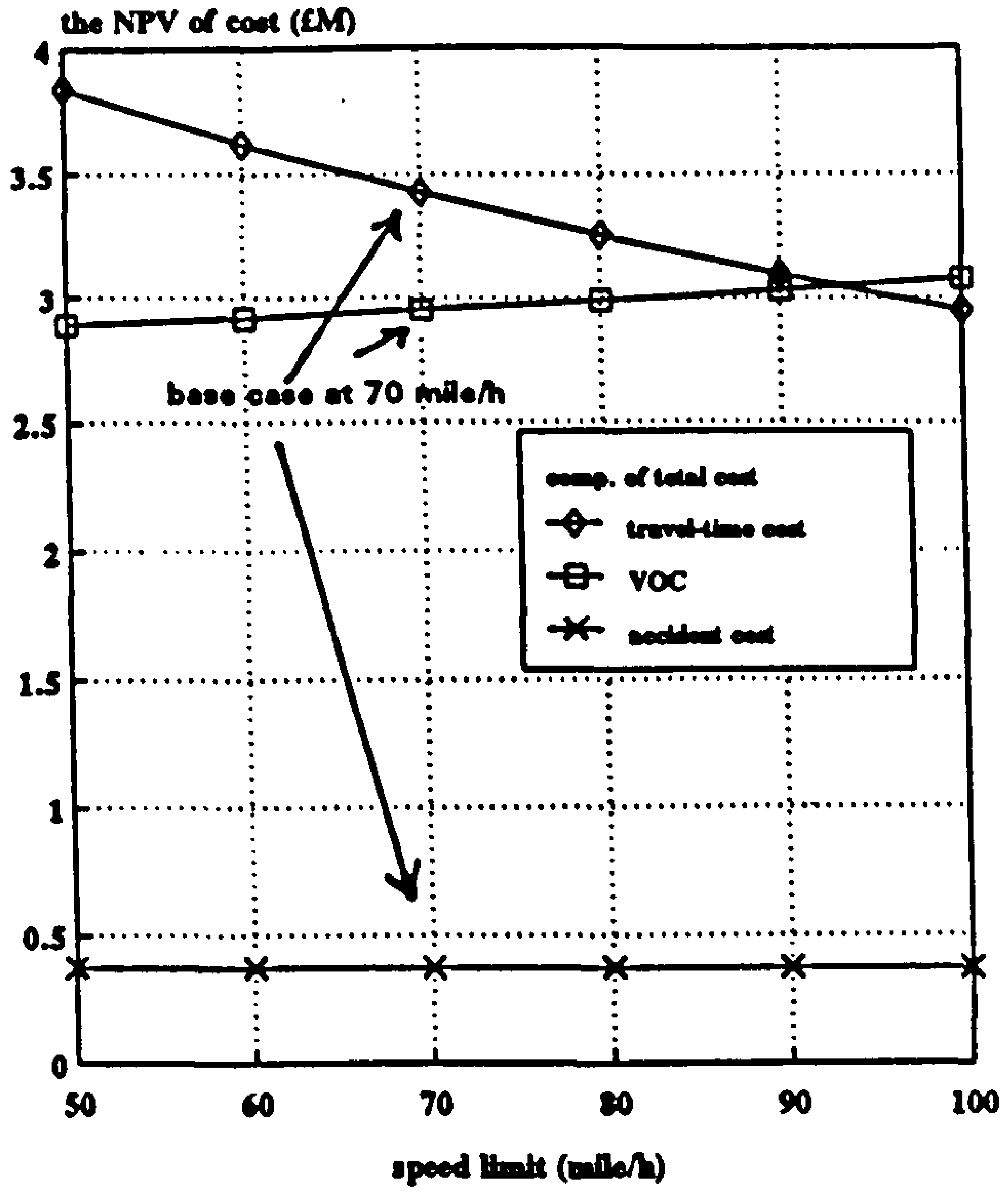


Figure 5.11b: The NPV of the Components of VOC for the Base Case at Various Speed Limits (high economic Growth)

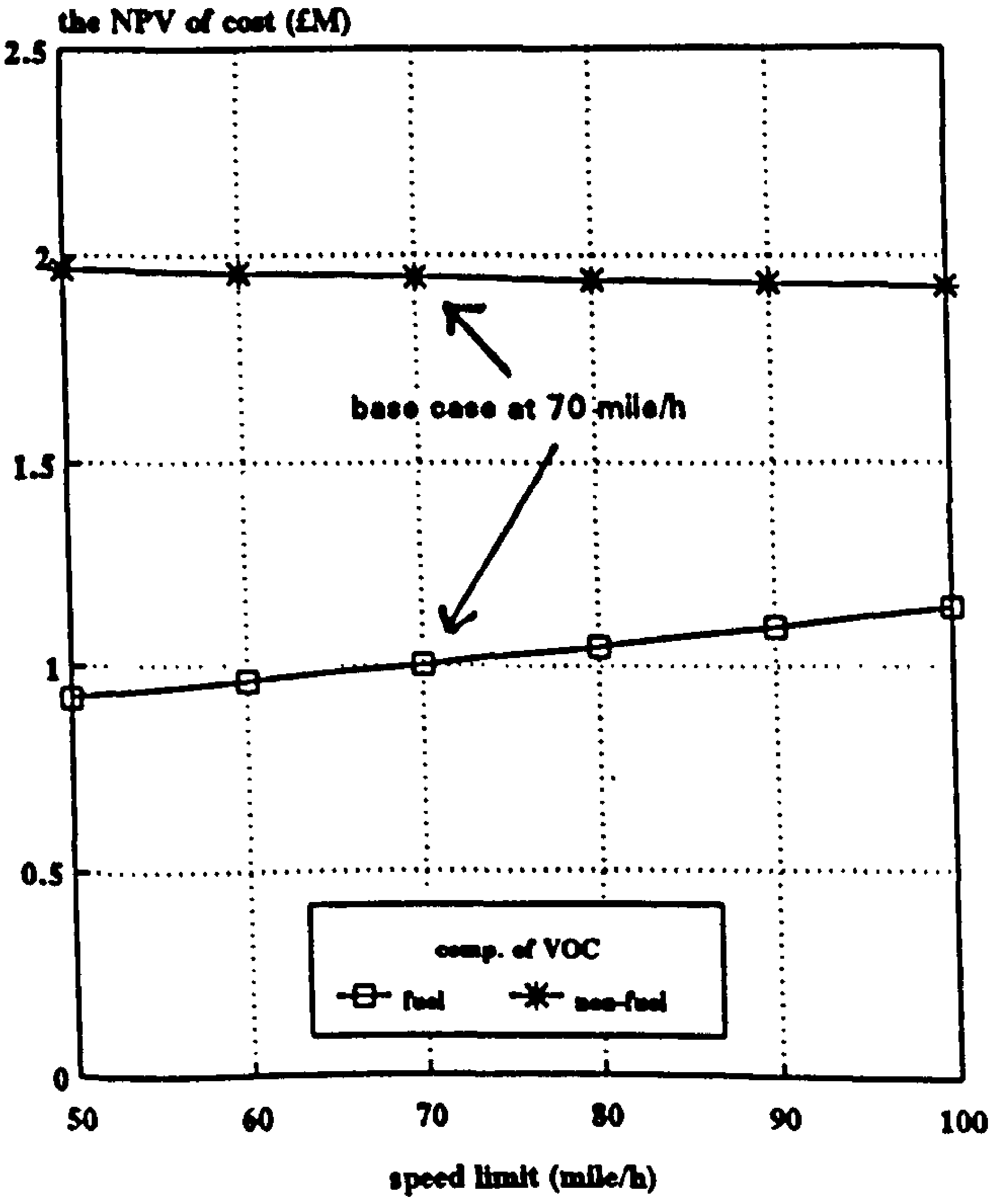


Figure 5.12a: The NPV of the Net Benefits Derived from Changing the Speed Limit of the Base Case to Various Speed Limits (low growth economic)
(note: the frequency and the severity of PIA was assumed to be constant)

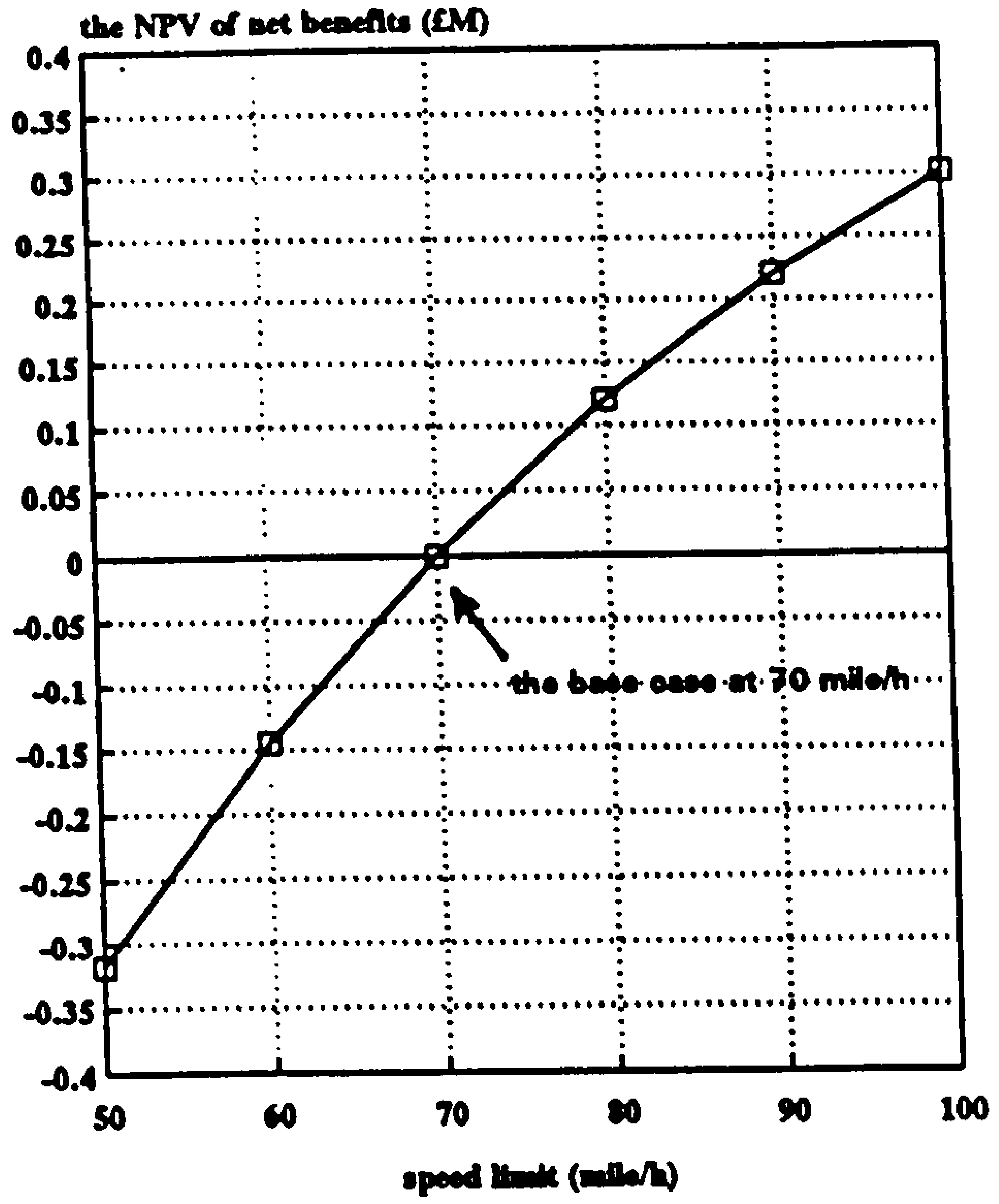
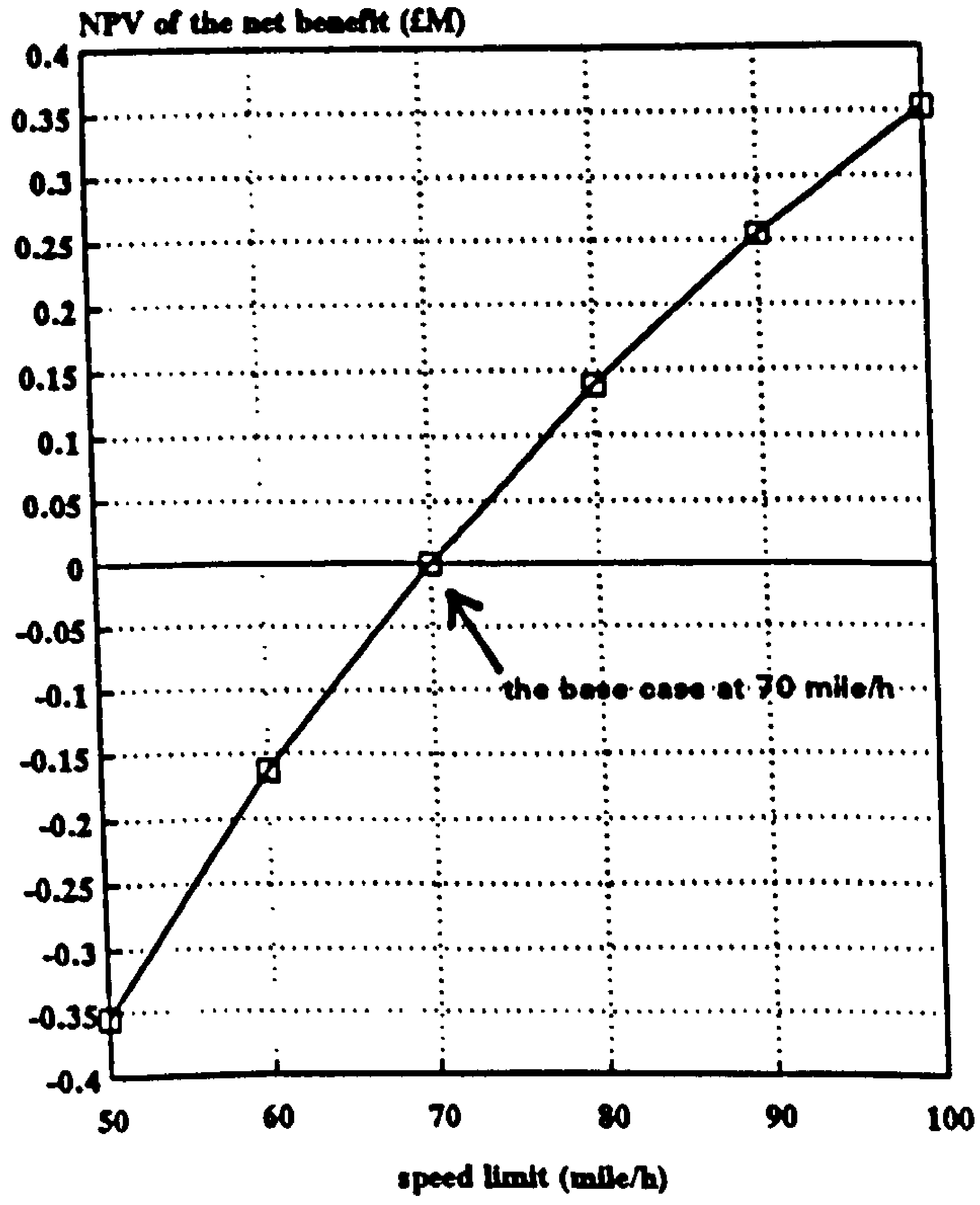


Figure 5.12b: The NPV of the Net Benefits Derived from Changing the Speed Limit of the Base Case to Various Speed Limits (high growth economic)
(note: the frequency and the severity of PIA were assumed to be constant)



5.11 The Uncertainty of the Contribution of Accident Cost to the Total Cost

5.11.1 Introduction

Some studies have revealed that there was a relationship between the mean speed of traffic and the frequency and the severity of accidents; others have claimed quite the opposite (see Sections 3.2.1, 3.2.2, and 3.2.3). Due to the uncertainty of this issue, the frequency and the severity of personal injury accidents (PIA) were assumed to be constant when the NPV of the total cost of road traffic was calculated at various speed limits together with the NPV of the net benefits of changing the speed limit of the base case to a number of different speed limits. This assumption was not, necessarily, true. A method was proposed to evaluate the seriousness of this assumption. The exercise was done for low economic growth only. The outcome of the same exercise for high economic growth would be similar.

5.11.2 The NPV of the net benefits Derived from Changing the Frequency and Severity of Accidents for the Base Case (low economic growth)

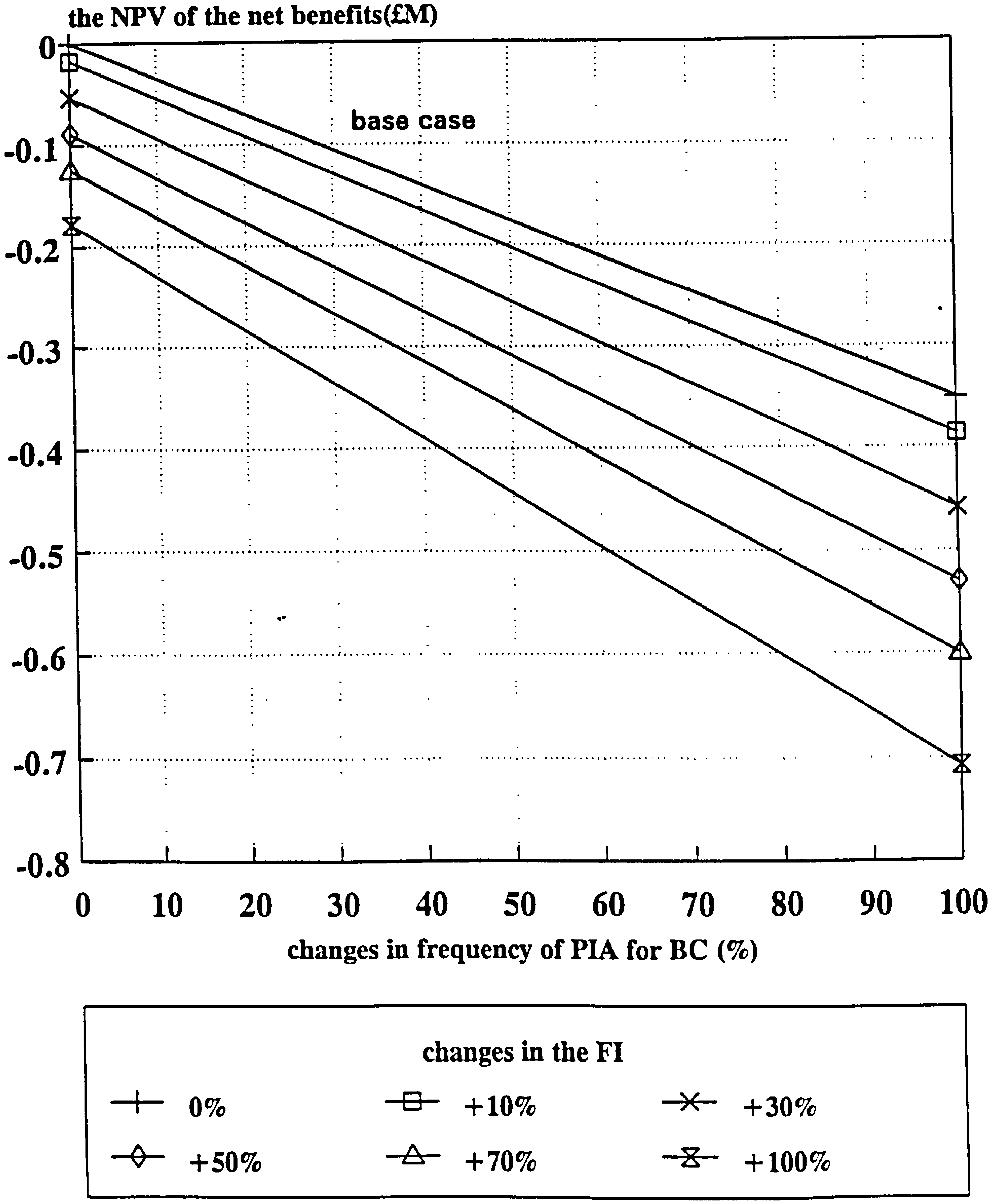
Break-even analysis was performed to explore the potential for accident cost to change the outcome of the economic assessment. "Breakeven analysis involves obtaining an equality between the magnitudes of the two sets of costs" (Lawlor, 1984). In this case, changes in the frequency and severity of PIAs were determined to produce a NPV of the net benefits of changes in PIAs of the base case to offset the NPV of the net benefits (i.e. either positive or negative) derived from changing the speed limit of the base case to a number of speed limits. The frequency of the PIA of the base case was changed. A change in the severity of accidents was presented by changing the number fatal injury (FI) casualties per average PIA for the base case (see Appendix III, Tables 5 and 7). The effect of changes in other types of injury casualty per average PIA of the base case was found to be unnecessary because the cost of changes in FI casualties per average PIA overwhelmed the cost of changes for other casualties. The costs of various combinations of changes in the frequency and severity of PIAs were calculated by changing the frequency and severity of PIAs for the base case and, in this way, the NPV of the net benefits were determined (Figure 5.13a and Figure 5.13b). The NPV of the net benefits derived from changing the speed limit of the

NPV of the net benefits derived from changing the speed limit of the base case assuming no change in the frequency and severity of PIAs (i.e. of the base case) were determined in previous sections.

5.11.3 The Changes Required in the Frequency and the Severity of PIAs to Offset the NPV of the Net Benefits derived from Changing the Speed Limit of the Base Case (i.e. the Break-Even Point) (low economic growth)

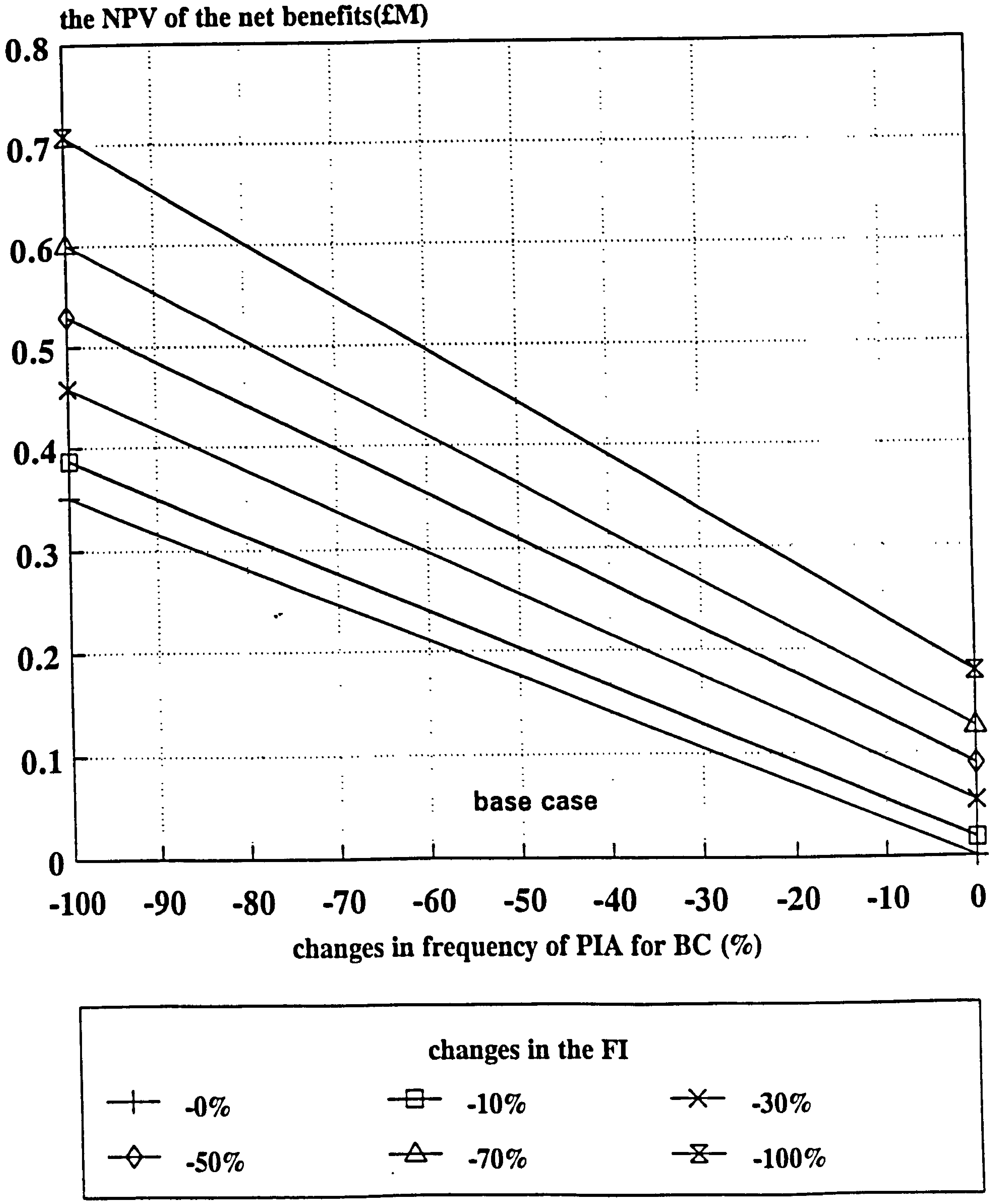
The NPV of the net benefits derived from changing the speed limit of the base case (i.e. with the assumption that the frequency and the severity of PIAs remained unchanged) were used to estimate the corresponding changes required in the frequency and severity of PIAs for the base case to achieve a break-even point (see Figure 5.13a). Some of these values were presented in Table 5.3a. These values were converted to ratios (i.e. the ratio of the change (%) in the frequency and FI casualties per average PIA to the change in the mean speed of traffic (km/h) at various speed limits) by dividing the values in Table 5.3a by the difference between the mean speed of traffic at the new speed limit and that for the base case (see Table 5.3b).

Figure 5.13a: The NPV of the Negative Net Benefits of Increases in the Frequency of PIAs and the FI Casualties per Average PIA for the Base Case (low economic growth)



BC: base case

Figure 5.13b: The NPV of the Positive Net Benefits of Reductions in the Frequency of PIAs and the FI Casualties per Average PIA for the Base Case (low economic growth)



BC: base case

Table 5.3a: Examples of the Required Combinations (Comb) of Changes in the Frequency of Personal Injury Accidents (PIA) (%) and Fatal Injury (FI) per average PIA (%) for the Base Case to Offset the NPV of the Net Benefits of Changing the Speed Limit of the Base Case(i.e. 70 mile/h) Determined from Figures 5.12a, 5.13a and 5.13b

Speed limit (mile/h)	Comb 1 0% ΔFI	Comb 2 ±*10%ΔFI	Comb 3 ±30%ΔFI	Comb 4 ±50%ΔFI	Comb 5 ±70%ΔFI	Comb 6 ±100%ΔFI
100	84.8	75.6	60	47.6	37.8	23.2
90	65.9	57.9	43.9	31.7	21.3	9.8
80	36.6	32.5	19.5	8.6	0	NA**
60	- 40.2	- 33.3	- 22.0	- 12.1	- 3.5	NA**
50	- 90.8	-80.3	-65.2	-51.2	-39.6	-25.6

*negative changes in the FI casualties per average PIA with negative changes in the frequency of PIA and vice versa

**NA: not applicable

Table 5.3b: Examples of the Required Combinations (Comb) of Changes Determined in Table 5.3a per unit Change in the Mean Speed of Traffic of the Base Case (%ΔPIA and %ΔFI per km/h) to Offset the NPV of the Net Benefits of Changing the Speed Limit of the Base Case (i.e. 70 mile/h)

Speed limit (mile/h)	Comb 1	Comb 2	Comb 3	Comb 4	Comb 5	Comb 6
100	4.8* 0	4.3 0.6	3.4*** 1.7	2.7 2.8	2.1 4.0	1.3 7.0
90	5.6 0	4.9 0.8	3.7 2.6	2.7 4.3	1.8 6.0	0.8 8.5
80	6.2 0	4.9 1.70	3.3 5.1	1.5 8.5	0 11.9	NA**
60	- 6.8 0	- 5.7 - 1.7	- 3.7 - 5.1	- 2.1 - 8.5	- 0.5 - 11.9	NA**
50	- 7.7 0	- 6.8 - 0.8	- 5.5 - 2.6	- 4.4 - 4.2	- 3.4 - 6.0	- 2.2 - 8.5

*ΔPIA/km/h
ΔFI/km/h

**NA: not applicable

*** Sample calculation of comb 3 @ 100 mile/h speed limit:

3.4%ΔPIA/km/h= ΔPIA determined in comb 3 @ 100 mile/h speed limit in Table 5.3b (i.e. +60%) divided by the difference between the expected mean speed of traffic @100 mile/h determined from Figure 5.7 under Speed Limit Model SPLA i.e. 126 km/h and the mean speed of the base case i.e. 108.56 km/h

1.7%ΔFI/km/h= ΔFI determined in comb 3 @ 100 mile/h speed limit in Table 5.3b (i.e. +30%) divided by the difference between the expected mean speed of traffic @100 mile/h determined from Figure 5.7 under Speed Limit Model SPLA i.e. 126 km/h and the mean speed of the base case i.e. 108.56 km/h

5.11.4 The Effect of Changing the Mean Speed of Traffic on the Frequency and Severity of PIA: A Review of Past Cases

It was felt important to compare the results presented in Table 5.3b with other case studies in order to identify any unrepresentative results. Three cases were reviewed and were summarised:

(i) The Experience of Imposing a Maximum Speed Limit of 70 mile/h in the UK in 1965 (Department of Transport U.K., 1967)

The mean speed of traffic decreased by 3.9 km/h. The frequency of personal injury accidents (PIA) dropped by 17.7 per cent which was equivalent to a change of 4.58 per cent in the frequency of PIA per unit change in the mean speed of traffic (km/h). The fatal injury (FI) casualties per average PIA decreased by 37.0 per cent which was equivalent to a change of 9.60 per cent in the FI casualties per average PIA per unit change in the mean speed of traffic (km/h);

(ii) The Experience of Imposing a Maximum Speed Limit of 55 mile/h in the USA in 1974 (ITE Technical Council Committee 4M-2, 1977)

The mean speed of traffic dropped by 7.6 km/h. The frequency of personal injury accidents (PIA) decreased by 16.3 per cent which was equivalent to a change of 2.2 per cent in PIA per unit change in the mean speed of traffic (km/h). The fatal injury (FI) casualties per average PIA decreased by 23.1 per cent which was equivalent to a change of 3.05 per cent in the FI casualties per average PIA per unit change in the mean speed of traffic (km/h); and

(iii) The Effect of the Mean Speed of Traffic on the Frequency of PIAs (Finch et al., 1994)

It was detected from previous cases where speed limits were imposed in a number of countries that there was a 3.1 per cent change in the frequency of personal injury accidents (PIA) for every 1 km/h change in the mean speed of traffic. No model was established for the effect on fatal injury casualties per average PIA per unit change in the mean speed of traffic.

5.12 Appraisal of the Method of Calculating the Costs and Benefits and the Results

5.12.1 The Base Case

The base case provided the characteristics where the introduction of a speed limit was considered to be most effective. The significance of these characteristics will be tested in Chapter Six.

(i) Road Characteristics

Most of the road characteristics met the criteria that were established previously which eliminated all factors that affected the mean speed of traffic other than the speed limit. It was assumed that any proposal to change the speed limit on a length of road should be based on the design speed of the road otherwise the proposed speed limit would prove to be meaningless.

ii) Traffic characteristics

The daily traffic flow was determined so as not to violate the free-flow criteria and taking into consideration the future growth, as well. Even though it was believed for the base case that a few of the free-flow hours would convert into restricted-flow during the assessment period, it was assumed that the net effect would not be significant because on the one hand, the traffic flow would be reduced in the future as was explained previously, and on the other hand, the growth of free-flow traffic would be added. The net daily free-flow traffic was expected not to change very much. The traffic growth was assumed to be applicable to the free-flow conditions as there was no evidence suggesting differently. It was difficult to obtain the actual composition of the traffic during the periods of free flow traffic (according to this study) so the national composition of motorway traffic was used. The mean speed of traffic for this class of road remained unchanged between 1991 (Department of Transport, 1992) and 1993 (Department of Transport, 1994b) so a zero annual growth scenario was adopted for the mean speed of traffic. The Speed Limit Effect Model 'SPLA' was used (see Chapter Two) to estimate the effect of changing the speed limit of the base case. Its predictions were closer to the earlier cases (for example, Finch et al. (1994)). The speed limits were chosen because they were either imposed (i.e.

50 mile/h) or proposed previously. It was assumed that changing the speed limit of the base case would not disturb the trip distribution through the network because it was most likely that the speed limit would be changed over the whole network of major roads.

(iii) Economic Parameters

It was assumed that the cost of traffic operation was well represented by the values of cost and prices issued by the Department of Transport in U.K. through their COBA manuals with the limitations that were discussed in Chapter Four. The economic assessment period was for ten years which was considered to be an appropriate time span for a management policy project that did not involve capital cost. The frequency and severity of accidents were assumed to be constant, for the range of mean speeds that were considered, due to the uncertainty expressed in the literature and the investigation that formed part of this study (i.e. Chapter Three). It was assumed that there was no annual growth in the frequency and severity personal injury accidents and that the enforcement of speed limits was assumed to be constant regardless of the speed limit. Past experiences revealed that the level of enforcement rose temporally when a new speed limits was introduced but would not last.

5.12.2 The Cost-Benefit Analysis for the Year 1994

(i)The Base Case

The cost of travel-time and the VOC formed most of the annual total cost (Figure 5.1a). The accident cost represented only 5 per cent whereas the non-fuel element cost formed more than two-thirds of the annual VOC (see Figure 5.1b).

(ii) Changing the Mean Speed of Traffic for the Base Case

The travel-time cost curve decreased as the mean speed of traffic for the base case increased (see Figure 5.3a), which was to be expected because travel-time is inversely proportional to speed. The travel-time cost curve dropped severely at 'lower' mean speeds of traffic but the curve began to flatten at 'higher' speeds. The non-fuel element of the VOC decreased as the mean speed of traffic increased (see Figure 5.3b). The rate of decrease was not balanced around the mean speed of traffic for the base case. Instead, there was a sharper decrease of the curve up to a mean speed of 80 km/h when the curve tended to level-out. Again, this was to be expected as the speed parameter (i.e. inverse effect) of the equation for the first part of the curve was dominating but as the speed increased the constant term took control so the reduction in the cost curve was much slower. The fuel consumption cost equation had two speed related parameters. At 'low' speeds the parameter which was inversely proportional to the mean speed of traffic regulated the outcome which meant the cost curve decreased (see Figure 5.3b). At around 60 km/h, the cost curve levelled-out and began to have a positive trend. At this stage the other related parameter, that is the square of the mean speed of traffic resulted in the curve rising at a much higher gradient. Non-fuel and fuel elements of cost comprised approximately equal proportions at, around, 195 km/h (it should be noted, of course, that it is not possible for road traffic to reach this mean speed), whereas at higher speeds the fuel element cost represented a bigger proportion of the VOC. The VOC had a pattern similar to the cost curve for the fuel element, though, the non-fuel element comprised most of the VOC (see Figure 5.3a). This was due to the dynamic behaviour of the fuel element cost curve in response to changes in the mean speed of traffic compared to the static behaviour of the non-fuel element cost curve. The travel-time cost and the VOC curves intersected at a mean speed of traffic of 110 km/h. The accident cost remained unchanged due to the assumption that was made. The trends in the components of the total cost were superimposed on the total cost curve (see Figure 5.2a). The total annual cost curve decreased as the mean speeds of traffic increased. Up to around 60 km/h, all the components of total cost decreased as the mean speed of traffic decreased except the accident cost. After this point, the fuel element cost started to grow. This did not prevent the total cost curve decreasing but the gradient of the reduction was lower than the previous trend. This could be seen in Figure 5.2b where the relative total annual cost of various speed limits to the annual total cost for the base case were compared. At the high end of the range of chosen speeds (i.e. around 200 km/h), the total cost curve levelled-out and began to decrease. Speeds higher than 200 km/h were unrealistic to consider.

(iii) The Annual Net Benefits of Changing the Mean Speed of Traffic for the Base Case

Positive net benefits were obtained when the mean speed of traffic for the base case was changed to higher values, and the opposite happened when it was lowered. The positive net benefits were smaller in their absolute magnitude than the net benefits at lower speeds. The positive net benefits tended to decrease as the speed increased. The benefits might have reduced to zero (i.e. the total cost of the base case) at a mean speed of traffic higher than 200 km/h but it was not practical to consider such a speed. These results were obtained assuming the accident cost for the base case were the same as for other mean speeds of traffic.

5.12.3 The NPV of the Cost-Benefit Analysis for the Economic Assessment Period 1994-2003

(i) The Base Case

The NPV of the total cost of the base case was £6.70 millions. The travel-time cost and the VOC represented, almost, an equal share of the total cost whereas the accident cost represented only 5 per cent of the total cost (see Figure 5.5a). The non-fuel element cost formed less than two-thirds of the VOC (see Figure 5.5b). In other words, the overall picture was similar to the result of the cost-benefit analysis for the year 1994. The results were similar for both high and low economic growth, except that for high economic growth the cost of the fuel-element within the VOC dropped (see Figure 5.6b) because it was assumed that, even though the fuel price would increase, the cost of fuel would decrease in response to more efficient engines and smaller vehicles. This reduction affected the VOC share of the total cost which decreased by 3 per cent (see Figure 5.6a) whereas the shares of travel-time and accident costs increased.

(ii) The Speed Limit Model

The development of the speed limit effect models were described in Chapter Two. Figure 5.7 included, as well, the hypothetical effect of speed limits on the mean speeds of traffic. The change in the mean speed of traffic (km/h) per unit change in the speed limit (km/h) where measured (i.e. the speed limits were converted to mile/h units on the figure). The chosen speed limit effect model was the SPLA. The model demonstrated a change of between 25 per cent and 50 per cent in the mean speed of traffic (km/h) of unit change in the speed limit. The model coincided with earlier cases (Finch et al., 1994). The second model, SPLM, had a more conservative effect.

(iii) The NPV of the Total Cost of Changing the Speed Limit for the Base Case

For low economic growth, the NPV of the travel-time cost decreased as the speed limit increased (see Figure 5.9a). The gradient of decrease was higher at speed limits lower than the speed limit of the base case. The NPV of the non-fuel element of the VOC only showed a slight drop as the speed limit increased (see Figure 5.9b). The NPV of the fuel-element VOC increased sharply relative to the non-fuel element, as the speed limit was increased (Figure 5.9b). The NPV of the VOC increased as the speed limit increased (see Figure 5.9a) due to the increase in the fuel element cost, even though, there was a decrease in the cost of the non-fuel element. The cost curves for travel-time and VOC intersected at a speed limit of approximately 70 mile/h; after that point, the VOC exceeded the cost of travel-time. The NPV of the accident costs remained unchanged due to the assumption that was made about the effect of the mean speed of traffic on the frequency and severity of the PIA. The NPV of the total cost decreased as the speed limit increased which could be explained using the previous discussion. The rate of change was, slightly, higher for speed limits lower than of the speed limit of the base case (see Figures 5.8a and 5.8b).

For high economic growth, similar characteristics were observed except for some differences in the absolute magnitudes of costs (see Figures 5.10a, 5.10b, 5.11a, and 5.11b). The curves of the NPV of the travel-time cost and VOC intersected at a speed limit of approximately 95 mile/h, which was higher than the one for low economic growth. The difference was due to a lower NPV for the fuel element of the VOC for high economic growth.

(iv) The NPV of the Net Benefits of Changing the Speed Limit of The Base Case

There were positive NPVs of the net benefits when the speed limit of the base case was increased and negative benefits when the speed limit of the base case was decreased (i.e. assuming the frequency and the severity of PIA were constant) (see Figure 5.12a). The rate of change of the NPV for the positive net benefits was smaller than the rate of change of the NPV for the negative net benefits. There were higher net benefits (i.e. both positive and negative) for high economic growth because the value of the travel-time and accident costs increased, even though, the VOC decreased (see Figure 5.12b).

5.12.4 The Uncertainty of the Effect of Changing the Speed Limit of the Base Case on the Frequency and Severity of PIA

Figures 5.13a and 5.13b illustrated the relationship between the NPV of the net benefits derived from changing the frequency of the PIA and the FI casualties per average PIA for the base case. As expected an increase in the frequency of the PIA and the FI casualties per the average PIA led to a decrease in the NPV of the net benefits of accident cost and vice versa. It was worthwhile noticing that when there was a reduction in the number of PIA representing -100 per cent this could mean a situation where there were no accidents and clearly represented the maximum, theoretical, possible reduction. Practically, this no accident situation was meaningless. The same argument stood true for the reduction in the FI casualties per average PIA. When changes in the FI casualties per average PIA was determined, the slight and serious injury casualties per average PIA had to be changed, as well; nevertheless, due to their insignificant contributions to the total accident cost compared to the contribution from the FI casualties per average PIA, the slight and serious injury casualties per average PIA were kept unchanged. The changes needed in the frequency of the PIA and the number of FI casualties per average PIA to offset the NPV of the net benefits produced from changing the speed limit of the base case were determined and shown in Table 5.3a. If, for example, the speed limit of the base case was increased to 90 mile/h, to offset the positive net benefits that would be produced by increasing the speed limit, the PIAs and the FI casualties per average PIA for the base case would have to increase by one of the following possible

PIA for the base case would have to increase by one of the following possible combinations (i.e. to produce 'break-even point') (i.e.Δ:change): 65.9% ΔPIA and 0% ΔFI, 57.9% ΔPIA and 10% ΔFI, 43.9% ΔPIA and 30% ΔFI, 31.7% ΔPIA and 50% ΔFI, 21.3% ΔPIA and 70% ΔFI, or 9.8% ΔPIA and 100 ΔFI (i.e. was not realistic because it meant no fatal injury accidents happened at this stage). Table 5.3b was produced to convert the changes in the number of PIA and FI casualties per average PIA to changes in the number of PIAs and FI casualties per average PIA per unit change in the mean speed (MS) of traffic. The required changes in the number of PIA and FI casualties per average PIA per unit change in the mean speed (MS) of traffic to offset the NPV of the net benefits of changing the speed limit of the base case to 90 mile/h were the following (i.e. Δ: change): 5.6% ΔPIA/ΔMS and 0% ΔFI/ΔMS, 4.9% ΔPIA/ΔMS and 0.82% ΔFI/ΔMS, 3.7% ΔPIA/ΔMS and 2.6% ΔFI/ΔMS, 2.7% ΔPIA/ΔMS and 4.3% ΔFI/ΔMS, 1.8% ΔPIA/ΔMS and 6.0% ΔFI/ΔMS, or 0.8% ΔPIA/ΔMS and 8.5% ΔFI/ΔMS (i.e. this was not realistic because it implied that there would be no fatal injury accident).

To judge the significance of these figures they had to be compared to reference cases. The problem in the first place was that there had been no firm evidence on the effect of changing the mean speeds of traffic on the frequency and severity of personal injury accident. Three cases were reviewed and summarised, bearing in mind all the limitations of the findings, and the reliability and compatibility of the data for comparison purposes.

The changes in the number of the PIA and fatal injury casualties in the U.K. case were higher than the changes in the frequency of PIAs and fatal injury casualties in U.S.A case. The study by Finch. et al. only produced the expected change in the frequency of PIAs which was, almost, midway between the two previous cases. There was no consistency in the outcomes. One reason to explain the difference in the U.K. rate was that there was no speed limit before the introduction of the 70 mile/h whereas in the U.S.A case there were different speed limits imposed before changing it to a 55 mile/h speed limit. It was important to understand the limitations of the results published from these previous cases. In order to be able to compare these observations some assumptions were made; for example they could be used to predict the effect of increasing and decreasing the speed limit, the changes behaved linearly regardless of the frequency and severity of PIAs for the base case. In determining these values many average values were considered, and there were additional assumptions and precautions noted in the sources from which these figures were obtained. If the figures for the three cases were used as a guideline to establish reasonable rates of change in Table 5.3b, the following would be noticed:

(i) if the change in the frequency of PIAs only was considered assuming no change in the severity (i.e. no change in the FI casualties per average PIA), the NPV of the net benefits derived from changing the speed limit of the base case could not be offset by changes in the frequency of the PIAs, only ;

(ii) the NPV of the net benefits of smaller changes in the speed limit of the base case (e.g. ± ten mile/h) was more difficult to offset by changes in the frequency and severity of PIA due to the small changes in the mean speed of traffic;

(iii) there were fewer possible changes in the frequency and severity of PIAs that would offset the positive NPV of the net benefits from increasing the speed limit of the base case compared to the negative NPV of the net benefits of decreasing the speed limit of the base case by the same amount;

(iv) if the changes in the frequency of PIAs and the fatal injury casualties of the U.K. case were adopted as the maximum possible changes in order to obtain a break-even point, the following results were obtained:

- to offset the positive NPV of the net benefits of changing the speed limit of the base case to 100 mile/h the frequency of PIAs and the FI casualties per average PIA for the base case had to increase by 60 per cent and 30 per cent, 47.6 per cent and 50 per cent, or 37.8 per cent and 70 per cent, respectively;
- to offset the positive NPV of the net benefits of changing the speed limit of the base case to 90 mile/h, the frequency of PIAs and the FI casualties per average PIA for the base case had to increase by either 31.7 per cent and 50 per cent or 21.3 per cent and 70 per cent, respectively;
- to offset the positive NPV of the net benefits of changing the speed limit of the base case to 80 mile/h, the frequency of PIAs and the FI casualties per average PIA for the base case had to increase by 19.5 per cent and 30 per cent respectively;
- to offset the negative NPV of the net benefits of changing the speed limit of the base case to 60 mile/h, the frequency of PIAs and the FI casualties per average PIA for

the base case had to drop. The amount of the reduction needed in the frequency and severity was more than the maximum guideline in this case; and

- to offset the negative NPV of the net benefits of changing the speed limit of the base case to 50 mile/h, the frequency of PIAs and the FI casualties per average PIA for the base case had to decrease by 39.6 per cent and 70 per cent respectively.

v) if the changes in the frequency of PIAs and the fatal injury casualties for the U.S.A. case were adopted as the maximum possible changes in order to obtain a break-even point, no changes in the frequency of PIAs and FI casualties per average PIA for the base case would be able to offset the NPV of the net benefits.

The two cases that were considered above took place more than twenty years ago and there validity for today would be questioned. It was believed that due to vast changes in aspects like: road design, driver training, vehicle design (especially safety features), and safety education since that time, no dramatic changes in the frequency and severity of PIA would be expected. The improvements in the safety that was encountered in the U.K. case when the speed limit was imposed was not believed to be applicable to the existing situation because of the vast differences in frequency and severity of PIA before imposing the speed limit in 1965, when there was no speed limit was imposed, and the base case. The U.S.A. case, being relatively more recent and taking into consideration that there were speed limits before imposing the 55 mile/h maximum speed limit, would be a more valid case to use for the comparison, though, the justification of any changes in the safety of traffic though a direct comparison would be debateable.

5.13 Conclusions

The results of the cost-benefit analysis revealed that a negative NPV would be expected for the net benefits if the speed limit of the base case was lowered and that the opposite would be expected if the speed limit of the base case was increased assuming that both the frequency and severity of personal injury accident would not change. The rate of increase of the NPV of negative net benefits was higher than the one for the NPV of positive net benefits. The assumption that the cost of PIAs were constant at various speed limits could have affected the final economic assessment. The 'break-even' analysis that was performed revealed that a change in the accident cost due to changes in the speed limit of the base case would have affected the final result of the economic assessment but, most probably, it would not have changed the sign of the NPV of the net benefits from lowering the speed limit of the base case, however, when the speed limit of the base case was increased the conclusion was more cautious, even though, any change in the sign of the NPV of the net benefits would still be less likely.

The travel-time cost played a major role in determining the NPV of net benefits which were derived from changing the existing speed limit. This should not be a surprise as shortening the journey time was a quest for mankind since the beginning of history. Lowering the speed limit would work in the opposite direction of this instinct. The large share of travel-time cost in the total cost is a natural reflection of this fact.

The decision making process of the appropriate speed limit should not be confined to a single viewpoint (e.g. improving road traffic safety or saving energy). A more comprehensive attitude should be adopted towards such decisions. This study was an attempt to achieve this goal which brought most of the consequences of changing speed limits to a common ground.

Though the conclusion was inclined to the opinion that positive net benefits would occur if the speed limit was increased, this conclusion should not overshadow other factors in the decision making process when deciding the level of a particular speed limit such as political considerations (e.g. the reaction of the public), safety considerations (e.g. the 'spill-over' effect on other types of road), social considerations (e.g. the image of 'fast' drivers), energy considerations (e.g. the global situation of energy supplies), economic considerations (e.g. the effect on the motor industry), environmental considerations (e.g. alternative fuels in the long run), and transportation considerations (e.g. the national transport strategy).

Chapter Six

Sensitivity Analysis Applied to the Variables Used in the Cost-Benefit Analysis

6.1 Introduction

The results of the cost-benefit analysis depended very much on the accuracy of the variables used in the calculation and the validity of the assumptions used in representing the real situation. The cost-benefit analysis that was included in Chapter Five involved many variables and was based on some assumptions. A sensitivity analysis was performed to test the relative contribution of each of the variables and assumptions to the determination of the outcome of the cost-benefit analysis. This chapter discusses the sensitivity analysis and the results that related directly to the effect of changing the speed limit of the base case.

6.2 Sensitivity Analysis

6.2.1 Introduction

"Sensitivity analysis is used to indicate those factors in which a minor variation in value causes a significant variation in the final result. To rank the factors in order of sensitivity, the complete calculation can be repeated with each factor in turn being varied throughout its expected range" (Hills and Prince, 1975). A similar method was used by Hooper and Mullen (1974) in their study on the effect of increased fuel prices on car travel.

6.2.2 Variables Used in the Cost-Benefit Analysis

The variables and assumptions that were examined for their effects on the NPV of the total cost and the NPV of the net benefits derived from changing the speed limit were: travel-time cost, the fuel and non-fuel elements of vehicle operating cost (VOC), the cost of personal injury accidents (PIA), the frequency of personal injury accidents (PIA), the fatal injury (FI) casualties per average PIA, the discount rate, the initial traffic flow in the base year, the traffic growth, the initial mean speed of traffic in the base year, the growth of the mean speed of traffic, the combined effect of traffic growth and the decrease in the mean speed of traffic, the traffic composition, and the effect of the speed limit model on the mean speed of traffic.

6.2.3 Sensitivity Analysis Method

The value of each variable was changed in turn within the expected range of each variable; this meant each variable was changed in steps usually to higher and lower values than the original base case. The cost-benefit analysis calculation, which was explained in Section 5.6, was repeated for each change in each variable and the NPV of the total cost and the NPV of the net benefits derived from changing the speed limit were determined each time. The calculation was done only for low economic growth because the high economic growth was expected to produce similar results. The results were presented for travel-time cost in Figures 6.1a and 6.1b, for the non-fuel element of VOC in Figures 6.2a and 6.2b, for the fuel element of VOC in Figures 6.3a and 6.3b, for VOC in Figures 6.4a and 6.4b, for accident cost in Figures 6.5a and 6.5b, for the effect of the mean speed of traffic on the frequency of PIAs in Figures 6.6a and 6.6b, for the effect of the mean speed of traffic on the number of fatal injury (FI) casualties per average PIA in Figures 6.7a and 6.7b, for the discount rate in Figures 6.8a and 6.8b, for the initial traffic flow in the base year in Figures 6.9a, 6.9b, and 6.c, for the traffic growth in Figures 6.10a, 6.10b, and 6.10c, for the combined effect of traffic growth and the decrease in the mean speed of traffic in Figures 6.11a, 6.11b, and 6.11c, for the initial mean speed of traffic in the base year in Figures 6.12a and 6.12b, for the growth in the mean speed of traffic in Figures 6.13a and 6.13b, for the traffic composition in Figures 6.14a and 6.14b, for the economic growth in Figures 6.15a and 6.15b, and for the effect of speed limits on the mean speed of traffic in Figures 6.16a and 6.16b.

6.2.4 Sensitivity Ratios

For each step in each variable the difference was determined between the NPV of the total cost of the outcome using the revised value of the variable and the NPV of the total cost using the original value of the variable for the base case. The ratio of the difference to the NPV of the total cost of the original value of the variable of the base case was determined and expressed as a percentage. The same procedure was repeated for each step for each variable. For each variable these percentage ratios were then summed and the sum was then divided by the sum of the percentage changes to the variable. The following equation sets this out in algebraic terms:

$$SR_V = \frac{\dfrac{|TC_{+\Delta V} - TC_V| + |TC_{-\Delta V} - TC_V|}{TC_V} \times 100}{P_{+\Delta V} + P_{-\Delta V}}$$

where;

SR_V= sensitivity ratio of variable (V)

$TC_{+\Delta V}$= NPV of total cost for the positive change in the value of the variable (V) (£)

$TC_{-\Delta V}$= NPV of total cost for the negative changes in the value of the variable (V) (£)

TC_V= NPV of total cost using the original value of the variable (V) for the base case (£)

$P_{+\Delta i}$= the percentage of the positive change in the value of the variable (V)

$P_{-\Delta i}$= the percentage of the negative change in the value of the variable (V)

(the results were presented in Tables 6.1a and 6.1b and Figure 6.17)

The sensitivity ratio could be interpreted as a percentage change in the NPV of the total cost of the outcome to a one per cent change in the variable tested. A sensitivity ratio of one was an indicator of the importance of that variable in the cost-benefit analysis as any change in its value would lead the outcome (e.g total cost) to change by the same percentage. As the sensitivity ratio decreased the importance of the variable decreased and vice versa.

Variables that were used in determining the NPV of the net benefits of changing the speed limit of the base case were tested in the same manner. The equation had the following form:

$$SR_V = \frac{\dfrac{|NB_{+\Delta V} - NB_V| + |NB_{-\Delta V} - NB_V|}{NB_V} \times 100}{P_{+\Delta V} + P_{-\Delta V}}$$

where;

SR_V= sensitivity ratio of variable (V)

$NB_{+\Delta V}$= NPV of net benefits for the positive change in the value of the variable (V) (£)

$NB_{-\Delta V}$= NPV of net benefits for the negative change in the value of the variable (V) (£)

NB_V= NPV of net benefits using the original value of the variable (V) for the base case (£)

$P_{+\Delta i}$= the percentage of the positive change in the value of the variable (V)

$P_{-\Delta i}$= the percentage of the negative change in the value of the variable (V)

(the results were presented in Tables 6.2a and 6.2b and Figure 6.18)

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Figure 6.2a: The Effect of Changes in the Non-Fuel Element of VOC on the NPV of the Total Cost as the Speed Limit Varied (low economic growth)

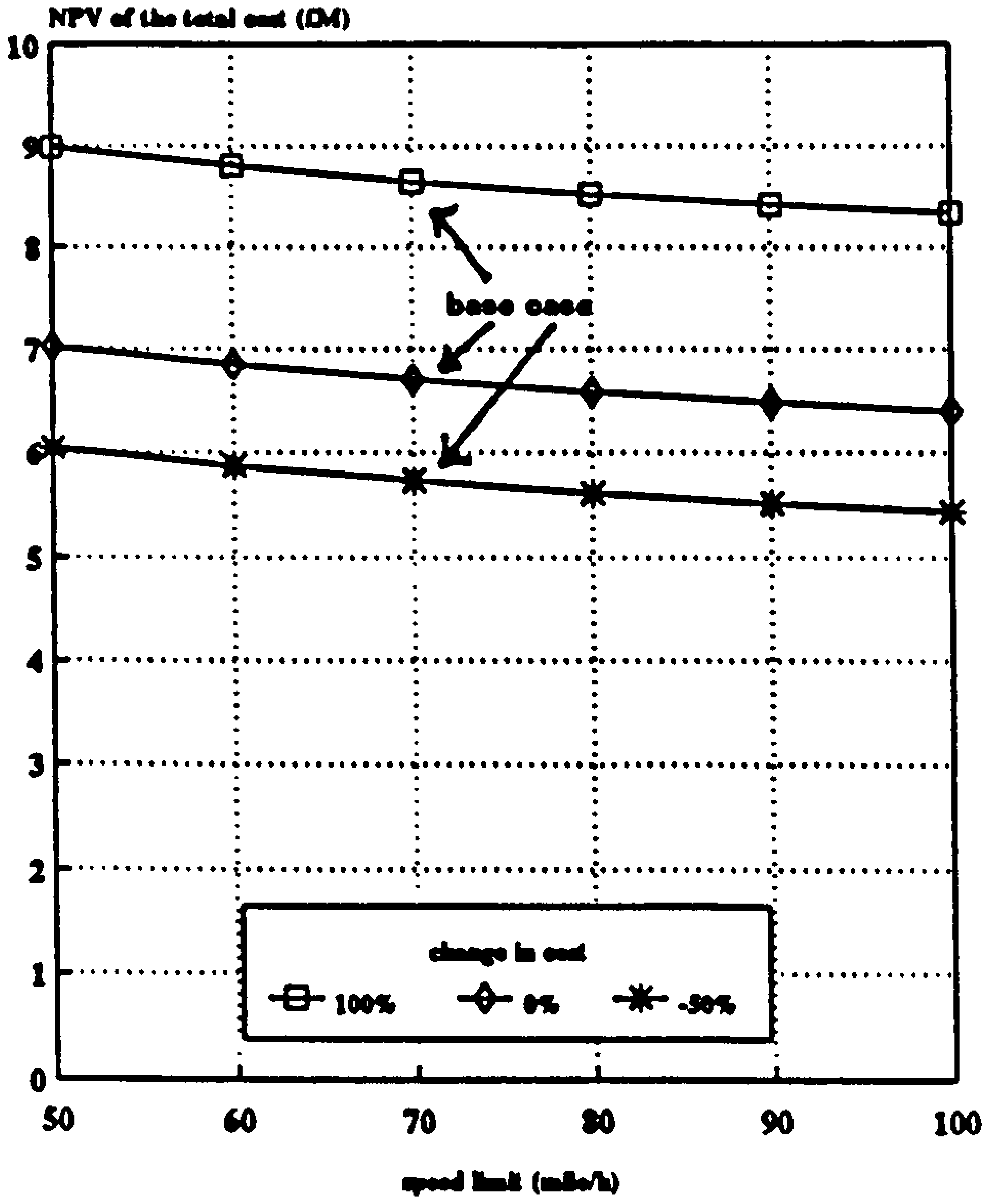


Figure 6.2b: The Effect of Changes in the Non-Fuel Element Cost of the VOC on the NPV of the Net Benefits of Changing the Speed Limit of the Base Case as Speed Limits Varied (low economic growth)

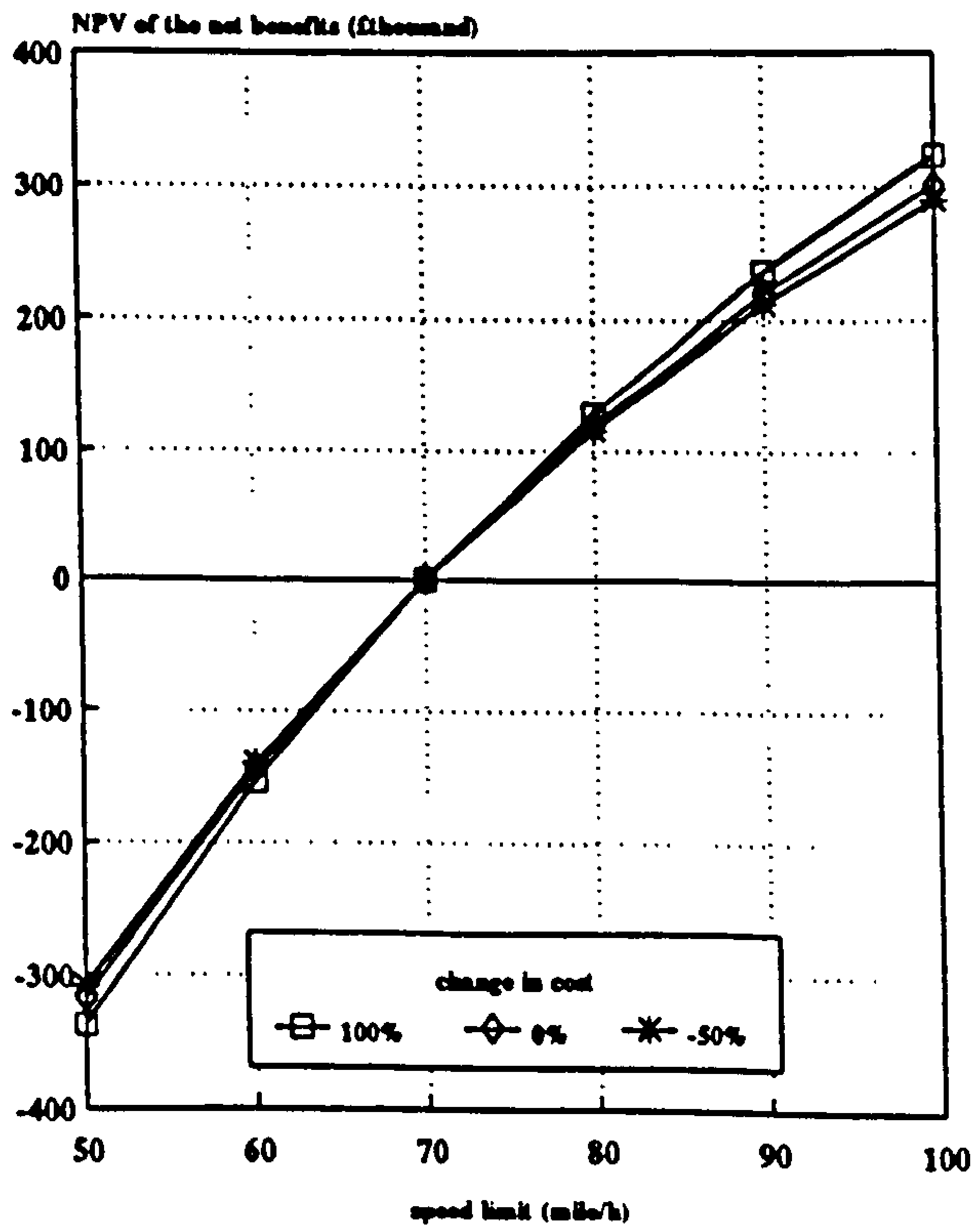


Figure 6.3a: The Effect of Changes in the Fuel Consumption Element of the VOC on the NPV of the Total Cost as the Speed Limit Varied (low economic growth)

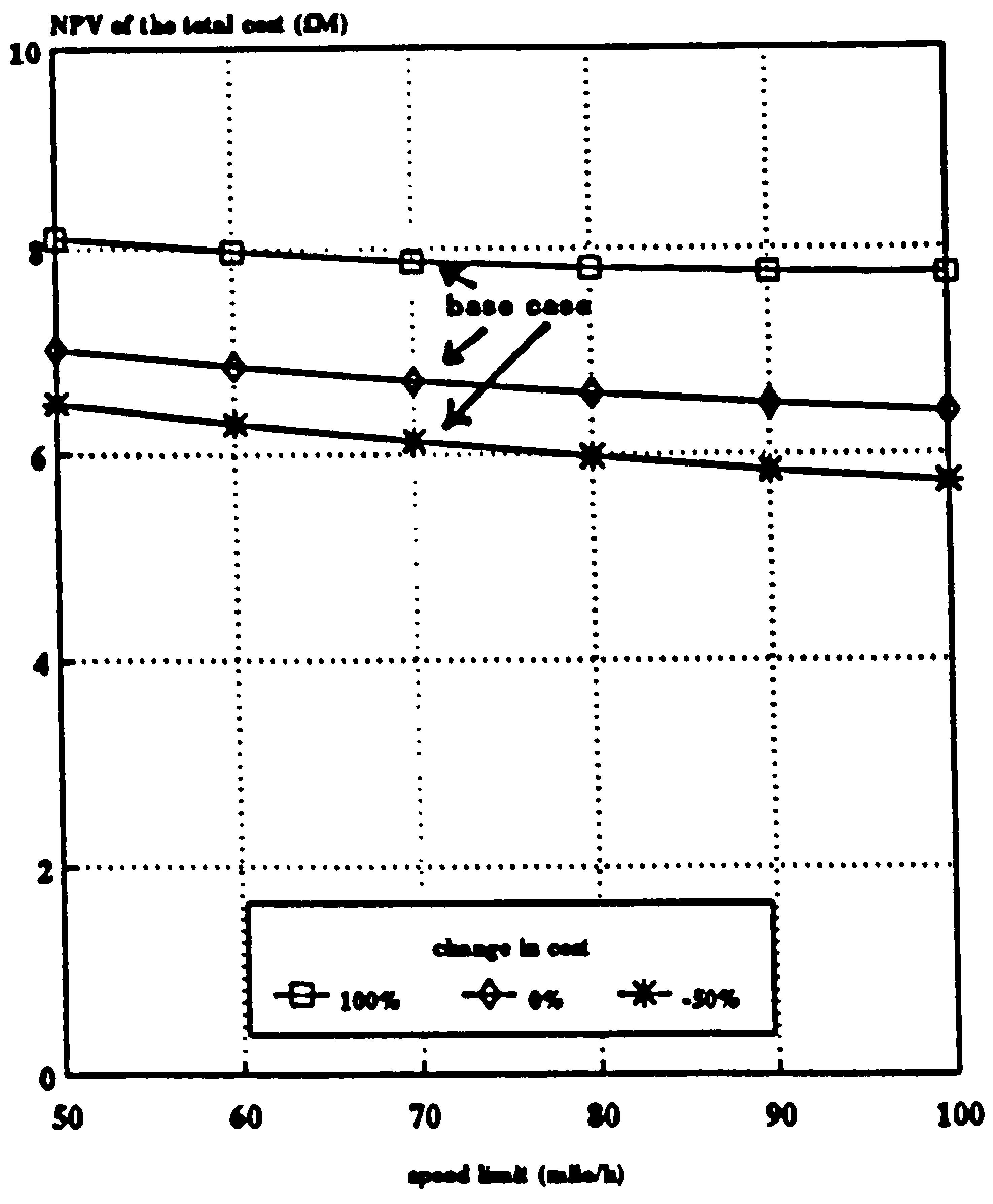


Figure 6.3b: The Effect of Changes in the Fuel Consumption Element of the VOC on the NPV of the Net Benefits as the Speed Limit Varied (low economic growth)

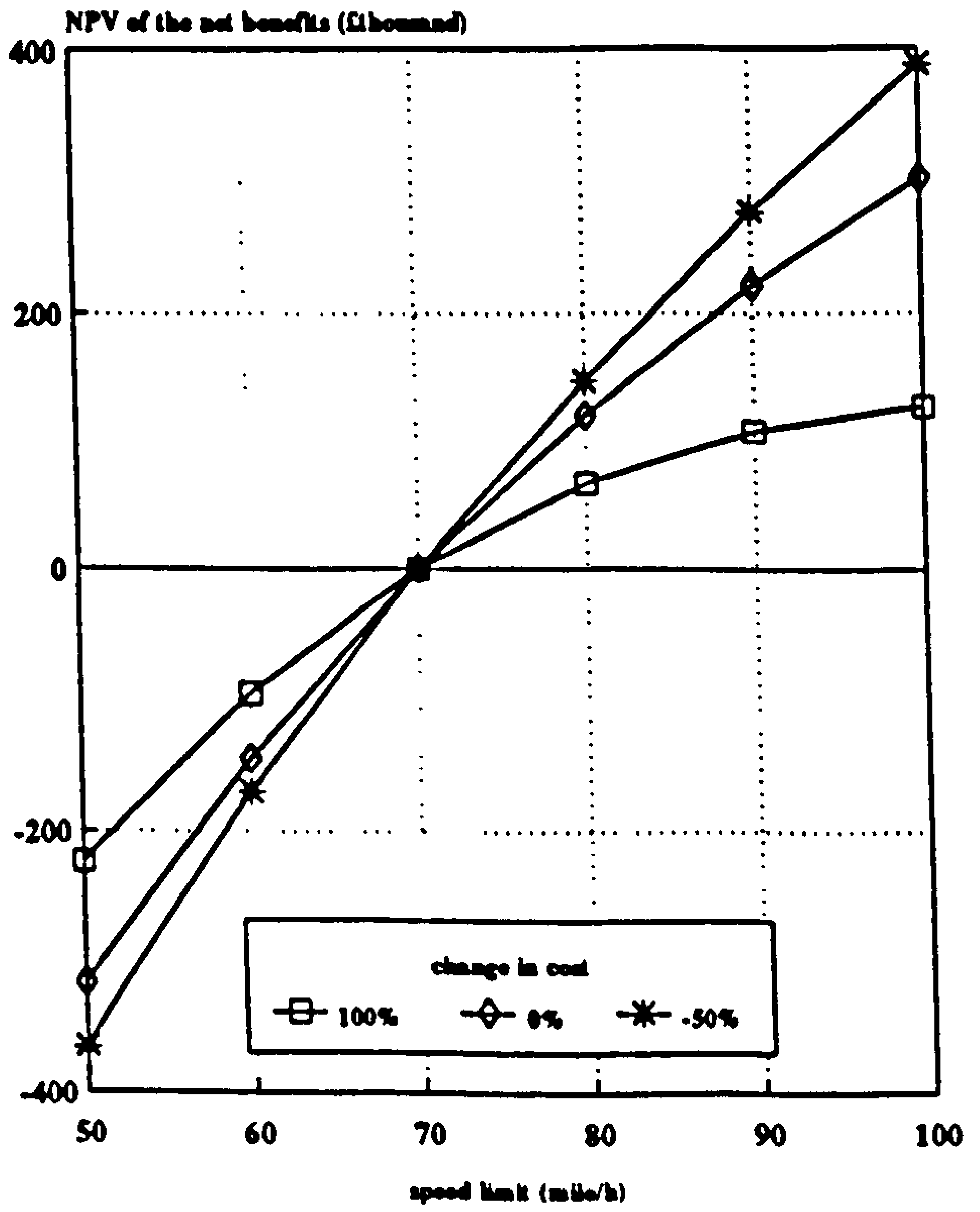


Figure 6.4a: The Effect of Changes in the VOC on the NPV of the Total Cost as the Speed Limit Varied (low economic growth)

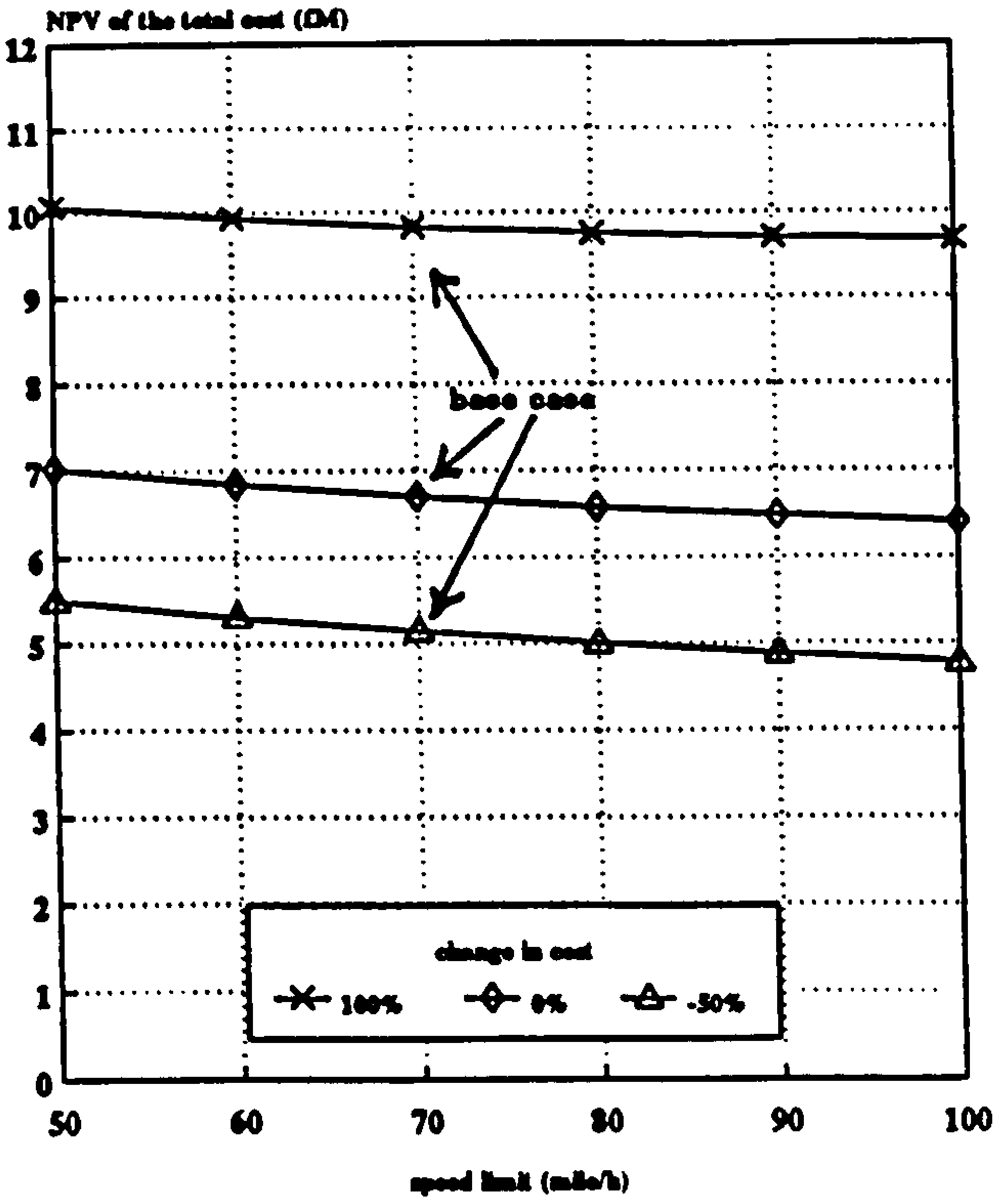


Figure 6.4b: The Effect of Changes in the VOC on the NPV of the Net Benefits as the Speed Limit Varied (low economic growth)

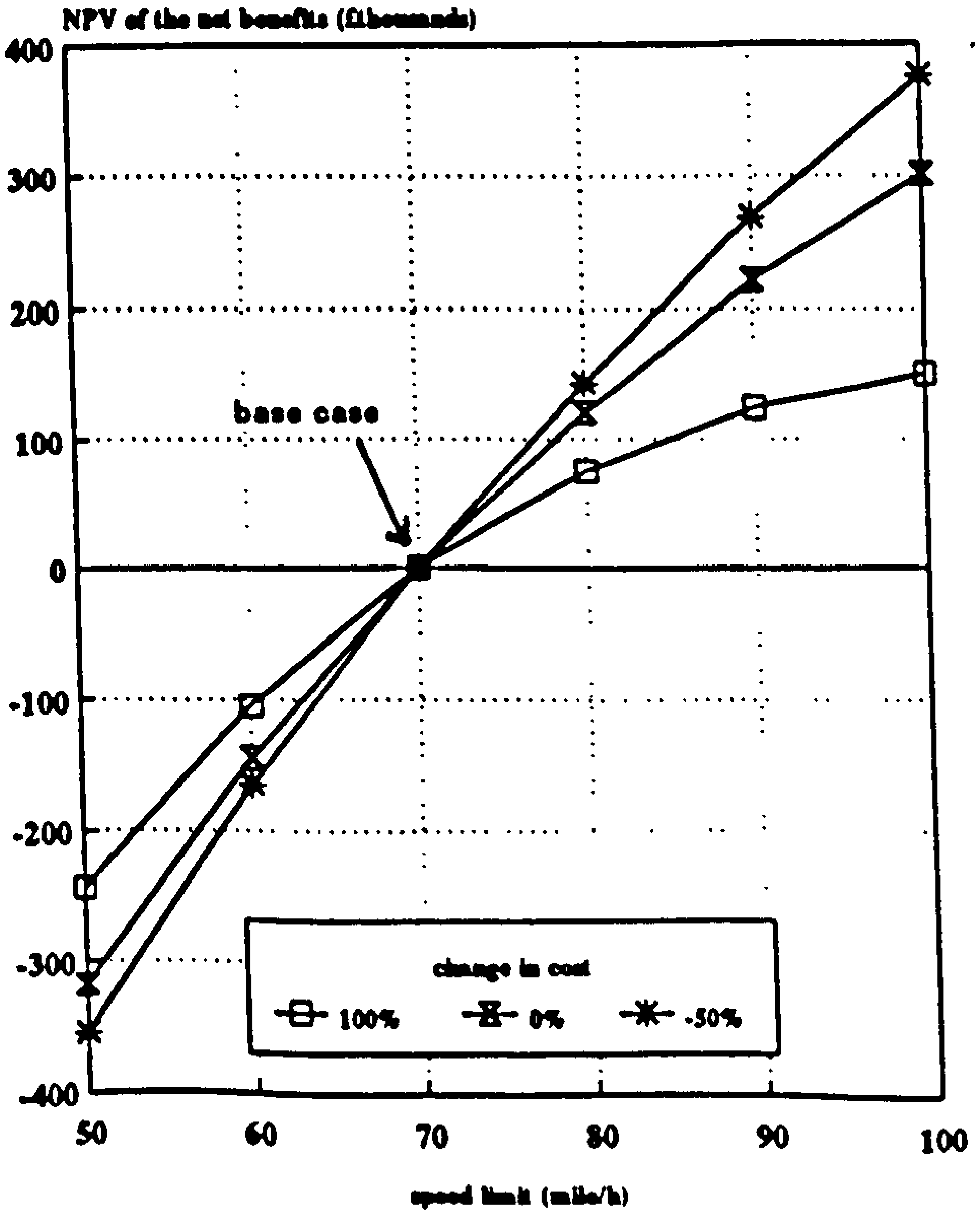


Figure 6.5a: The Effect of Changes in the PIA Cost on the NPV of the Total Cost as the Speed Limit Varied (low economic growth)

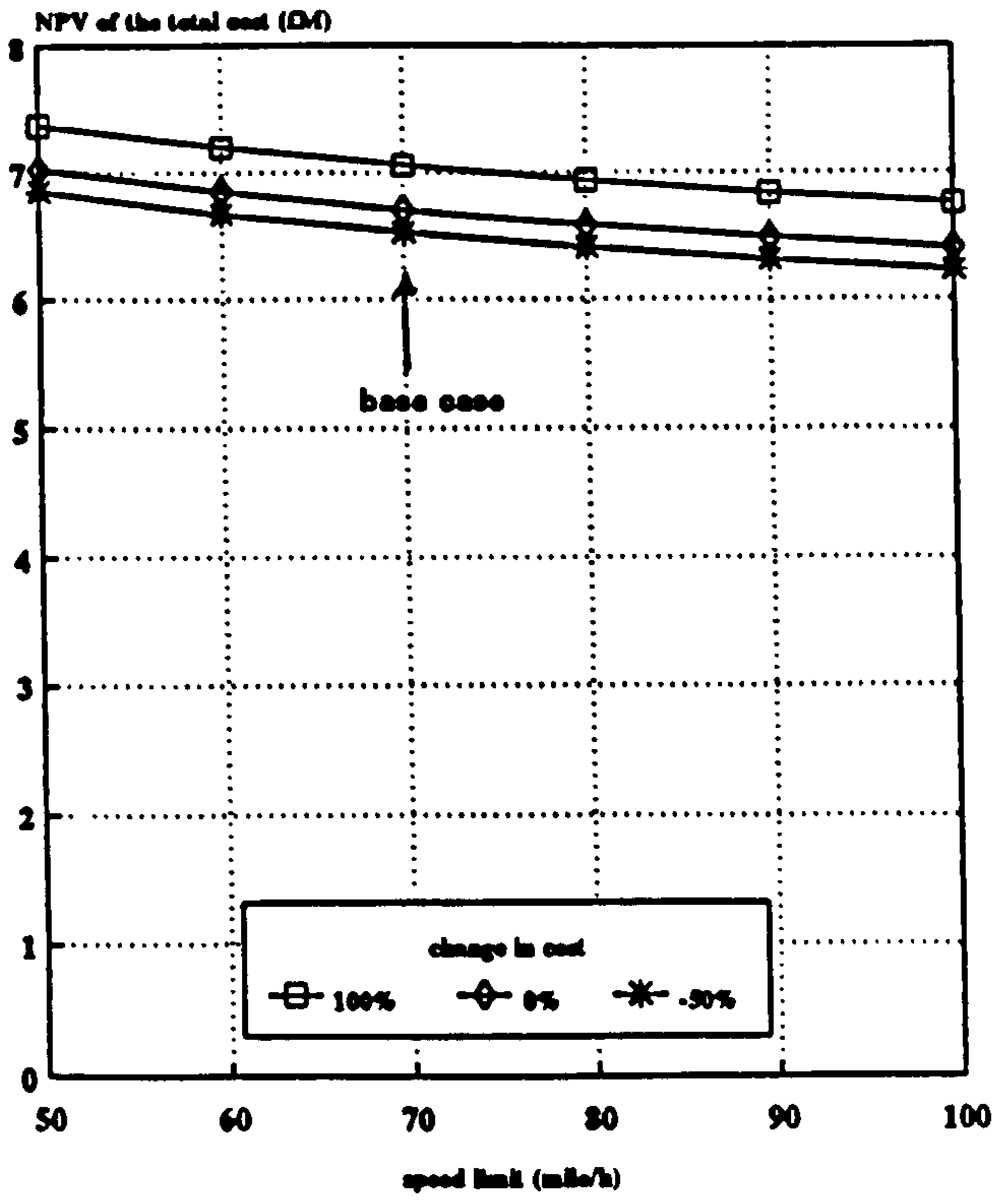


Figure 6.5b: The Effect of Changes in the PIA Cost on the NPV of the Net Benefits as the Speed Limit Varied (low economic growth)

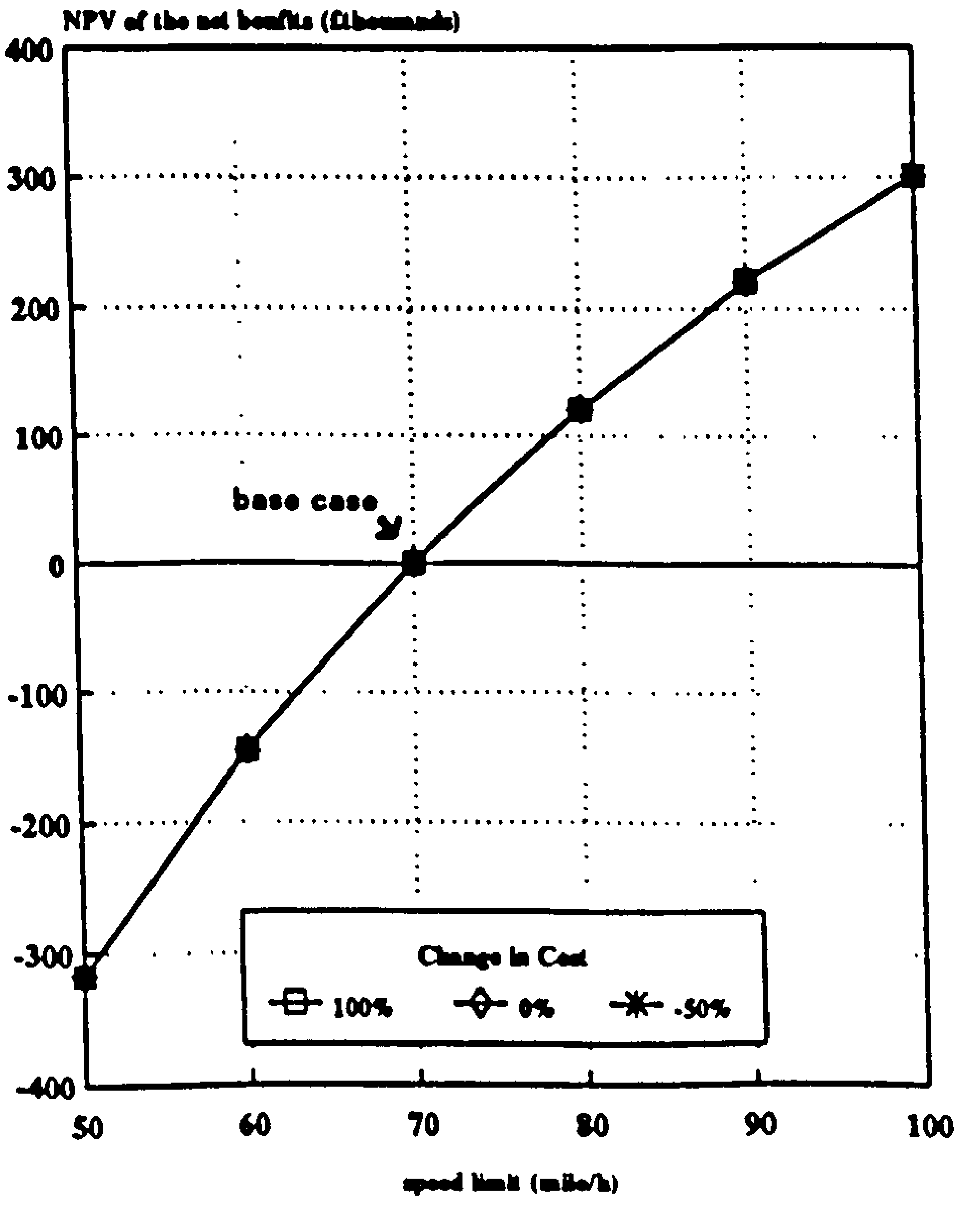


Figure 6.6a: The Effect of Changes in the Frequency of PIAs on the NPV of the Total Cost as the Speed Limit Varied (low economic growth)

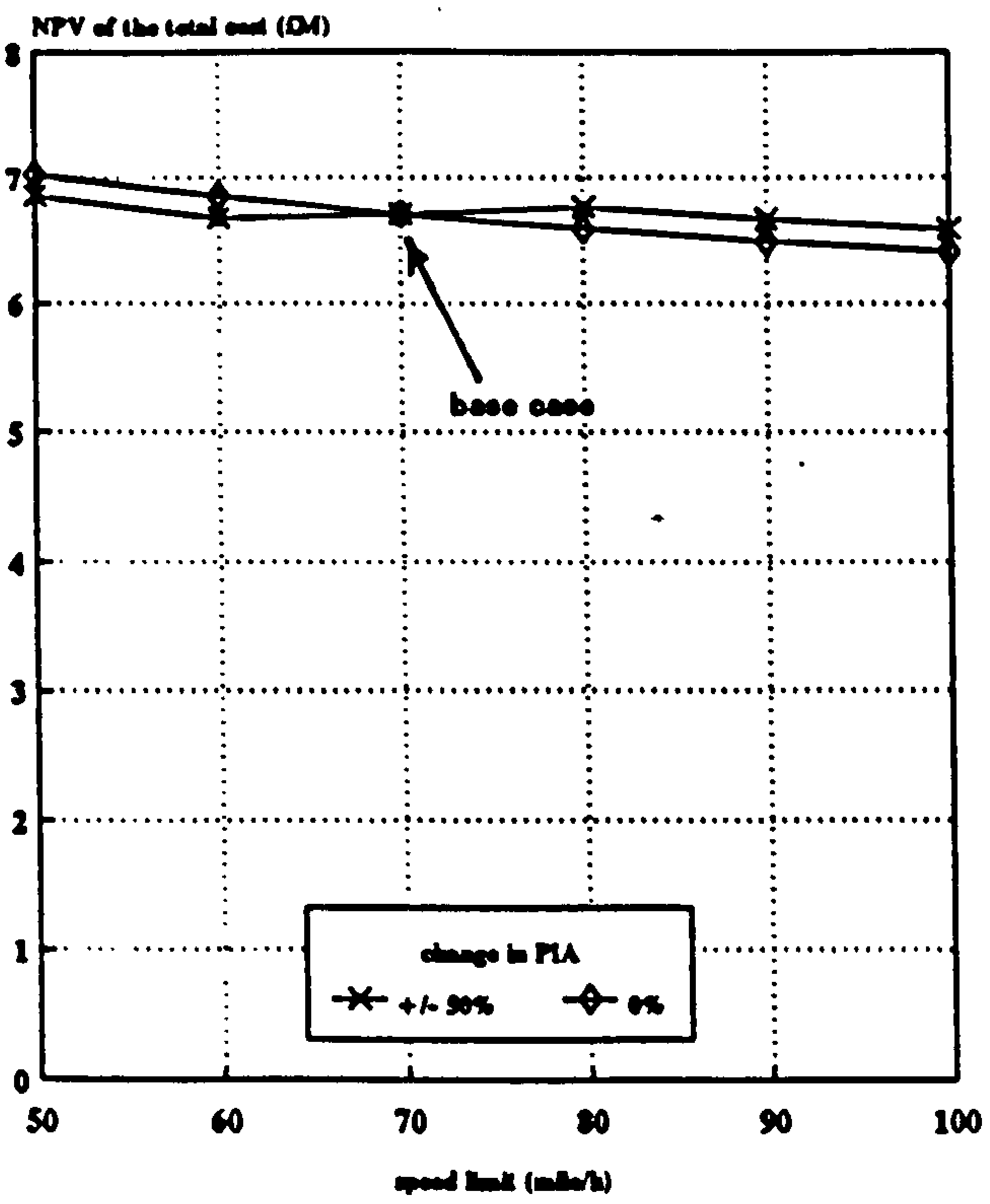


Figure 6.6b: The Effect of Changes in the frequency of PIAs on the NPV of the Net Benefits as the Speed Limit Varied (low economic growth)

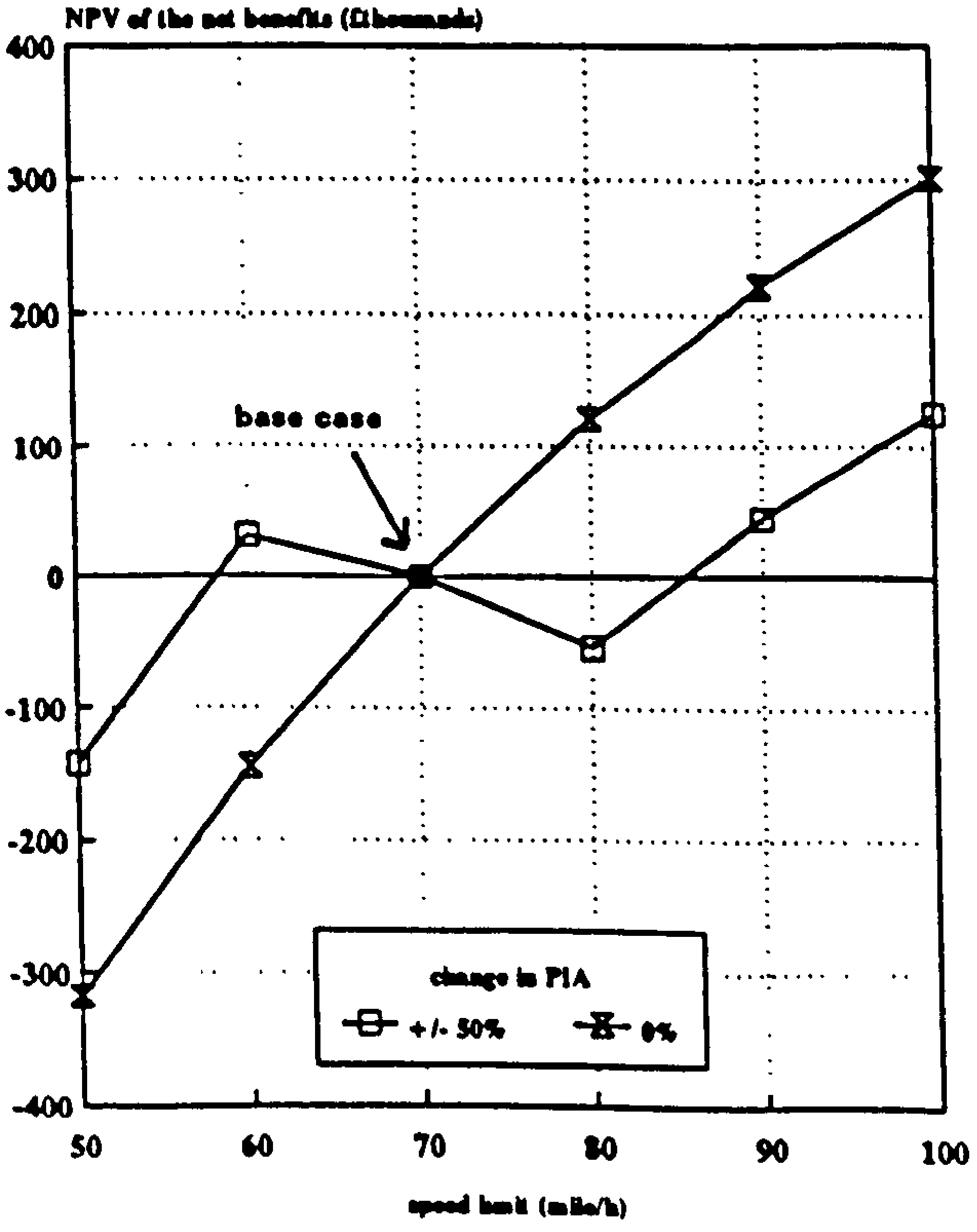


Figure 6.7a: The Effect of Changes in the number of FI Casualties per average PIA on the NPV of the Total Cost as the Speed Limit Varied (low economic growth)

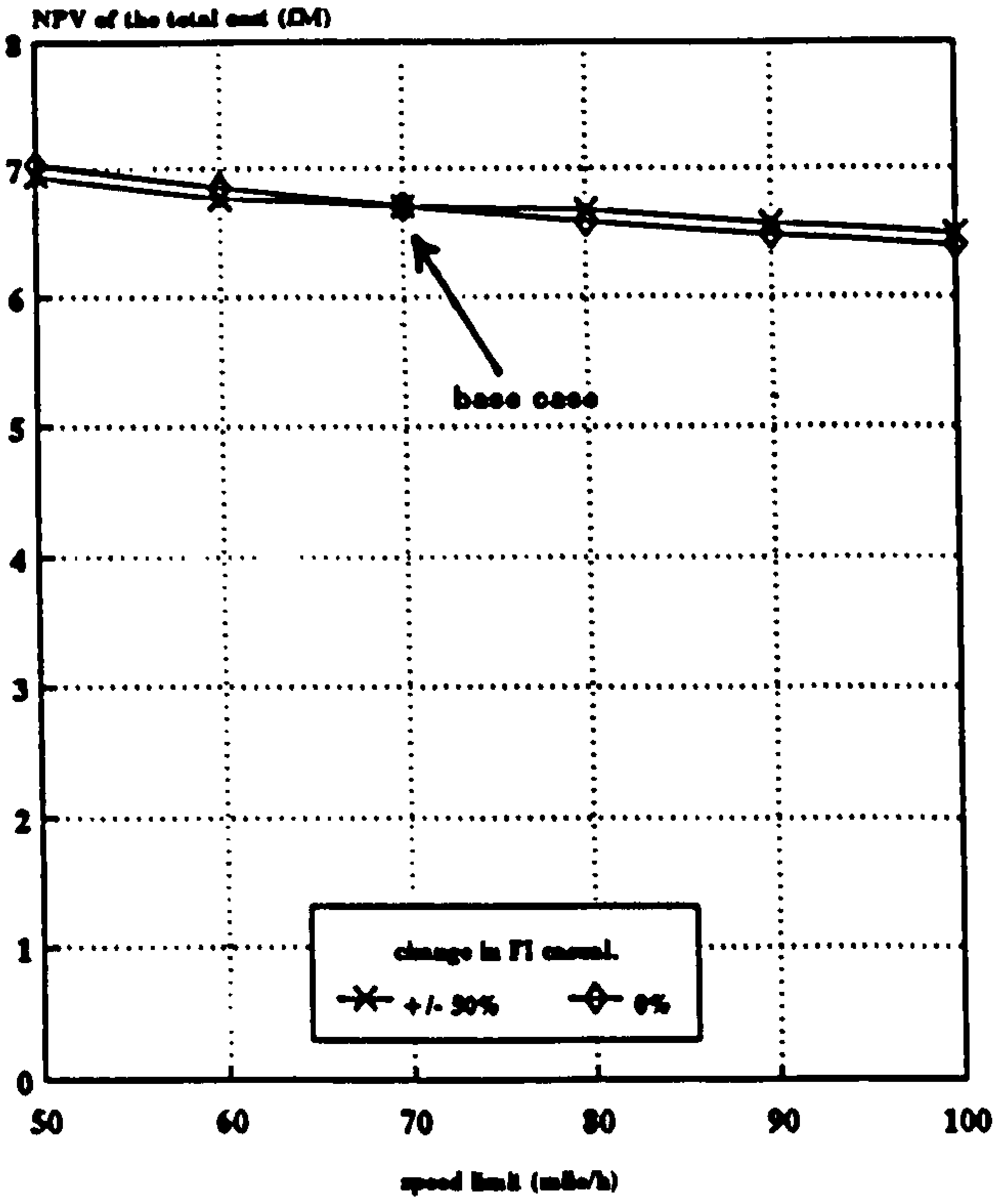


Figure 6.7b: The Effect of Changes in the number of FI Casualties per Average PIA on the NPV of the Net Benefits as the Speed Limit Varied (low economic growth)

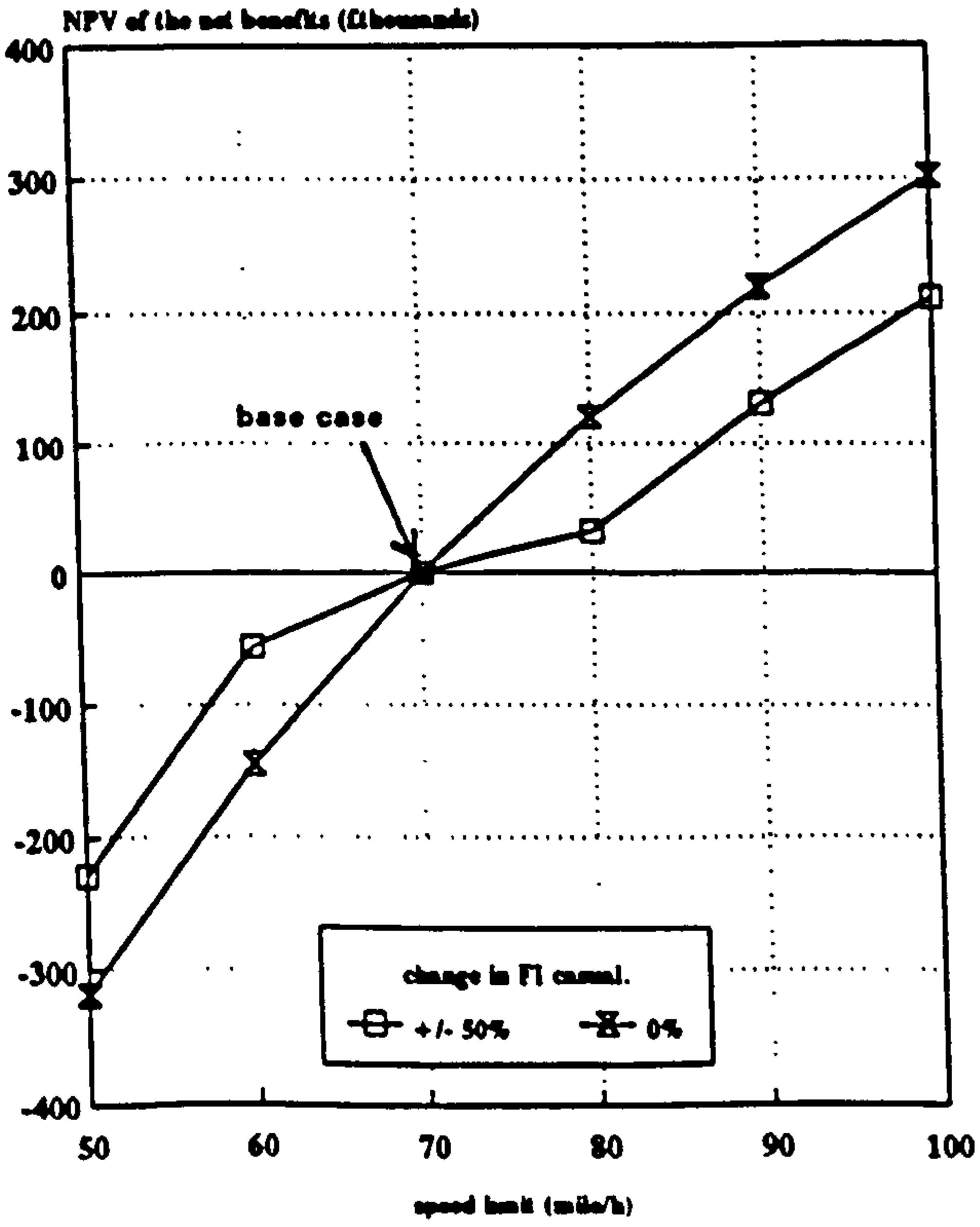


Figure 6.8a: The Effect of Changes in the Discount Rate on the NPV of the Total Cost as the Speed Limit Varied (low economic growth)

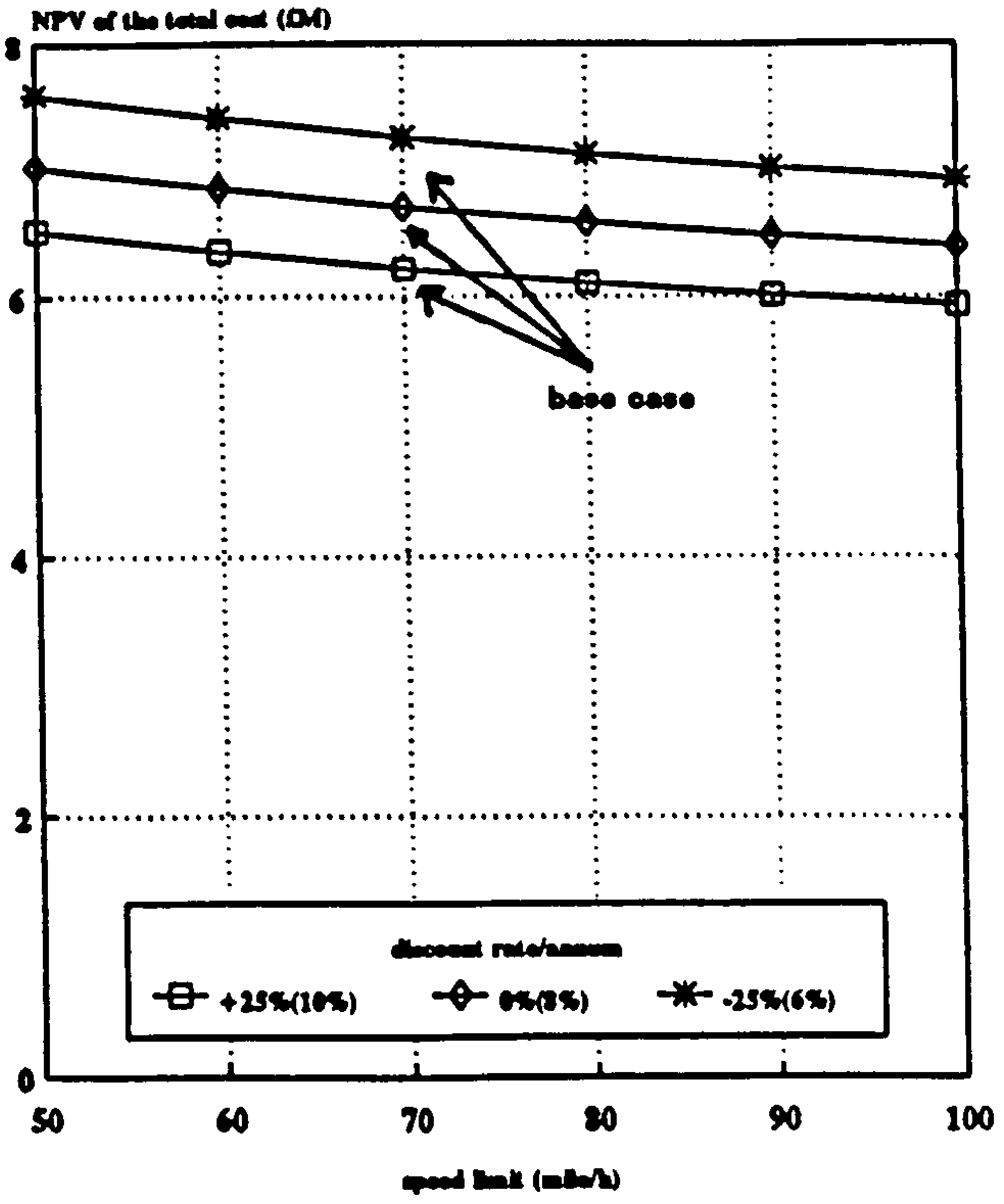


Figure 6.8b: The Effect of Changes in the Discount Rate on the NPV of the Net Benefits as the Speed Limit Varied (low economic growth)

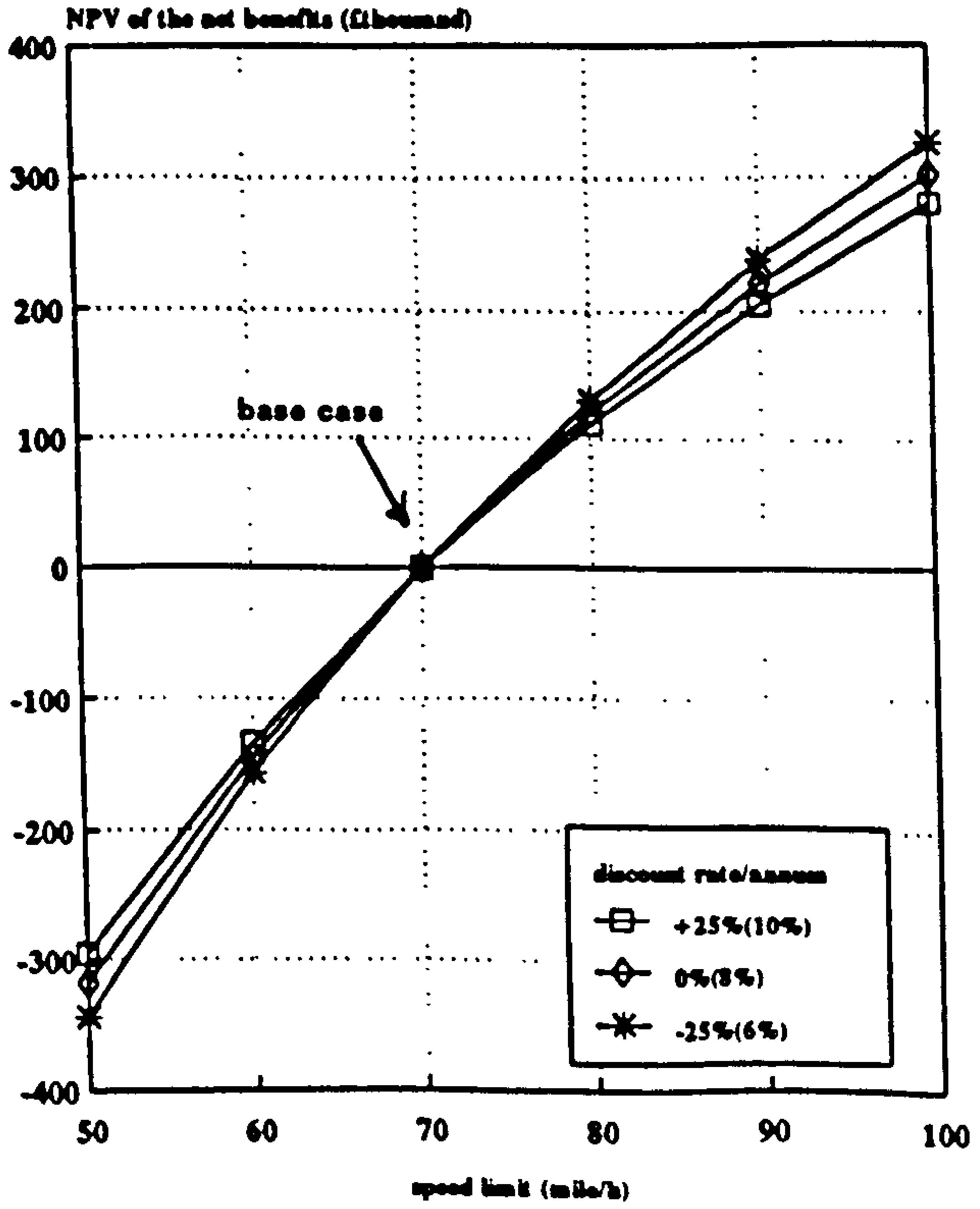


Figure 6.9a: The Effect of Changes in the Initial Daily Traffic Flow in the Base Year on the NPV of the Total Cost as the Speed Limit Varied (low economic growth)

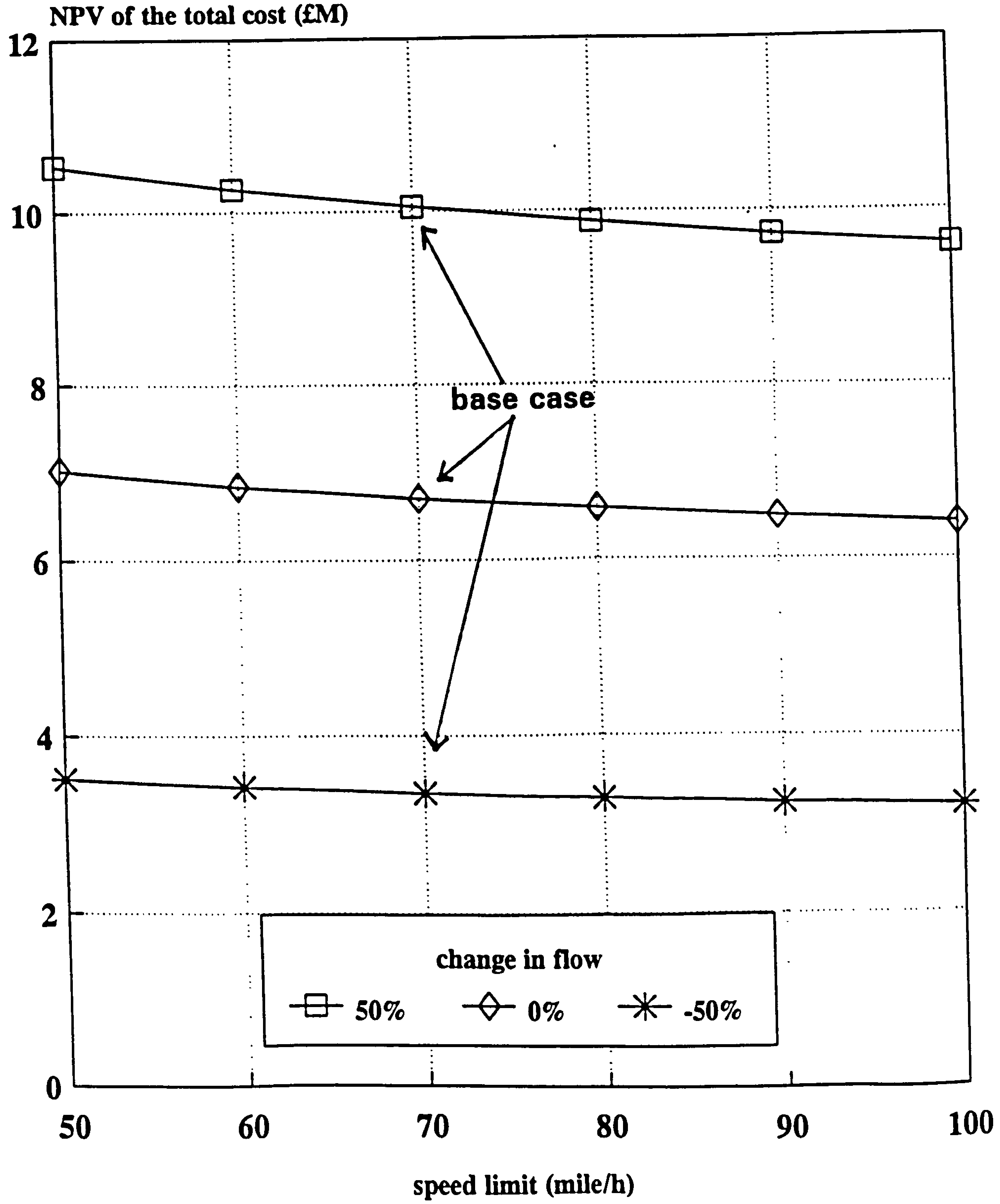


Figure 6.9b: The Effect of Changes in the Initial Daily Traffic Flow in the Base Year on the NPV of the Net Benefits as the Speed Limit Varied (low economic growth)

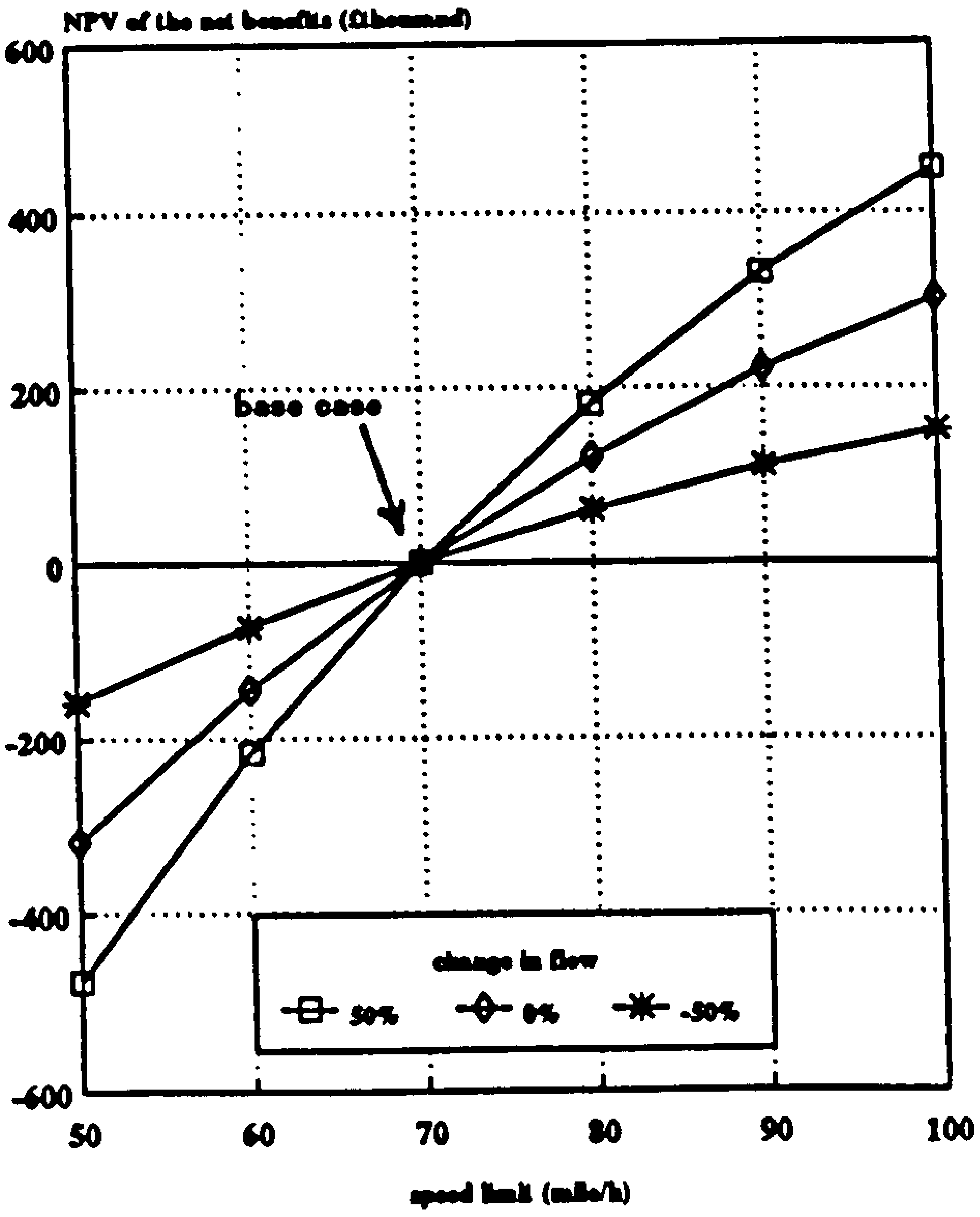


Figure 6.9c: The Effect of Changes in the Initial Daily Traffic Flow in the Base Year on the Ratio of the NPV of the Net Benefits to the NPV of the Total Cost of the Base Case as the Speed Limit Varied (low economic growth)

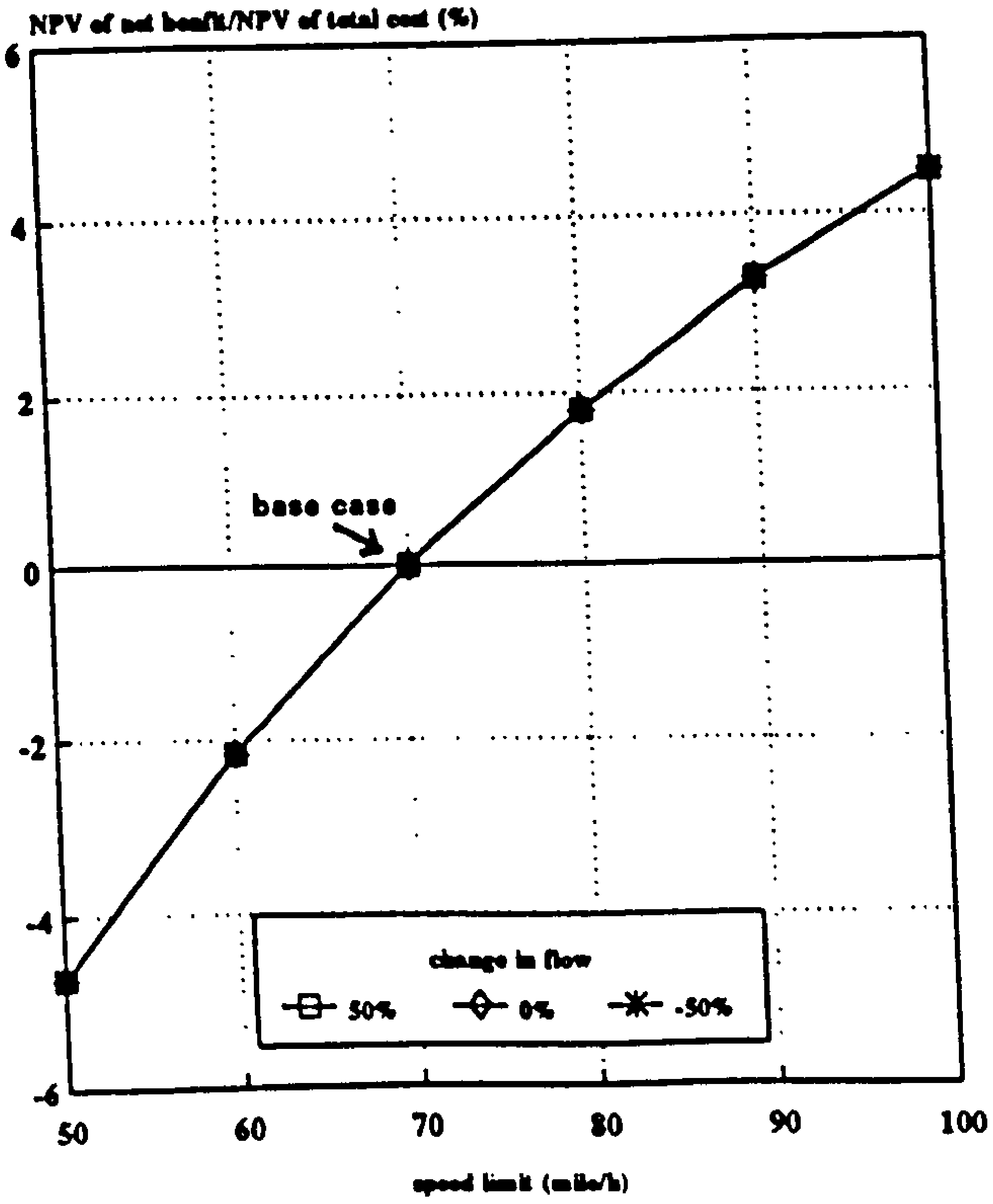


Figure 6.10a: The Effect of Changes in the Annual Traffic Growth on the NPV of the Total Cost as the Speed Limit Varied (low economic growth)

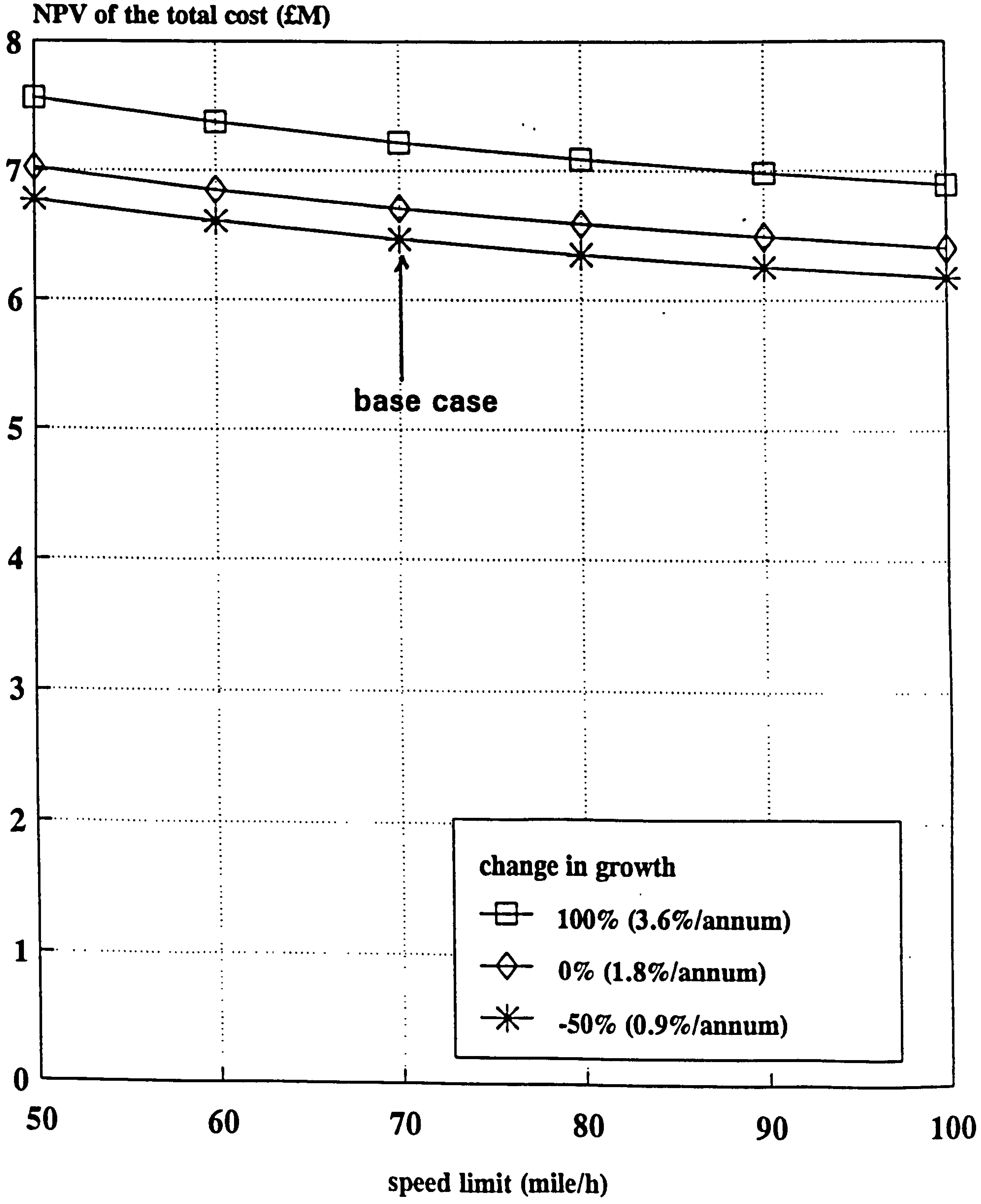


Figure 6.10b: The Effect of Changes in the Annual Traffic Growth on the NPV of the Net Benefits as the Speed Limit Varied (low economic growth)

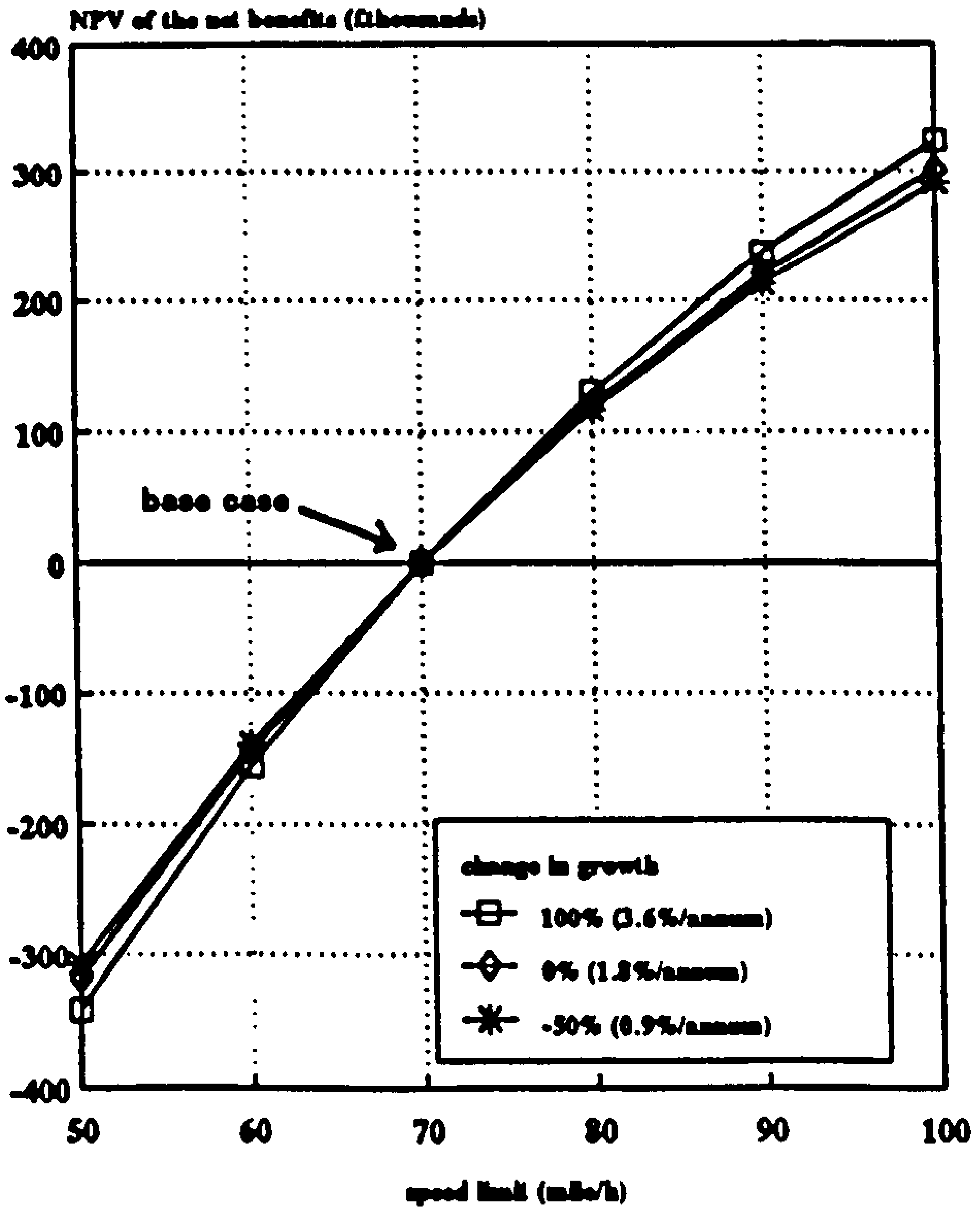


Figure 6.10c: The Effect of Changes in the Annual Traffic Growth on the Ratio of the NPV of the Net Benefits to the NPV of the Total Cost of the Base Case as the Speed Limit Varied (low economic growth)

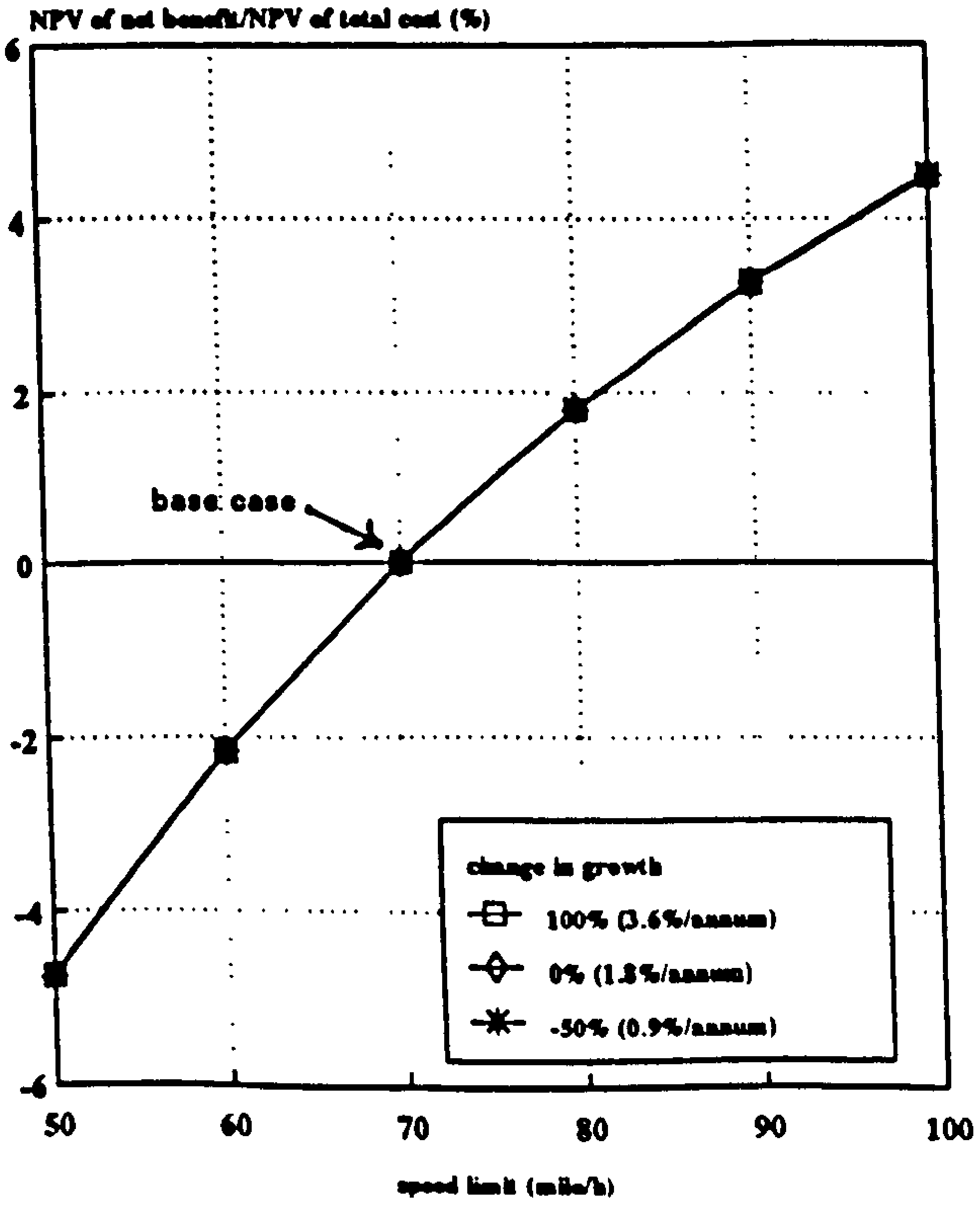


Figure 6.11a: The Effect of Increasing the Annual Traffic Growth with a Corresponding Decline in the Annual Growth of the Mean Speed of Traffic (-5% per annum) on the NPV of the Total Cost as the Speed Limit Varied (low economic growth)

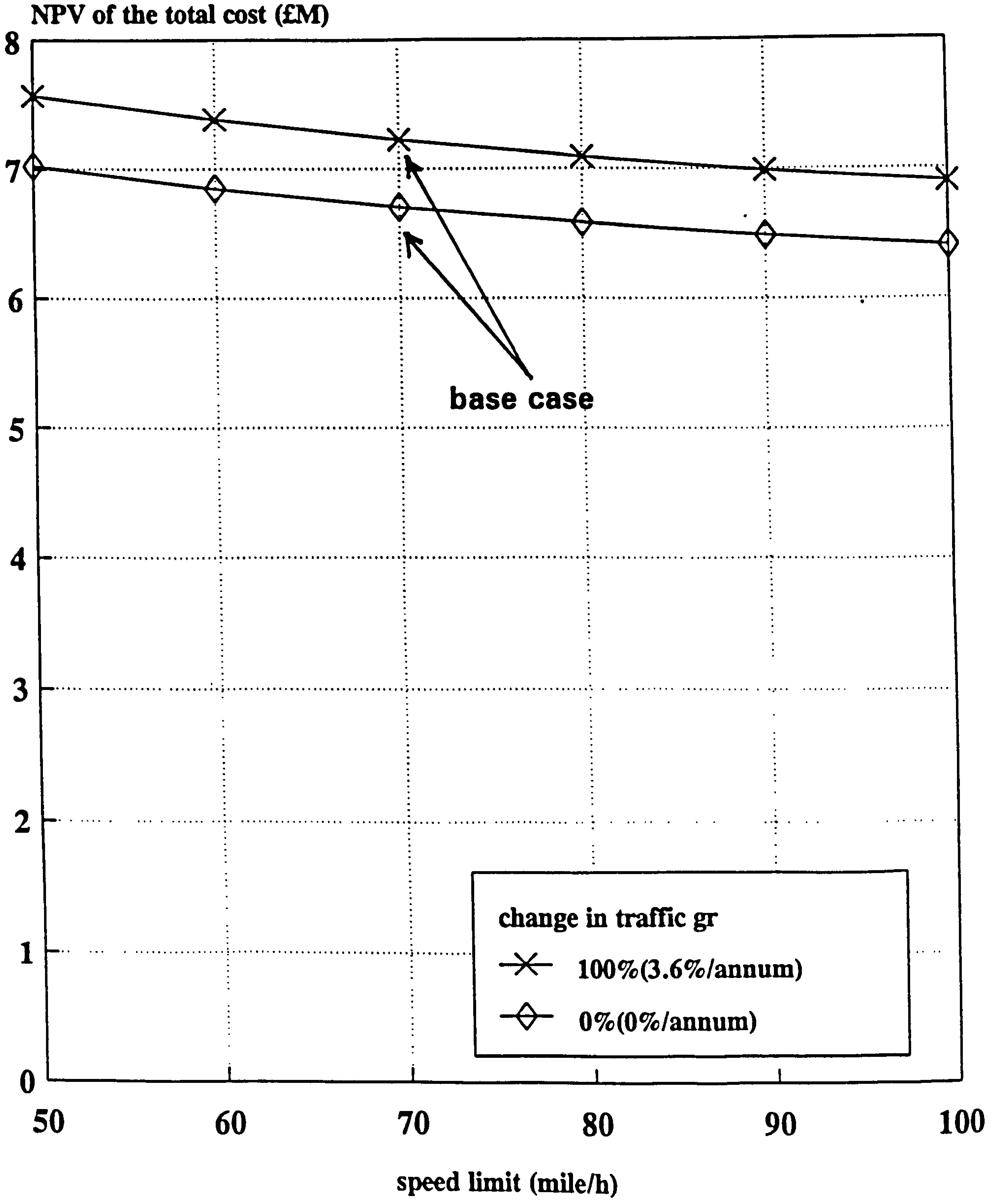


Figure 6.11b: The Effect of Increasing the Annual Traffic Growth with a Corresponding Decline in the Annual Growth of the Mean Speed of Traffic (-5% per annum) on the NPV of the Net Benefits as the Speed Limit Varied (low economic growth)

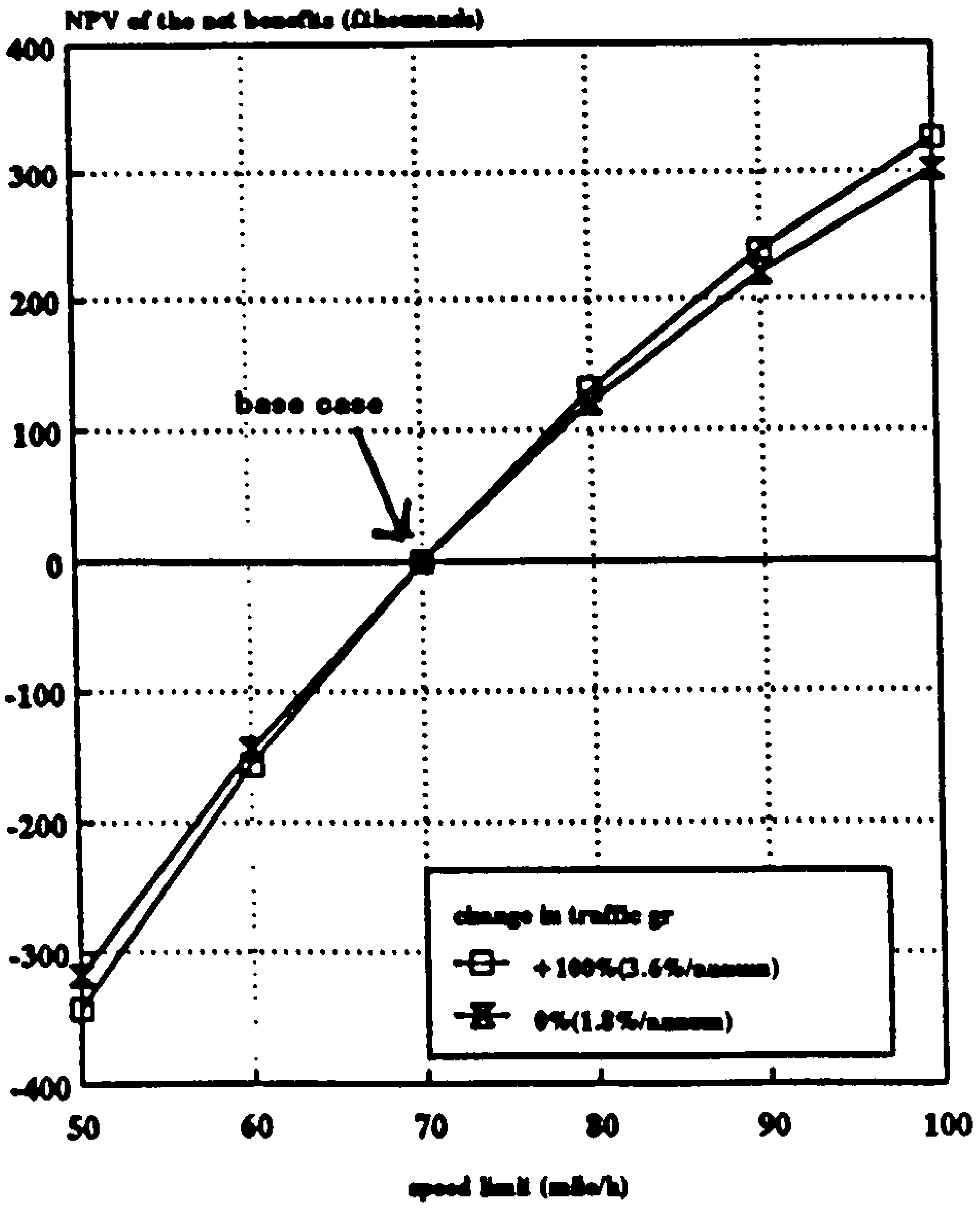


Figure 6.11c: The Effect of Increasing the Annual Traffic Growth with a Corresponding Decline in the Annual Growth of the Mean Speed of Traffic (-5% per annum) on the Ratio of the NPV of the Net Benefits to the NPV of the Total Cost as the Speed Limit Varied (low economic growth)

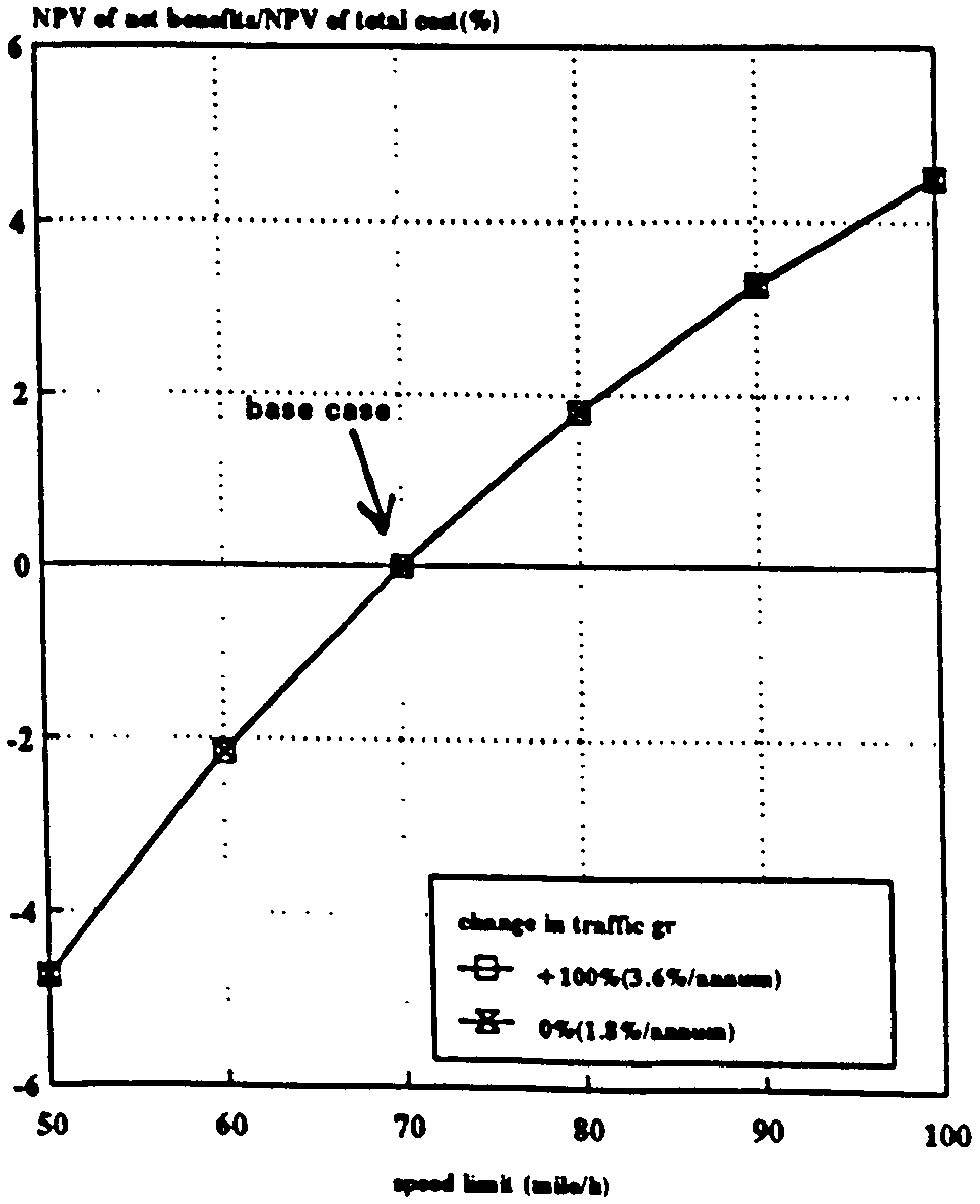


Figure 6.12a: The Effect of Changes in the Initial Mean Speed of Traffic in the Base Year on the NPV of the Total Cost as the Speed Limit Varied (low economic growth)

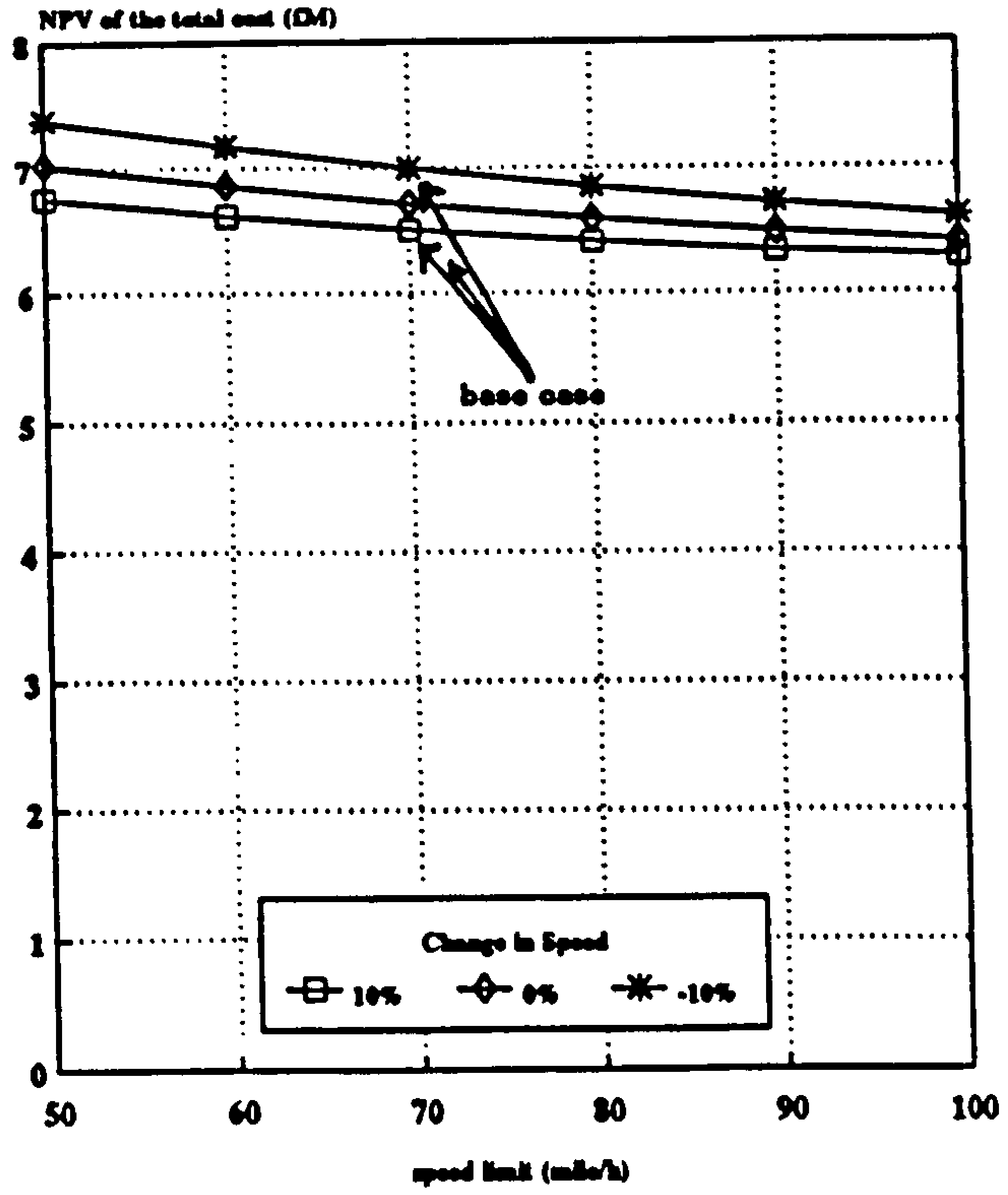


Figure 6.12b: The Effect of Changes in the Initial Mean Speed of Traffic in the Base Year on the NPV of the Net Benefits as the Speed Limit Varied (low economic growth)

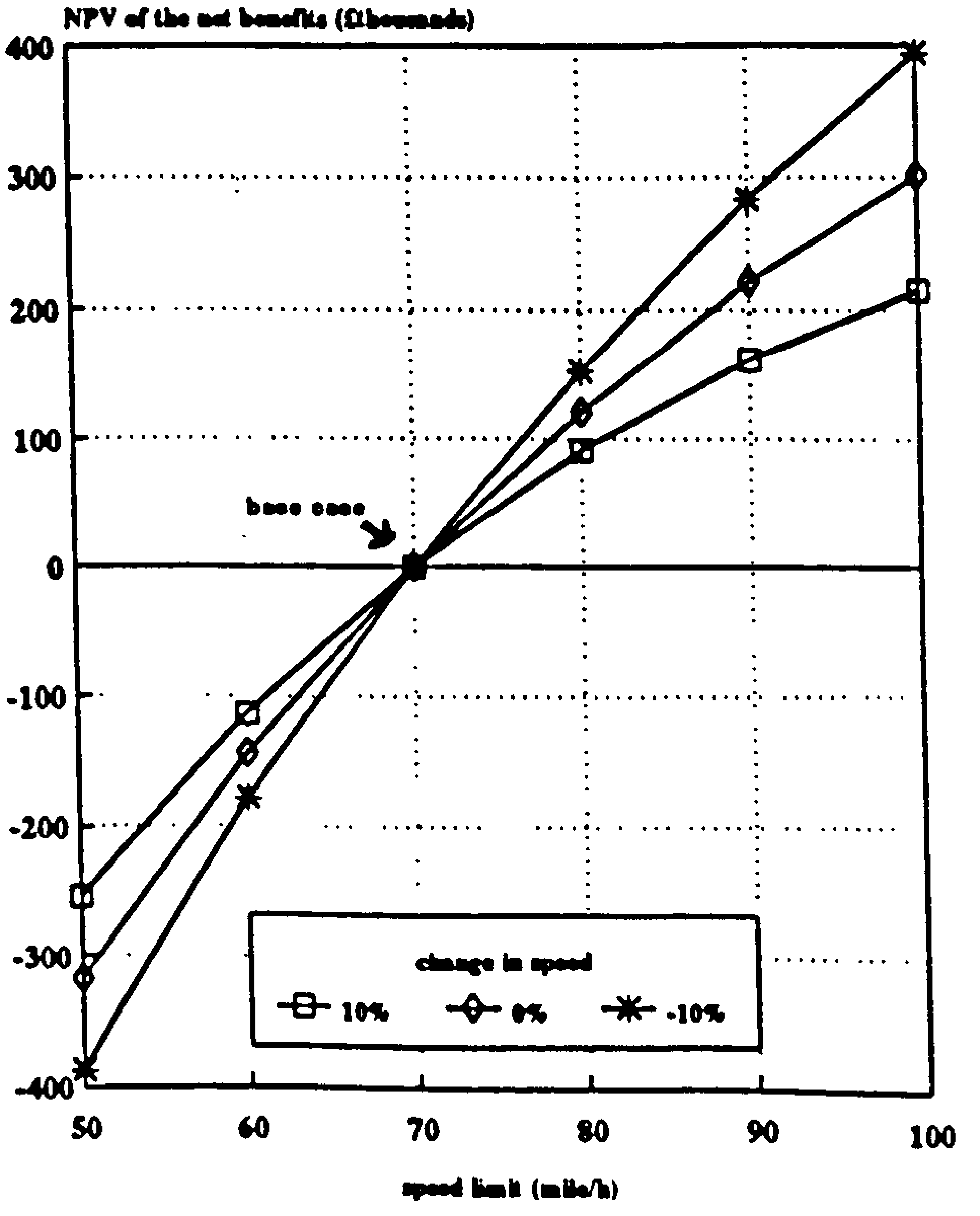


Figure 6.13a: The Effect of Changes in the Annual Growth of the Mean Speed of Traffic on the NPV of the Total Cost as the Speed Limit Varied (low economic growth)

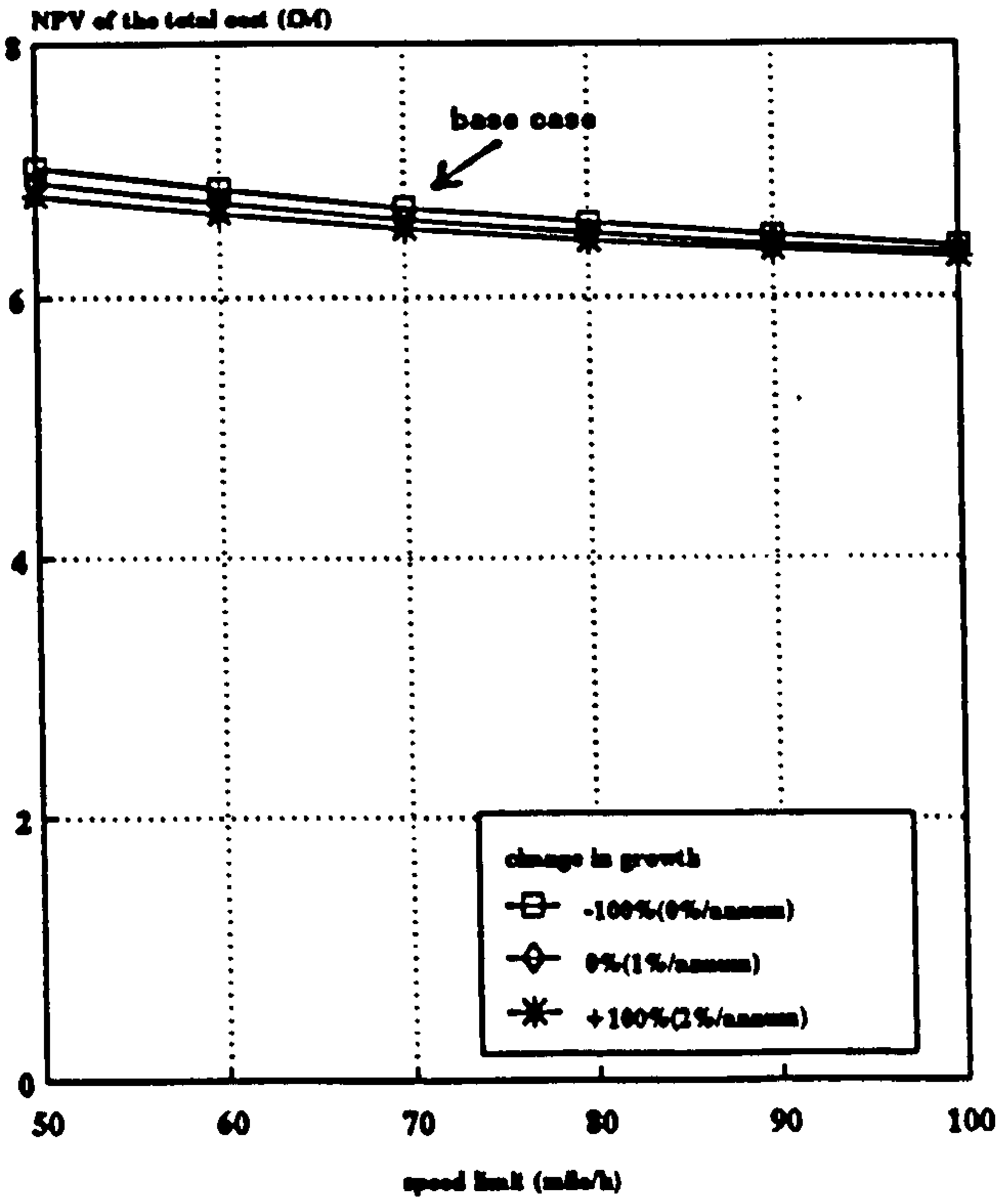


Figure 6.13b: The Effect of Changes in the Annual Growth of the Mean Speed of Traffic on the NPV of the Net Benefits as the Speed Limit Varied (low economic growth)

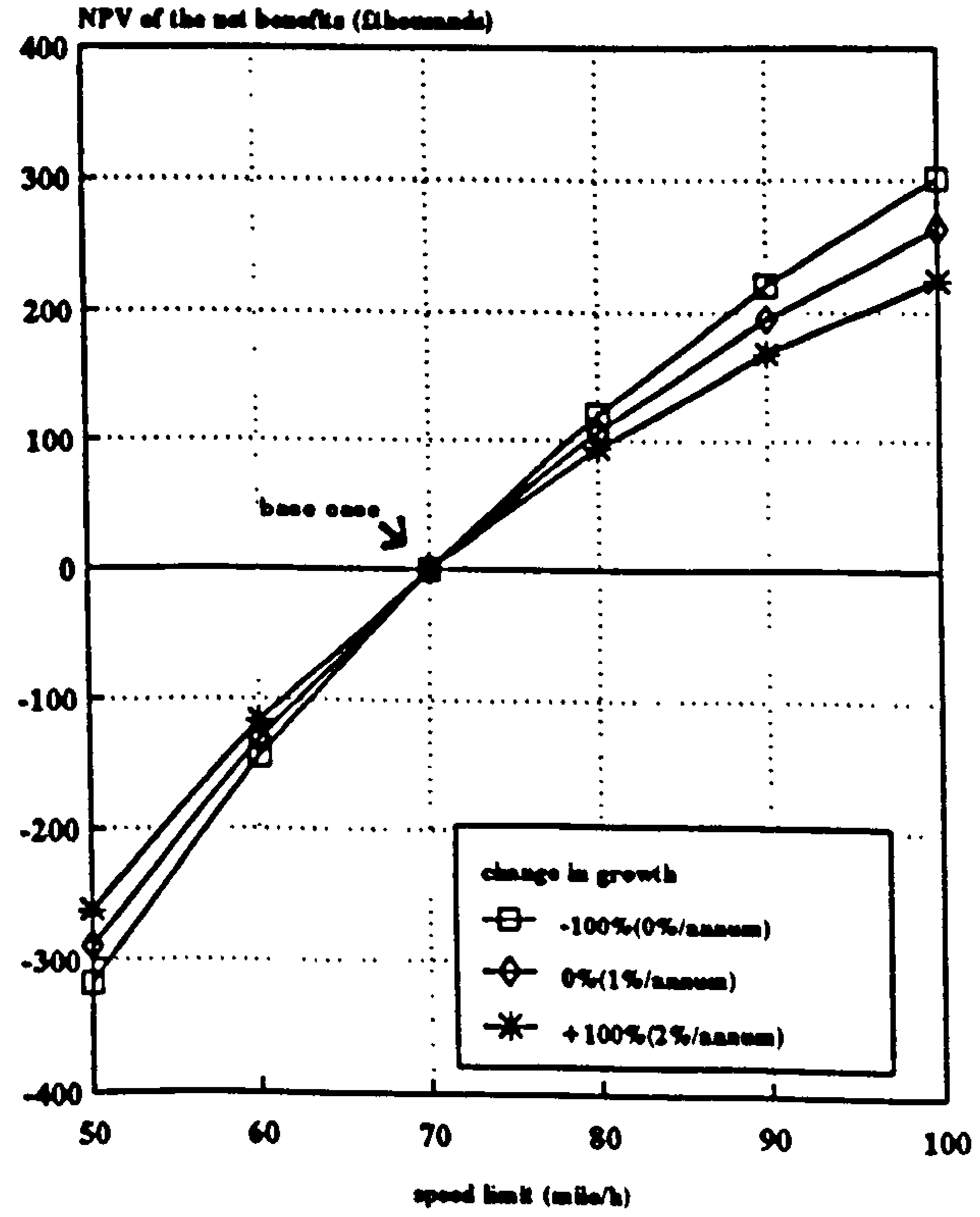


Figure 6.14a: The Effect of Changes in the Proportion of Cars in the Traffic Stream on the NPV of the Total Cost as the Speed Limit Varied (low economic growth)

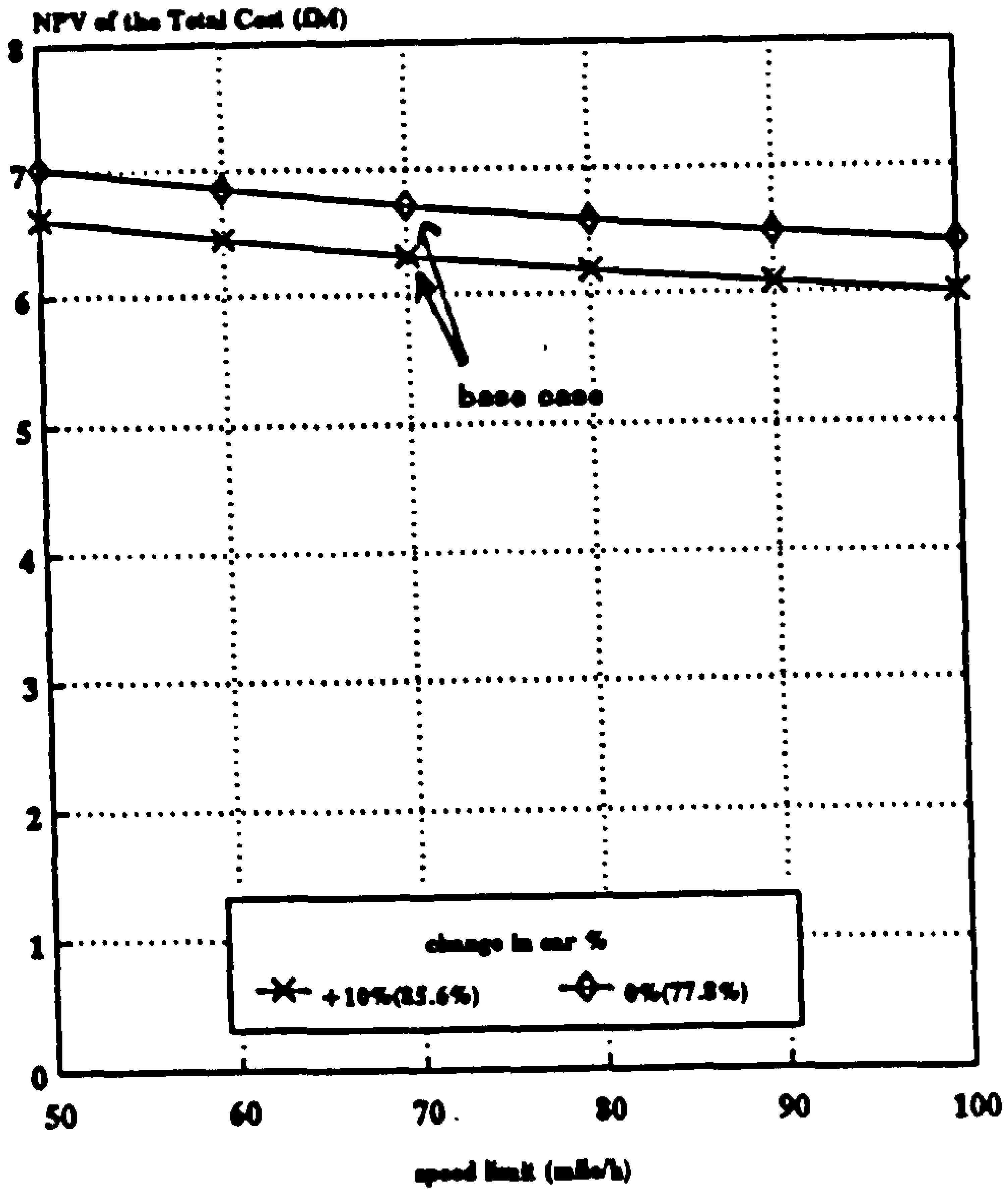


Figure 6.14b: The Effect of Changes in the Proportion of Cars in the Traffic Stream on the NPV of the Net Benefits as the Speed Limit Varied (low economic growth)

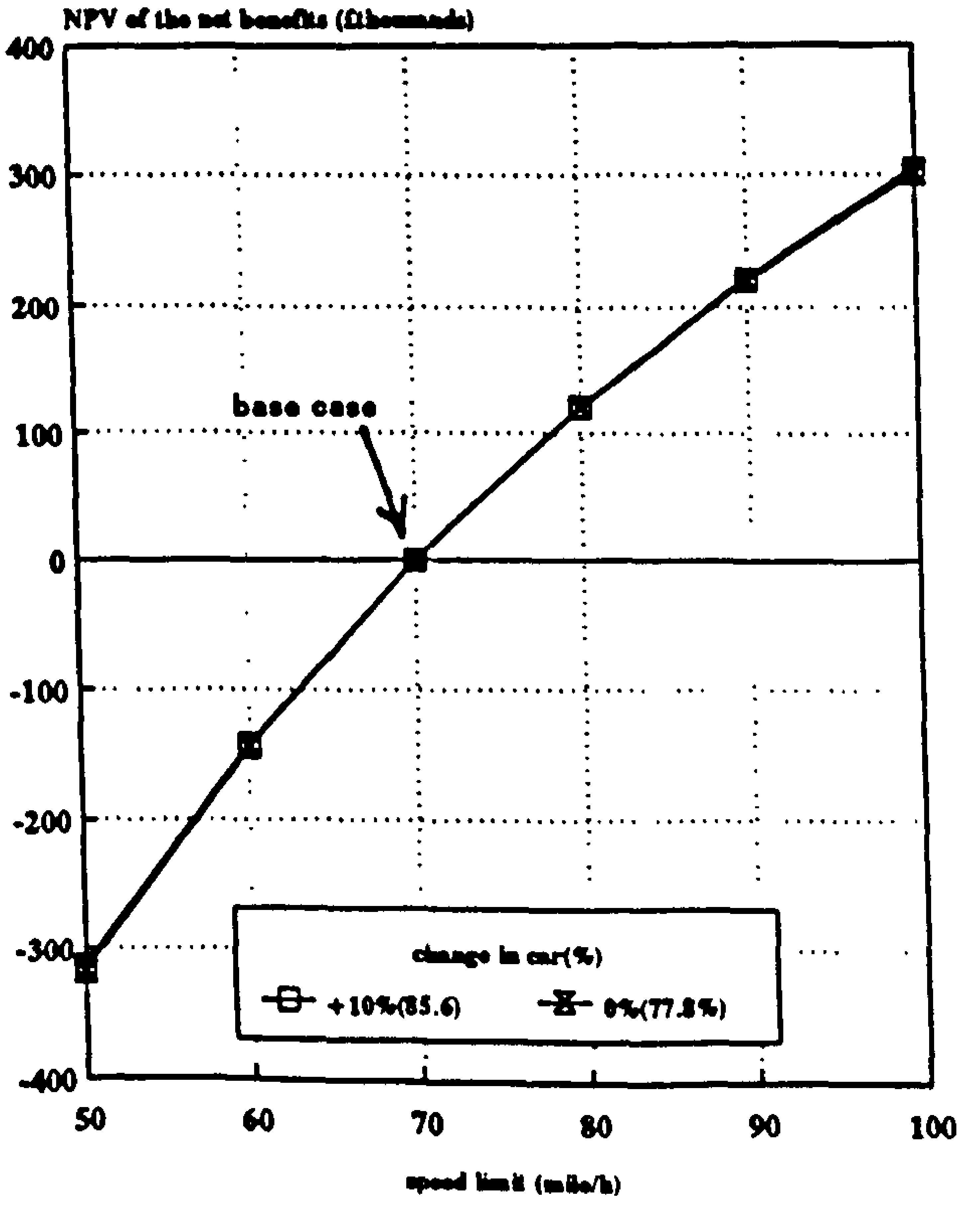


Figure 6.15a: The Effect of Changes in Economic Growth on the NPV of the Total Cost as the Speed Limit Varied (low economic growth)

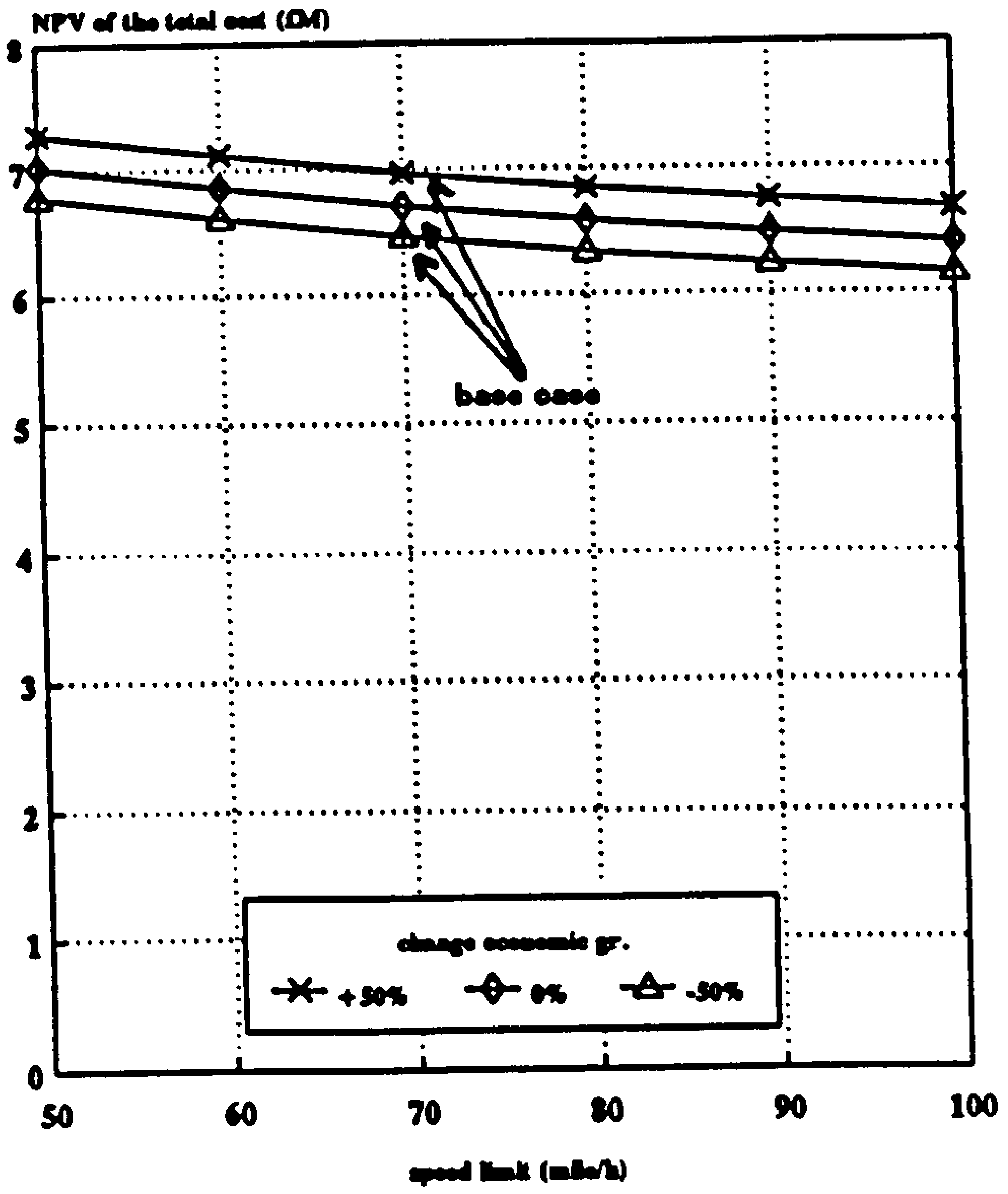


Figure 6.15b: The Effect of Changes in Economic Growth on the NPV of the Net Benefits as the Speed Limit Varied (low economic growth)

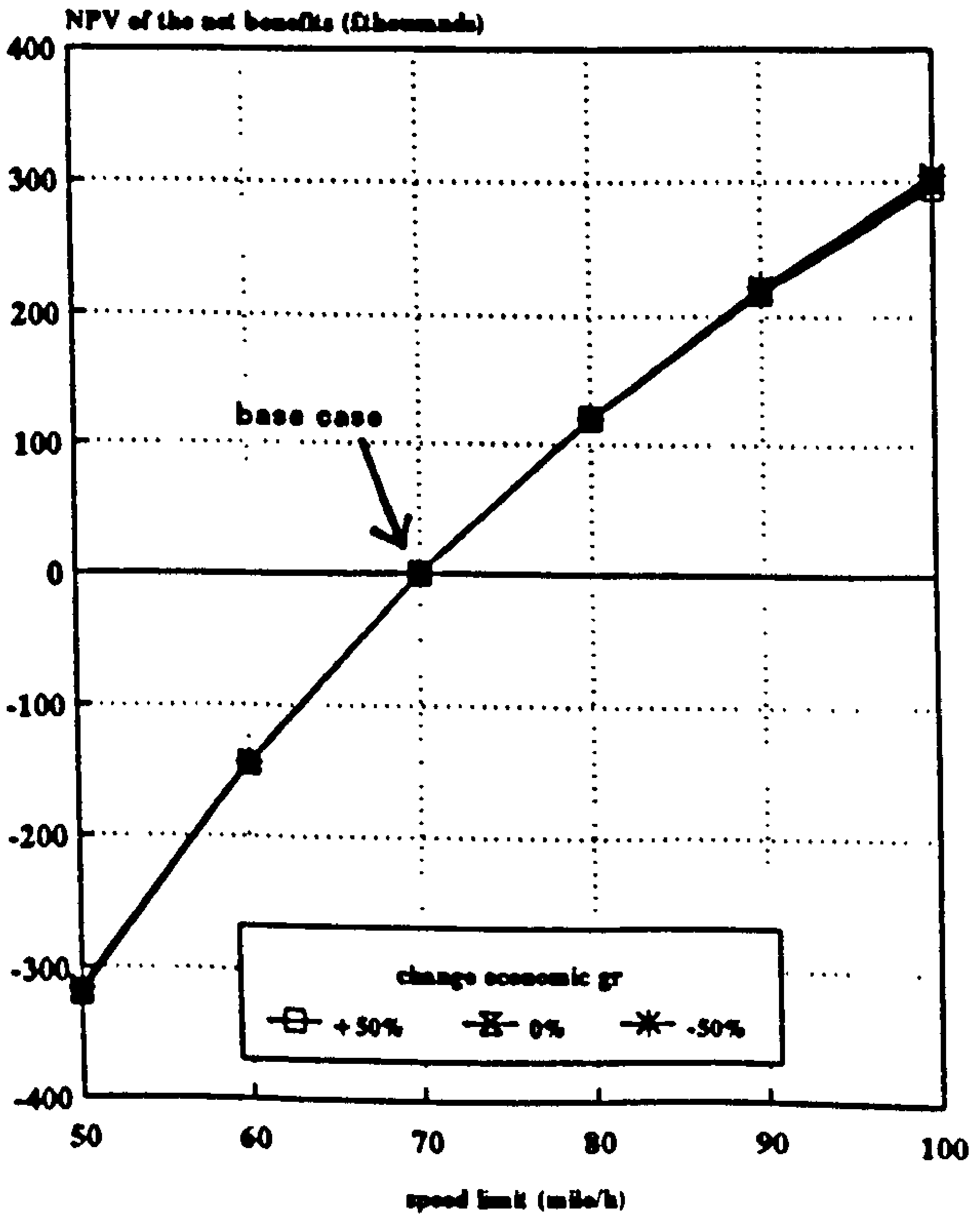


Figure 6.16a: The Effect of Changes in the Speed Limit Effect Model on the Mean Speed of Traffic on the NPV of the Total Cost as the Speed Limit Varied (low economic growth)

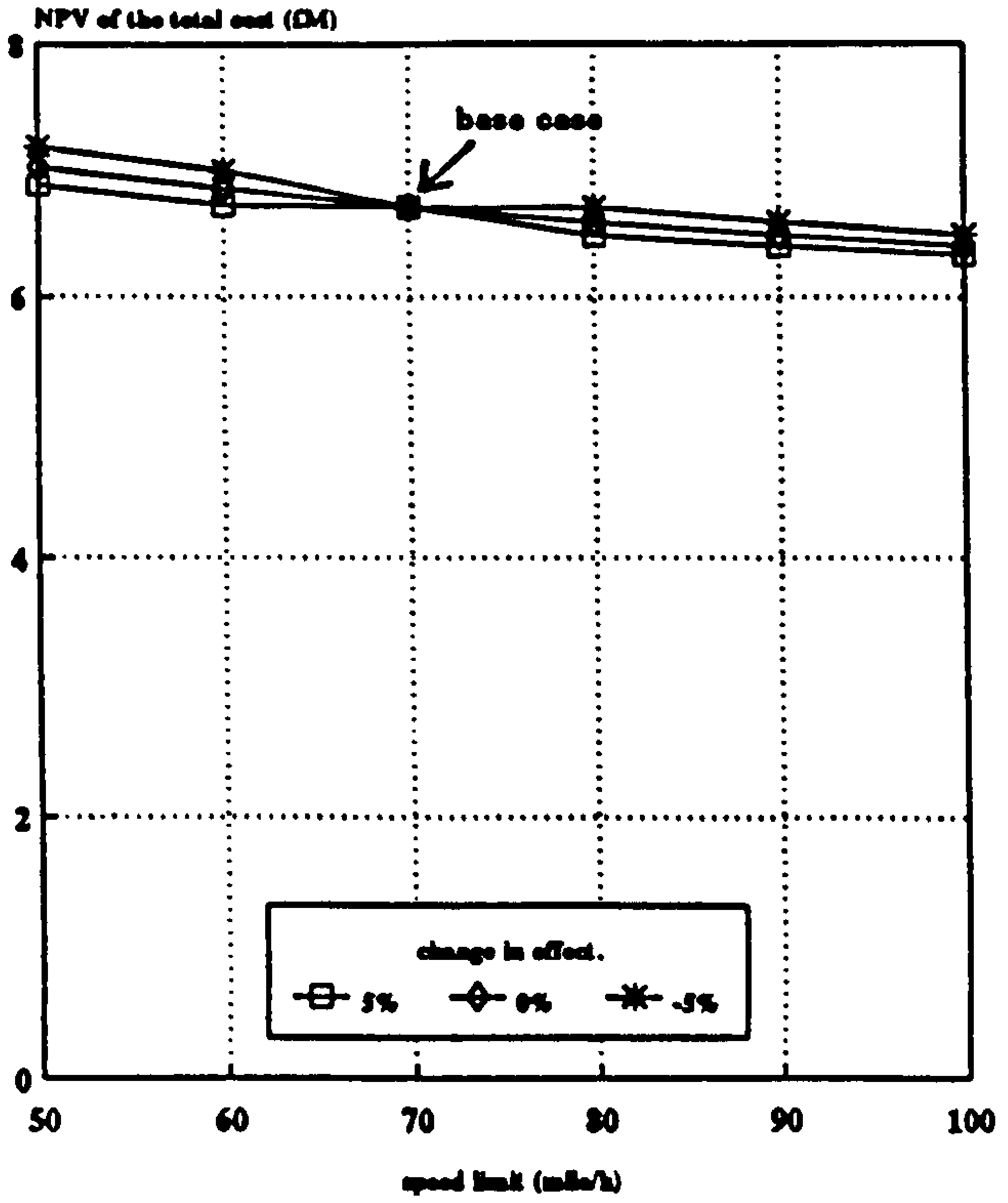


Figure 6.16b: The Effect of Changes in the Speed Limit Effect Model on the Mean Speed of Traffic on the NPV of the Net Benefits as the Speed Limit Varied (low economic growth)

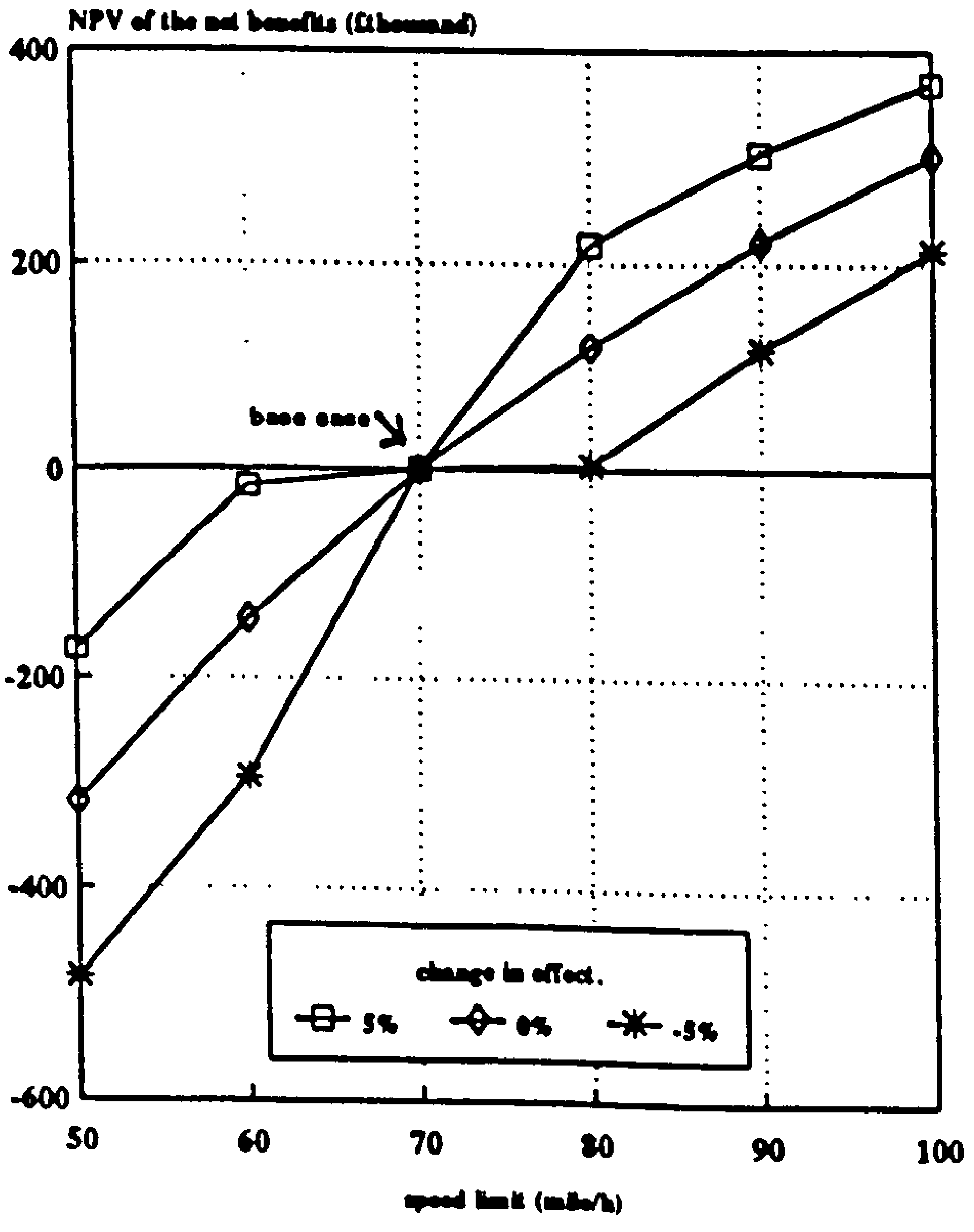


Table 6.1a: Sensitivity Ratios for the Variables Used in the Cost-Benefit Analysis: the NPV of the Total Cost as the Speed Limit Varied

Speed limit (mile/h)	50	60	70	80	90	100
Initial daily traffic flow in the base year	0.67	0.67	0.67	0.67	0.67	0.67
Proportion of cars in traffic stream	0.58	0.59	0.60	0.61	0.62	0.63
Travel-time cost	0.52	0.50	0.48	0.47	0.45	0.43
Initial mean speed of traffic in the base year	0.45	0.41	0.37	0.33	0.29	0.25
Speed limit effect	0.44	0.41	NA*	0.33	0.29	0.24
Non-fuel element of VOC	0.28	0.29	0.29	0.29	0.30	0.30
Discount rate	0.25	0.25	0.25	0.25	0.25	0.25
Fuel consumption element of VOC	0.15	0.16	0.17	0.19	0.20	0.21
VOC	0.14	0.15	0.16	0.16	0.17	0.17
Traffic growth	0.12	0.12	0.12	0.12	0.12	0.12
Growth in traffic and a decline in speed	0.08	0.08	0.08	0.08	0.08	0.08
Economic growth	0.07	0.07	0.07	0.08	0.08	0.08
Frequency of PIAs	0.05	0.05	0.00	0.05	0.05	0.05
PIA cost	0.05	0.05	0.05	0.05	0.05	0.05
FI casualties per average PIA	0.03	0.03	0.00	0.03	0.03	0.03
Growth of the mean speed of traffic	0.02	0.01	0.01	0.01	0.01	0.01

*NA: not applicable

Table 6.1b: Ranking of the Sensitivity Ratios for the Variables Used in the Cost-Benefit Analysis: the NPV of the Total Cost as the Speed Limit Varied

Speed limit (mile/h)	50	60	70	80	90	100
Initial daily traffic flow in the base year	1	1	1	1	1	1
Proportion of cars in traffic stream	2	2	2	2	2	2
Travel-time cost	3	3	3	3	3	3
Initial mean speed of traffic in the base year	4	4	4	4	5	5
Speed limit effect	5	5	14	5	6	7
Non-fuel element of VOC	6	6	5	6	4	4
Discount rate	7	7	6	7	7	6
Fuel consumption element of VOC	8	8	7	8	8	8
VOC	9	9	8	9	9	9
Traffic growth	10	10	9	10	10	10
Growth in traffic and a decline in speed	11	11	10	11	11	11
Economic growth	12	12	11	12	12	12
Frequency of PIAs	13	13	15	13	13	13
PIA cost	14	14	12	14	14	14
FI casualties per average PIA	15	15	16	15	15	15
Growth of the mean speed of traffic	16	16	13	16	16	16

Table 6.2a: Sensitivity Ratios of the Variables Used in the Cost-Benefit Analysis: the NPV of the Net Benefits as the Speed Limit Varied

Speed limit (mile/h)	50	60	80	90	100
Speed limit effect	9.80	19.16	17.78	8.39	5.18
Initial mean speed of traffic in the base year	2.10	2.23	2.56	2.75	2.97
Travel-time cost	1.23	1.28	1.38	1.43	1.50
Frequency of PIAs	1.10	2.43	2.91	1.59	1.17
Initial traffic flow in the base year	0.67	0.67	0.67	0.67	0.67
FI casualties per average PIA	0.56	1.23	1.48	0.81	0.59
Fuel consumption of VOC	0.30	0.34	0.44	0.51	0.58
Discount rate	0.24	0.24	0.24	0.24	0.24
VOC	0.23	0.28	0.38	0.43	0.50
Proportion of cars in the traffic stream	0.15	0.11	0.01	0.06	0.13
Traffic growth	0.12	0.11	0.11	0.11	0.11
Growth of the mean speed of traffic	0.10	0.10	0.12	0.13	0.15
Traffic growth and decline in the mean speed of traffic	0.08	0.08	0.07	0.07	0.07
Non-fuel element of VOC	0.06	0.06	0.07	0.07	0.08
Economic growth	0.00	0.00	0.01	0.02	0.03
PIA cost	0.00	0.00	0.00	0.00	0.00

Table 6.2b: Ranking of the Sensitivity Ratios for the Variables Used in the Cost-Benefit Analysis: the NPV of the Net Benefits as the Speed Limit Varied

Speed limit (mile/h)	50	60	80	90	100
Speed limit effect	1	1	1	1	1
Initial mean speed of traffic in the base year	2	3	3	2	2
Travel-time cost	3	4	5	4	3
frequency of PIAs	4	2	2	3	4
Initial traffic flow in the base year	5	6	6	6	5
FI casualties per average PIA	6	5	4	5	6
Fuel consumption element of VOC	7	7	7	7	7
Discount rate	8	9	9	9	9
VOC	9	8	8	8	8
Proportion of cars in the traffic stream	10	10	14	14	11
traffic growth	11	11	11	11	12
Growth of mean speed of traffic	12	12	10	10	10
Traffic growth and decline in speed	13	13	12	12	14
Non-fuel element of VOC	14	14	13	13	13
Economic growth	15	15	15	15	15
PIA cost	16	16	16	16	16

Figure 6.17: Sensitivity Ratios for the Variables Used in the Cost-Benefit analysis: the NPV of the Total Cost as the Speed Limit Varied

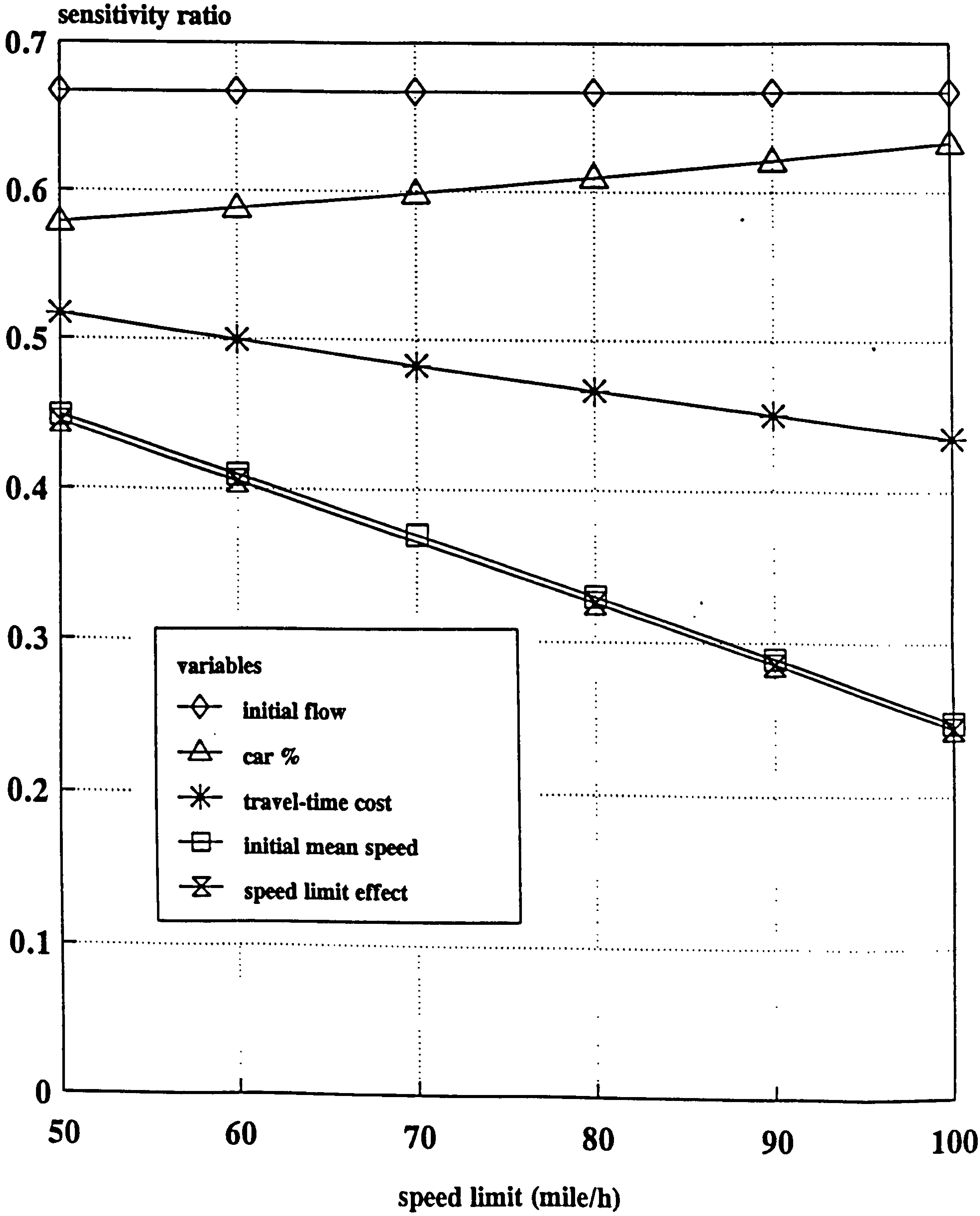


Figure 6.17: (Continued)

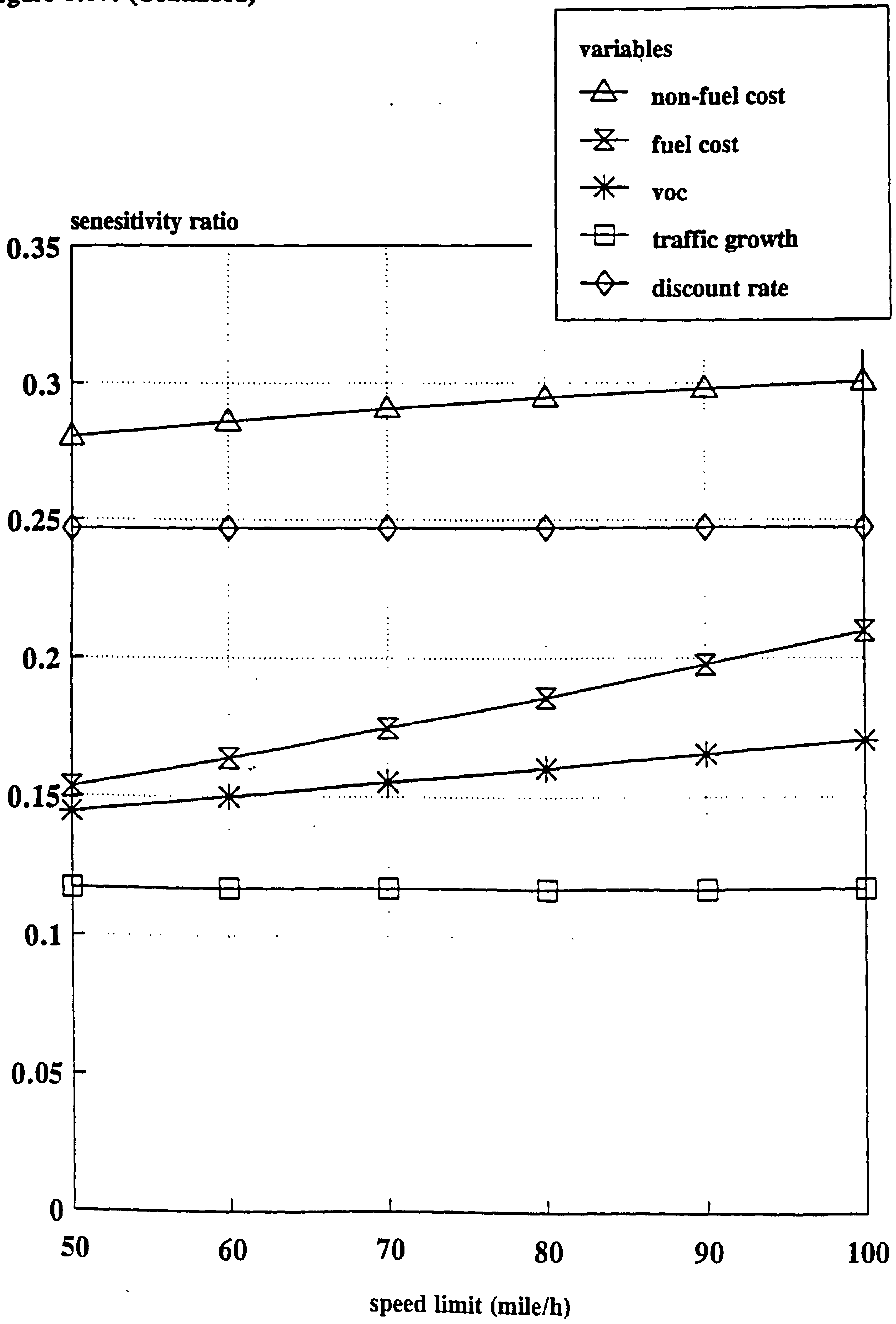


Figure 6.17: (Continued)

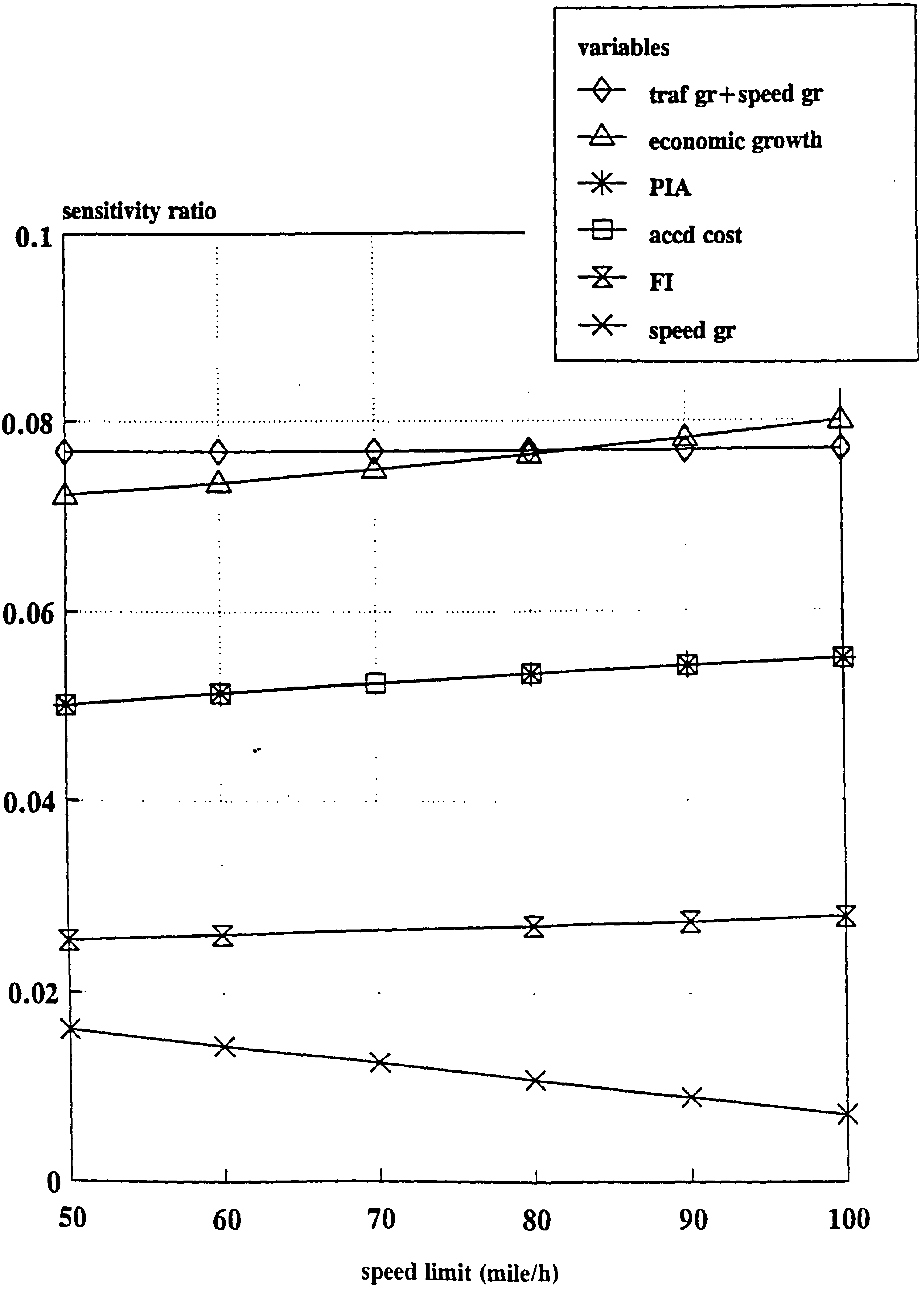


Figure 6.18: Sensitivity Ratios for the Variables Used in the Cost-Benefit Analysis: the NPV of the Net Benefits as the Speed Limit Varied

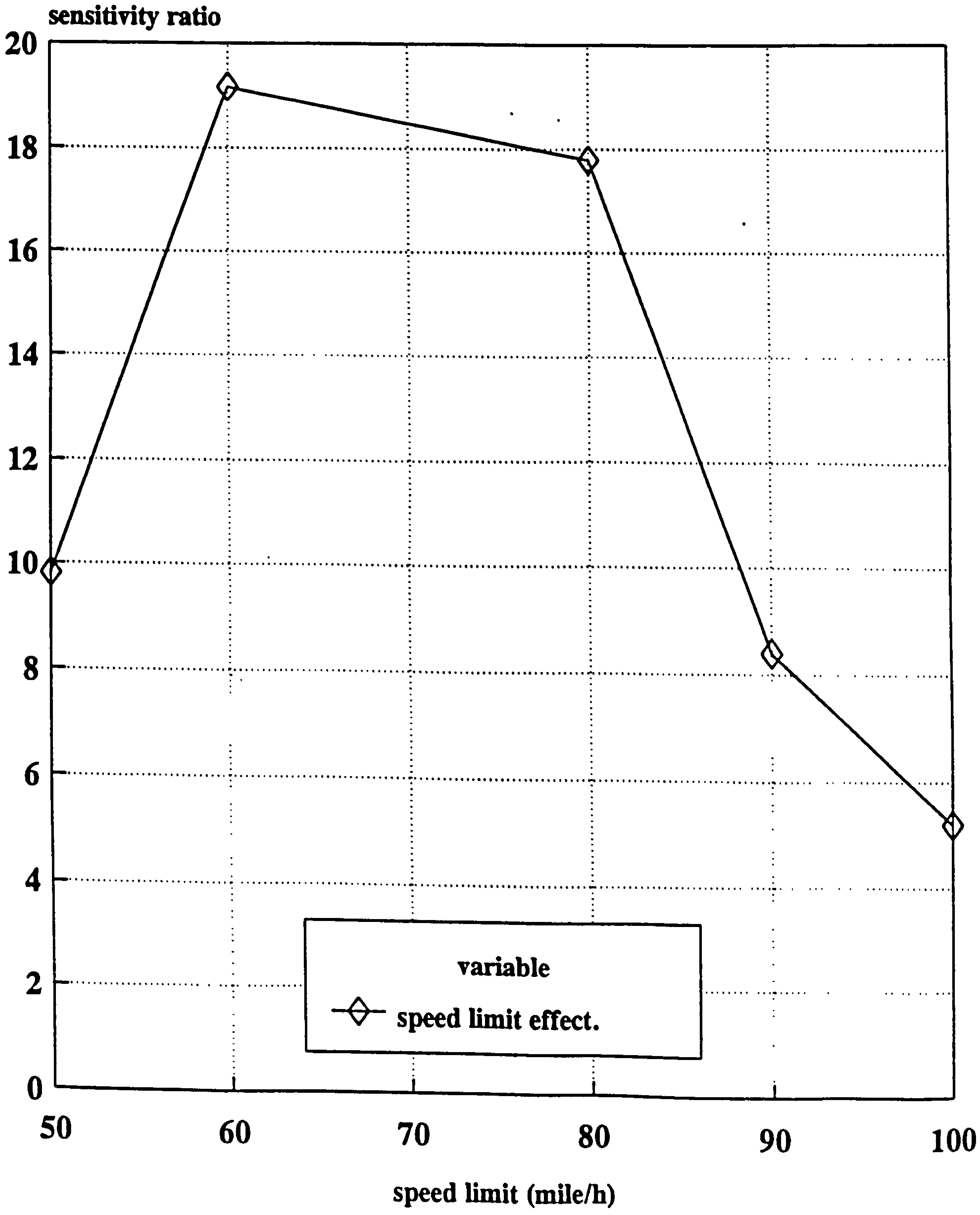
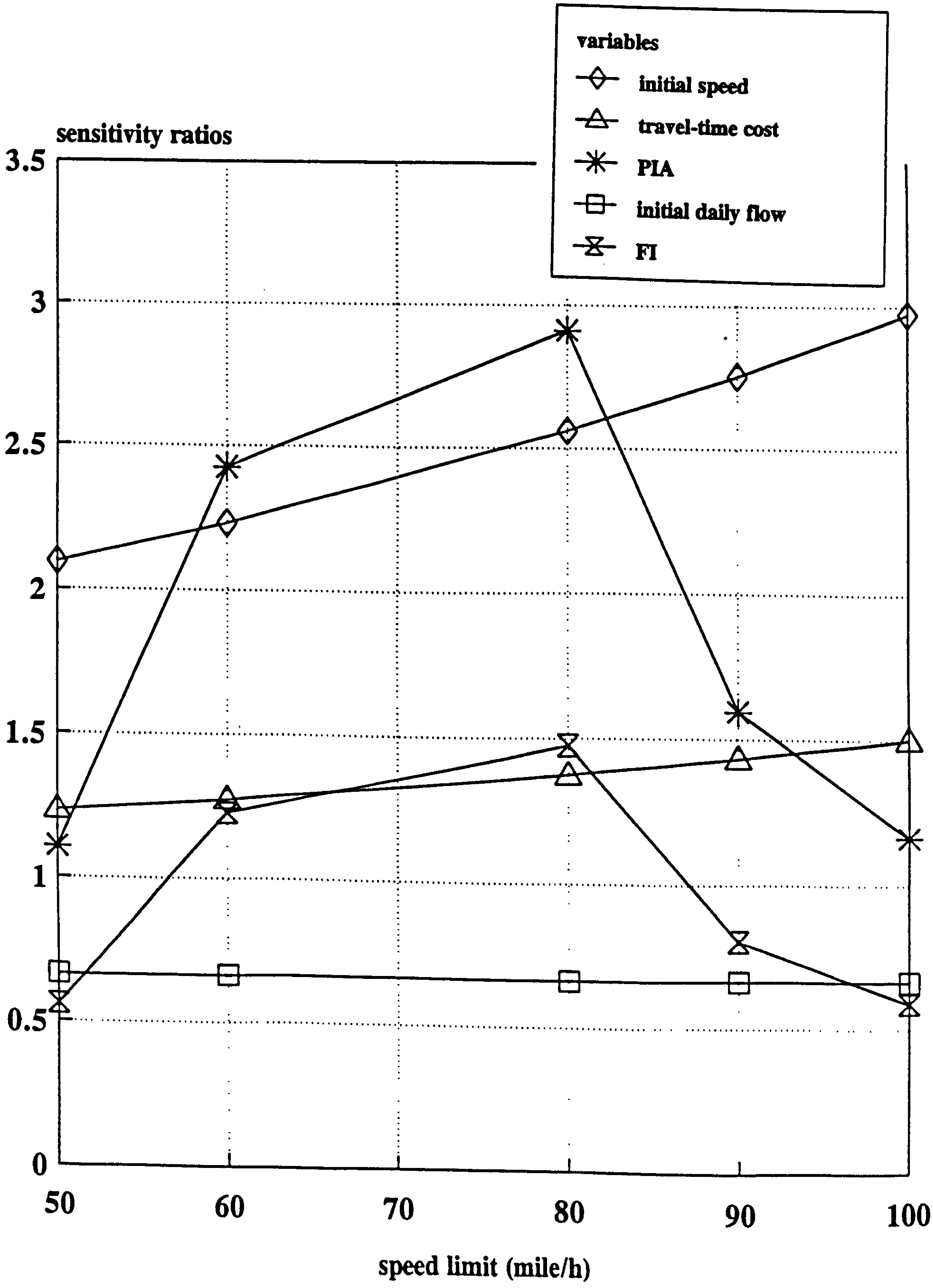


Figure 6.18: (Continued)



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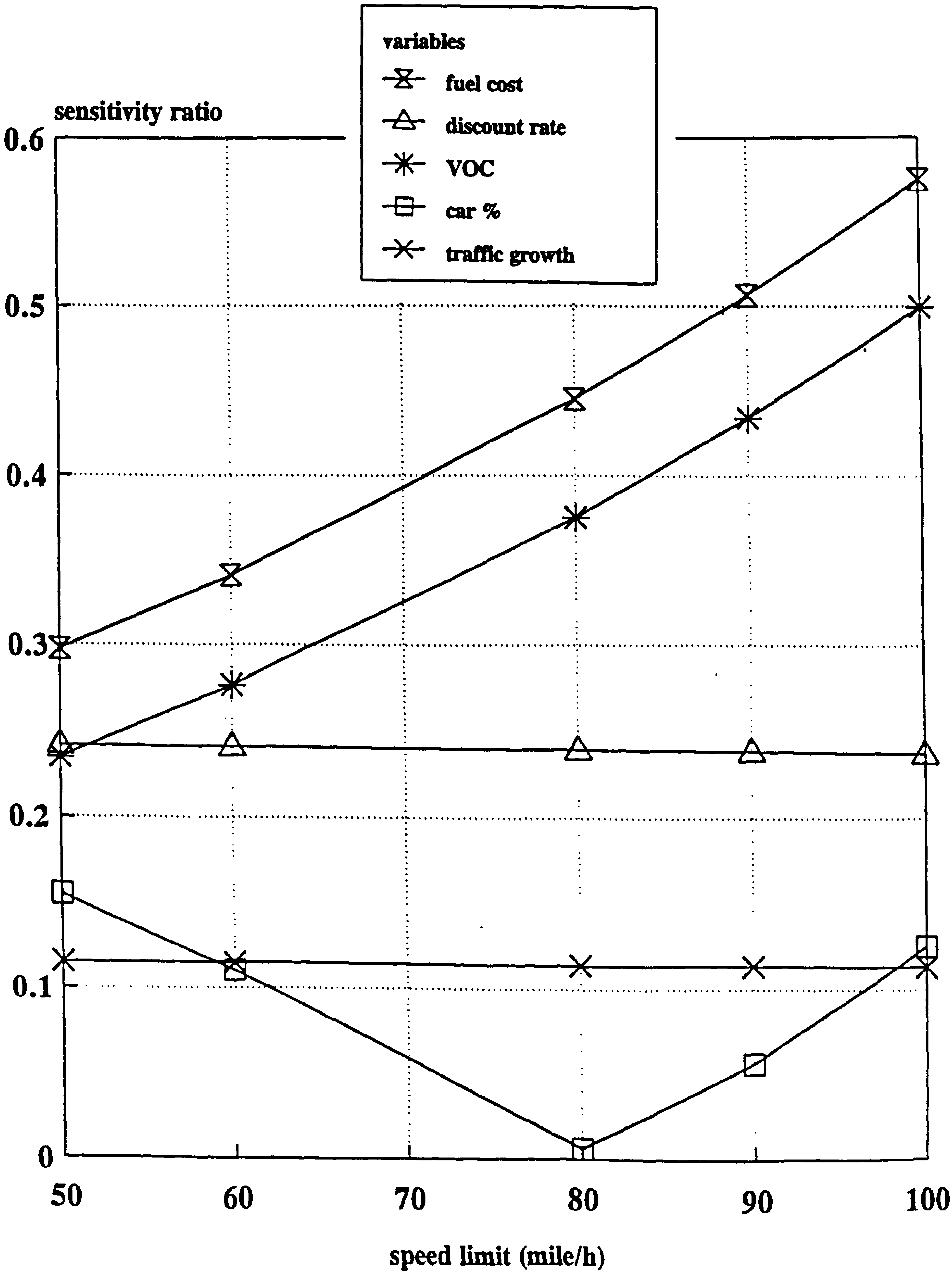

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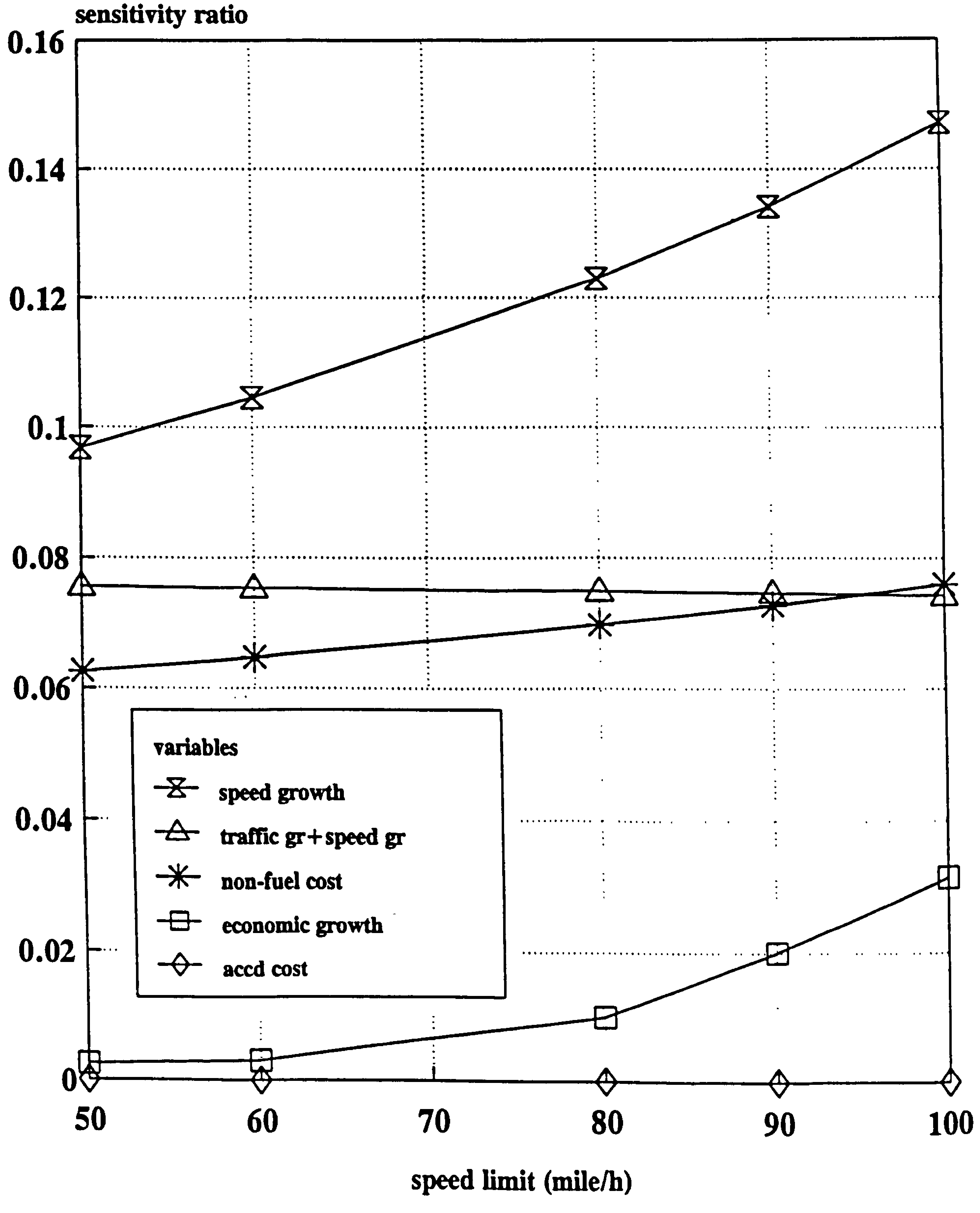

6.3 Discussion

6.3.1 The Effect of the Changes in the Values of the Variables Used in the Cost-Benefit Analysis

The Travel-Time Cost

The travel-time cost was tested at both +100 per cent and -50 per cent of its value. The NPV of the total cost and the NPV of net benefits increased as travel-time cost increased and vice versa. The effect of the changes was greatest on both the NPV of the total cost and the net benefits derived from changing the speed limit of the base case (Figures 6.1a and 6.1b) because of the large share of travel-time cost within the NPV of total cost. The effect of varying the travel-time cost was more noticeable at 'lower' speed limits for the NPV of the net benefits due to the rapid changes in travel-time cost with the mean speed of traffic at 'lower' speed limits.

The Non-Fuel Element of VOC

The non-fuel element of VOC was tested at both +100 per cent and -50 per cent of its value. The NPV of the total cost and the NPV of the net benefits increased as the non-fuel cost increased. There was a significant impact on the NPV of total cost due to the contribution of the non-fuel element to the total VOC (i.e. about two-thirds as indicated in Section 5.5.2) (see Figure 6.2a). The NPV of the net benefits hardly changed as the cost of the non-fuel element was altered (see Figure 6.2b) which was due, firstly, to the larger contribution of the travel-time cost at lower speed limits which over-shadowed the effect of the change in the non-fuel element cost and secondly, at higher speed limits, the non-fuel element cost did not vary considerably with changes in speed limits because the constant term in the non-fuel element equation took control over the speed related term (see Section 4.3.2).

The Fuel Element of VOC

The fuel element of VOC was varied by the same multiples as the non-fuel element. The NPV of the total cost and the NPV of the net benefits increased as the cost of fuel increased. The fuel cost had a considerable effect on the NPV of the total cost, especially, on higher speed limits (see Figure 6.3a). The same was observed for the NPV of net benefits (Figure

6.3b). The changes were more noticeable at 'higher' speed limits. At 'lower' speed limits the travel-time cost controlled the outcome, as was the case for the non-fuel element. At 'higher' speed limits, where the effect of the travel-time cost was less and the square of the speed term in the fuel consumption equation contributed more than the inverse of speed term in the same equation, the changes in the fuel element cost reflected more on both the NPV of the total cost and the NPV of the net benefits derived from changing the speed limit of the base case (see Section 4.3.2).

The VOC

Changes in VOC, both the non-fuel and fuel elements of VOC were changed, was more sensitive at higher speed limits, in a similar way to the behaviour of the fuel element cost (see Figures 6.4a and 6.4b).

The Accident Cost

Due to the assumption that the frequency and severity of PIAs was constant for different speed limits, the NPV of the net benefits did not show any response to changes in accident cost (see Figures 6.5a and 6.5b).

The Frequency of PIAs

To test the sensitivity of the NPV of the total cost and the NPV of the net benefits to the assumption that the frequency of PIAs was constant, the PIA for the base case was changed by +50 per cent for increasing speed limits and -50 per cent for lowering the speed limit. The NPV of the total cost increased as the frequency of PIA increased. The NPV of the net benefits decreased as the frequency of PIAs increased and vice versa. The impact on the NPV of the total cost was not impressive (see Figure 6.6a) but it did change the outcome of the NPV of the net benefits derived from changing the speed limit of the base case and, in some cases, changed the sign (e.g. the negative NPV of the net benefits of changing the speed limit of the base case to 60 mile/h was converted to a positive benefit) (see Figure 6.6b).

The Number of FI Casualties per average PIA

To test the other assumption that the severity of PIAs was constant, the number of FI casualties per average PIA (i.e. which represented the severity of PIAs; see Section 5.10.1) was altered by +50 per cent for increasing the speed limit of the base case and -50 per cent for lowering the speed limit of the base case. The NPV of the total cost and the NPV of the net benefits responded in a similar manner to the previous case. The NPV of the total cost changed less than the previous case (see Figure 6.7a). The NPV of the the net benefits was more sensitive than the NPV of the total cost but it was less than the impact of changes in the frequency of PIAs (see Figure 6.7b).

The Discount Rate

The discount rate per annum was tested at 10% and 6% which was equivalent to testing at ±25 per cent of that used in the base case. The NPV of the total cost and the NPV of the net benefits increased as the discount rate was lowered and the opposite happened when the discount rate was increased. Moderate changes in both the NPV of the total cost and the NPV of the net benefits were observed (see Figure 6.8a and Figure 6.8b).

The Initial Daily Traffic Flow in the Base Year

The initial daily traffic flow for the base year was tested at +50 per cent and -50 per cent of its original value in the base year. It was not changed to higher values in order not to violate the assumption of free-flow conditions. Changes in the initial daily traffic flow for the base year had a great effect on the NPV of the total cost and the NPV of the net benefits which was expected because all the costs and benefits depended on traffic flow (see Figures 6.9a and 6.9b). The NPV of the total cost and the NPV of the net benefits increased as the initial daily traffic flow increased. There was no cost or benefit generated independently of the number of vehicles like, for example, a capital cost of road construction or a cost of road maintenance. The cost-benefit was, basically, per vehicle so any change in the number of vehicles would produce a corresponding change in cost-benefit. The changes in the NPV of net benefits due to changes in the initial daily traffic flow should be seen in this context. To examine this point further, the relative ratios of the NPV of the net benefits to the NPV of the total cost were determined. The results were always the same regardless of any changes in the initial daily traffic flow (see Figure 6.9c).

The Annual Growth of Traffic

The annual growth of traffic was tested at +100 per cent and -50 per cent which did not influence the outcome of the NPV of the total cost much and, had an even smaller effect on the NPV of the net benefits (see Figures 6.10a and 6.10b). The NPV of the total cost and the NPV of the net benefits increased as the annual traffic growth increased. The same discussion of the effect of the initial daily traffic flow stood true for the effect of changes in the annual traffic growth (see Figure 6.10c).

The Annual Growth of Traffic with a Corresponding Decline in the Speed of Traffic

To explore the effect of an increase in the annual traffic growth with a corresponding decline in the mean speed of traffic, the traffic growth was raised by 100 per cent and a decline of 5 per cent per annum was assumed in the mean speed of traffic. The NPV of the total cost and the NPV of the net benefits increased as the annual traffic growth increased (see Figures 6.11a and 6.11b). The relative ratio of the NPV of the net benefits to the NPV of the total cost was not affected by changes in the annual traffic growth, as was mentioned before (see Figure 6.11c).

The Initial Mean Speed of Traffic in the Base Year

Changes in the initial mean speed of traffic in the base year of ±10 per cent affected the NPV of the total cost and the NPV of the net benefits. The higher initial mean speed of traffic yielded a lower NPV for both the total cost and the net benefits where a lower initial mean speed of traffic yielded higher outcomes (see Figures 6.12a and 6.12b). The influence at lower speed limits were greater than the higher speed limits because of the large contribution of travel-time cost.

The Annual Growth of the Mean Speed of Traffic

It was assumed, in the cost-benefit analysis, that there was no growth in the mean speed of traffic over time. To test this assumption the growth was changed to +1 per cent per annum (which was considered to be the base case) and +2 per cent per annum which was equivalent to +100 per cent change in the base case. Both the NPV of the total cost and the NPV of the net benefits decreased as the annual growth of the mean speed of traffic increased. The NPV of the total cost and the NPV of the net benefits, hardly, were affected by the changes (see Figures 6.13a and 6.13b).

The Traffic Composition

The traffic composition was tested by increasing the proportion of cars in the traffic stream by +10 per cent and with corresponding decreases in other vehicles. There was, almost, no change in the NPV of the net benefits (see Figure 6.14b) and a decrease in the NPV of the total cost was observed (see Figure 6.14a). Most of this reduction was due to the reduction in travel-time cost for the users of other types of vehicles.

The Annual Economic Growth

The annual economic growth was changed by +50 per cent and -50 per cent. The NPV of the total cost increased as the annual economic growth increased and vice versa (see Figure 6.15) but there was, barely, any change in the NPV of the net benefits (see Figure 6.15b).

The Effect of Speed Limit Model on the Mean Speed of Traffic

The results of the speed limit model that was adopted in the cost-benefit analysis were tested for their effect on the outcome. The effect of speed limits on the mean speed of traffic was varied by +5 per cent and -5 per cent. The NPV of the total cost increased as the effect of the speed limit decreased. The NPV of the net benefits increased as the speed limit effect increased for 'higher' speed limits but decreased for 'lower' speed limits. The opposite happened when the speed limit decreased. The changes had a huge impact on the NPV of the net benefits compared to the effect on the NPV of the total cost because the change in the speed limit model effect was not applied to the mean speed of the base case which was the result of the direct observation of road traffic (see Figures 6.16a and 6.16b).

6.3.2 Sensitivity Ratios

Sensitivity Ratios of the Variables Used in the Cost-Benefit Analysis of the NPV of the Total Cost

The changes that were applied to different variables used in the cost-benefit analysis were not consistent in their magnitude because the changes had to be within reasonable limits, which varied according to the variable tested. To standardise the changes, sensitivity ratios were determined. All the the changes in the variables were expressed as a percentage change in the NPV of the total cost or the NPV of the net benefits for every one per-cent change in the value of the variable.

The sensitivity ratios for the NPV of the total cost to various variables were ranked according to their values at various speed limits (see Table 6.1 and Figure 6.17). No variable reached a sensitivity ratio of 1. The initial daily traffic flow for the base year was the most sensitive variable in determining the NPV of the total cost followed by the proportion of cars in the traffic stream, the travel-time cost, the initial mean speed of traffic in the base year, the speed limit effect on the mean speed of traffic, the non-fuel element cost and the discount rate in descending order for most of the speed limits. This result should be seen within the context of the discussion in Section 6.3.1. Other variables had a sensitivity ratio of less than 0.25 which was an indicator of their less significant roles in the cost-benefit analysis of the NPV of the total cost (See Table 6.1a and 6.1b, and Figure 6.17). The ranking of the variables was largely unchanged at different speed limits.

The Sensitivity Ratios of the Variables Used in the Cost-Benefit Analysis of the NPV of the Net Benefits

The NPV of the net benefits were most sensitive to the effect of the speed limit model, the initial mean speed of traffic in the base year, the travel-time cost, the frequency of PIAs, and the number of FI casualties per average PIA (see Tables 6.2a and 6.2b and Figure 6.18). The speed limit effect model was used to estimate mean speeds of traffic for speed limits other than the speed limit of the base case. The mean speed of traffic for the base case was obtained by direct observation. This reflected the high ranking of the sensitivity ratio of the speed limit effect model variable. The same argument stood true for the effect of the mean speed of traffic on the frequency of PIAs and the number of FI casualties per average PIA, which were observed directly for the base case and assumed hypothetically for other speed limits. The cost of travel-time was the most influential component of traffic operating cost. The variables relating to traffic flow should be seen in the context of the previous discussion in Section 6.3.1. Generally, the lower ranking sensitivity ratios remained unchanged as the speed limit varied. Excluding the highest ranking variable, other top ranking variables changed places as the speed limit varied. Generally, the NPV of the net benefits for 'higher' speed limits were more sensitive to changes in the values of the variables and in some other cases the sensitivity ratios were greater around the speed limit of the base case.

Comparison between the Sensitivity of The NPV of the Total Cost and the Net Benefits Derived from Changing the Speed Limit of the Base Case

The ranking of the sensitivity ratios for the variables, generally, differed between the cost-benefit analysis of the NPV of the total cost and the NPV of the net benefits. For example, the speed limit effect model had a moderate effect on the NPV of the total cost but its role in determining the NPV of the net benefits exceeded all other variables by far. In most cases, the NPV of the net benefits were more sensitive to changes in the values of the variables of cost-benefit analysis due to their low magnitude when compared to the NPV of the total cost.

6.4 Conclusion

Sensitivity ratios were used to determine the relative importance of each of the variables used in the cost-benefit analysis to assess the final outcome. The variables tested were: the travel-time cost, the cost of fuel and non-fuel elements of VOC, the accident cost, the frequency of PIAs, the number of FI casualties per average PIA, the discount rate, the initial traffic flow in the base year, the traffic growth, the initial mean speed of traffic in the base year, the growth of the mean speed of traffic, the combined effect of traffic growth and the decrease in the mean speed of traffic, the traffic composition, and the speed limit effect on the mean speed of traffic. They were tested for their effects on the NPV of both the total cost and the net benefits.

The NPV of the total cost was most sensitive to changes in the values of initial daily traffic flow in the base year, the proportion of cars in the traffic stream, and the travel-time cost. The NPV of the net benefits of changing the speed limit of the base case was most sensitive to changes in the values of the effect of the speed limits on the mean speed of traffic, the initial mean speed of traffic in the base year, the travel-time cost, the changes in the frequency of the PIAs, and the number of FI casualties per average PIA (i.e. in descending order of importance in most cases). The sensitivity of the NPV of the net benefits, to some variables, increased as the speed limit increased. For some other variables, which were related to speed limits other than the speed limit of the base case, it was most sensitive at speed limits close to the speed limit of the base case. The sensitivity of the NPV of the net benefits to the effect of the speed limit on the mean speed of traffic exceeded the sensitivity to other variables which pointed out the need for a precise knowledge of this variable before any attempt to change an existing speed limit, or else, the reliability of the outcome of the cost-benefit analysis would be eroded. The existing mean speed of traffic was found to be an important variable in determining the results of the cost-benefit analysis outcome. An accurate measurement of the existing mean speed of traffic was a crucial part of any cost-benefit analysis when a change in the speed limit was being considered. The initial mean speed of traffic in the base year could form the basis of when to change a speed limit. The relationship between the frequency and severity of personal injury accidents with the mean speed of traffic proved to be highly significant factors which could not be overlooked, even though, it was one of the most difficult relationships to develop and even more difficult to obtain firm conclusions. Any fluctuation in the travel-time cost in the future would have a serious impact on the results of the cost-benefit analysis and the effect would be more than, for example, the cost of fuel, which was the sole reason for changing speed limits in some previous cases. Uncertainty, if any, in other variables did not have large impacts on the final results.

The significance of the variables varied between the cost-benefit analysis of the NPV of the total cost and the NPV of the net benefits. Generally, the NPV of the net benefits was more sensitive to changes in these variables.

Chapter Seven

Conclusions and Recommendations

7.1 Introduction

The overall aim of this study was to evaluate the consequences of changing speed limits on major roads. To achieve this aim, both the relationship between the speed limit and the mean speed of traffic and the relationship between the mean speed of traffic and the personal injury accidents were investigated. An economic evaluation was applied to assess the consequences of changing the speed limit. The three main outcomes of the study are summarised in this chapter. They are accompanied by conclusions and recommendations. Comments and recommendations concerning speed limits in general are included at the end of the chapter.

7.2 The Effect of the Speed Limit on the Mean Speed of Traffic

The literature on the relationship between speed limits and the mean speed of traffic was reviewed with a special emphasis on previous cases where speed limits were changed in the U.K. and in some other countries. The conclusions of these studies were not consistent (see Section 2.3). Based on a hypothesis an experiment was designed in which sites were selected with similar geometric and traffic conditions (see Section 2.4) to investigate this relationship further. The main objectives of the experiment were to verify the relationship between the speed limit and the mean speed of traffic and , if it existed, to investigate the implications of the relationship. The study was limited to times and places in which the speed limit was believed to be most effective (i.e. times of the day when free-flow traffic existed and to high quality sections of highway). The data was collected according to established criteria from 11 sites in Tyne & Wear, England and 14 sites in the State of Bahrain using automatic speed recorders which were calibrated by a radar speed meter. The data collected in Bahrain was used compared with the Tyne and Wear data. The speed limits that were investigated were: 40, 50 and 70 (maximum speed limit) mile/h in Tyne and Wear and 50, 70, 80 and 100 (maximum speed limit) km/h in Bahrain. Roads with lower speed limits did not fulfil the requirements. The speed distributions of the vehicles followed a normal distribution, in most cases (see Figures 2.4a and 2.4b). The speed of the vehicles did not vary significantly through the day and the week. There was no definite relationship between the speed and the flow of traffic which satisfied the criteria set for the observations (see Figures 2.3a and 2.3b). For each speed limit, there were differences in the mean speed of the traffic (see Tables 2.4a and 2.4b). As the speed limit increased, the mean, the eighty-fifth percentile and the median (i.e. the fiftieth percentile) speeds of the traffic increased but the speed limit violations decreased. The standard deviation of the speed of the vehicles did not show a particular relationship with speed limits (see Figures 2.5a and 2.5b).

The trip length and the length of the sections of the roads varied between the observed sites. The length of vehicle trips at each site were not available so the engineering judgements of professionals (i.e. the local highway authority engineers) was used to rank the length of trips into categories (see Table 2.6). The length of each section was categorised (see Table 2.5) because it was believed that there was a positive relationship between the speed of the traffic and the length of the section of road. The exact relationship was not obvious. It was assumed that the speed of traffic was more sensitive to the 'short' sections of road than the 'long' sections. The length of the sections were allocated into seven categories. The ranges of the categories that were used reflected this assumption. The variables that could have affected the mean speed of traffic were included in the regression; namely the posted speed limit on the road, the trip length, the length of the section, the number of lanes and the heavy vehicle content. Other factors that might influence the speed of traffic (e.g. the geometric features) was avoided due to the criteria set for site selection. Three types of regression analysis were performed: linear (additive), non-linear (multiplicative), and non-linear (additive) to explore all the possibilities of links between these variables. The non-linear (additive) fit did not produce significant results, so it was discarded. The best regression equations that described this relationship had the following two forms, i.e. linear and multiplicative:

Tyne & Wear

$$\mathrm{MST} = 14.59 + 0.36\ \mathrm{SPL} + 4.07\ \mathrm{TRPLN} + 1.87\ \mathrm{LSEC}$$

$R^2 = 93.2\%$

$$MST = 6.74\ SPL^{0.43}\ LSEC^{0.09}\ TRPLN^{0.23}$$

$R^2 = 94.2\%$

Bahrain

$$MST = 33.50 + 0.26\ SPL + 4.62\ TRPLN + 1.93\ LSEC$$

$R^2 = 93.0\%$

$$MST = 18.34\ SPL^{0.24}\ LSEC^{0.08}\ TRPLN^{0.22}$$

$R^2 = 94.1\%$

where

MST: the mean speed of traffic (mile/h for Tyne & Wear and km/h for Bahrain)

SPL: the speed limit (mile/h for Tyne & Wear and km/h for Bahrain)

LSEC: the length of section category (from 1 to 7)

TRPLN: the trip length category (from 1 to 5)

(all the variables in the models were significant)

There was strong evidence from both sets of data that speed limits had a positive effect on the mean speed of traffic (i.e. from the values of t-test and R^2). Also, the length of trips and the length of the section of the road under observation were highly correlated to the mean speed of traffic. The number of lanes and the heavy vehicle contents in the traffic stream were found to be statistically insignificant because the criteria set for the test sites included free-flow traffic and high quality sections of roads which minimised the effect of these variables. Both, the linear (see Tables 2.8a and 2.8b) and the non-linear (multiplicative) models (see Tables 2.10a and 2.10b) produced satisfactory results exhibiting very high coefficients of fit. The regression fit for the eighty-fifth percentile speed of traffic gave similar results to the mean speed of traffic. The confidence intervals were relatively large which was due to the limited number of observations (See Appendix I). The predictions from the two forms of regression were similar from a practical point of view (see Figures 2.6a, 2.6b, 2.7a, and 2.7b). Generally, the average ratio between the change in the mean speed of the traffic to the change in the speed limit was about 1 to 3, in the linear model. In the multiplicative model, the average ratio was more conservative which was about 1 to 5 but both of the models tended to over-predict the results for higher speed limits. Generally, in the speed limit effect model for Tyne and Wear, the mean speed of the traffic was more sensitive to the speed limit than in the Bahrain Model which could be explained by the drivers' behaviour in terms of observing speed limits. The results agreed with some previous studies that were reviewed (e.g. (Newby, 1970), (Department of Transport U.K., 1967), (ITE Metropolitan Section of New York and New Jersey, 1977), and (Finch et al., 1994)).

The interpretation of these models should be confined to the scope of the study (i.e. free-flow traffic and high quality sections of roads) where the speed limit was believed to be most effective. Other situations (e.g. single-carriageways, sections of road with horizontal bends and congested traffic) might yield different results especially if the mean speed of traffic over a road network was to be determined. The high values of constants in the equations meant that the mean speed of traffic would not decrease below a certain level even if the speed limit was lowered. This suggested that the models should not be used for speed limits lower than those used in this study.

To establish more comprehensive results, the following recommendations were suggested:

(i) more sites should be investigated. The area of investigation should be enlarged, enabling the whole national road network to be considered when choosing suitable sites and, in this way, provide more confidence in the results;

(ii) the trip length proved to be a significant variable in determining the final results and it would be useful to estimate the variable more objectively (e.g. having on-site interviews with the drivers);

(iii) to enhance the speed limit model, it would be worth investigating different models for different types of vehicles. This could be achieved by using a more advanced type of automatic speed recorder and a wider choice of highway links that carry different proportions of vehicle types;

(iv) stated preference techniques should be used to correlate the results with those obtained from the automatic speed recorder to investigate the drivers perception of speed ; and

(v) it would be interesting to alter the posted speed limit on selected sites and observe the behaviour of drivers in response to such a change in both the short and long term.

7.3 The Effect of the Mean Speed of Traffic on the Frequency and Severity of Personal Injury Accidents

Chapter Three was devoted to the investigation of the relationship between the mean speed of traffic and the frequency and severity of personal injury accidents. The literature was reviewed on this subject. The opinion of the experts was divided on this matter (see (Ministry of Transport, 1967), (Johnson et al., 1981), (Middleton and Kenyon, 1981), (Garber and Gadiraju, 1990) and (Indiana University, 1970)). It was clear that more research was needed to explore the relationship between the mean speed of traffic and the frequency and severity of personal injury accidents. Criteria were established based on a hypothesis of comparing similar sites (Sections 3.3 and 3.4). The accident records for 9 sites in Tyne and Wear and 10 sites in Bahrain were selected according to the established criteria. It was difficult to find more suitable sites within these areas. Various characteristics of the speed distributions were used to test against the frequency and severity of personal injury accidents. Some of these definitions were obtained from the literature, whereas the others were developed for this particular study. The multiplicative relationship between the number of accidents and the speed, the length of section and the traffic flow was found to be particularly suitable for this kind of analysis. The distribution was positive and discrete with the probability of accidents decreasing as the accident frequency increased. The Poisson probability distribution modelled such a relationship. The severity of accidents were analyzed in two ways. First, each category of severity was treated in a similar way to the frequency of the total accident analysis. Secondly, it was analyzed as an outcome probability of an attempt (i.e. the attempt was the personal injury accident and the outcome could be three possibilities: slight injury, serious injury, or fatal injury). The Binomial probability distribution was suitable to describe the relationship (e.g. the number of accidents in the particular severity class was the numerator and the total number of accidents was the denominator).

Relationships between the speed of traffic and the frequency and severity of personal injury accidents were established using the data collected. The significant relationships had the following forms:

Tyne & Wear

$$ACC=0.10\ FL^{1.02}\ CUSS^{1.09}$$

$$ACCLF=0.11\ CUSS^{1.03}$$

Bahrain

$$ACCL=3.3x10^{-7}\ FW^{0.31}\ SP^{3.3}$$

$$ACC=0.16\ LG^{1.16}\ FW^{0.56}\ SI^{3.21}$$

(all the models were valid statistically in describing the relationships)

ACC= the average number of accidents per year

ACCL= the average number of accidents per km

ACCLF= the average number of accidents per year per vehicle km

LG= the length of the section (km)

FW= the traffic volume (in 10^5 veh/year)

FL= the interaction effect of the length of the section and traffic flow (FW*LG) (10^5 veh/year km)

SP= the mean speed of the traffic (km/h)

CUSS= the Coefficient of Upper Speed Spread:

$$CUSS=\frac{\text{the } 85^{th} \text{ percentile speed-the } 50^{th} \text{ percentile speed}}{\text{the } 50^{th} \text{ percentile speed}}$$

SI= the Skewness Index (symmetry):

$$SI=\frac{2\times(93^{rd} \text{ percentile speed-}50^{th} \text{ percentile speed})}{93^{rd} \text{ percentile speed-}7^{th} \text{ percentile speed}}$$

The analysis of the Tyne & Wear data did not reveal a significant relationship between the mean speed of traffic and the frequency of personal injury accidents but it revealed that differential speeds, represented in this case by the coefficient of the upper speed spread (CUSS) of vehicles, played a major role in predicting the frequency of personal injury accidents. The model that assumed the length of the section and the traffic flow were linearly related to the number of accidents, revealed high statistical results. The validation of the results revealed good agreement between the observed and the number of accidents predicted by the model (see Figure 3.2a). This result implied that as the difference between the eighty-fifth percentile speed of traffic and the median speed of traffic increased, more vehicles exhibited excessive speeds which led to more accidents. Such differences had a more severe effect if the median speed was 'low', which meant the difference would be high when it was considered relative to the median speed. Some of the speed differential characteristics had a significant effect on the frequency of injury accidents but these were less significant than CUSS. This could be explained by the fact that the speed differentials of the upper half of the speed distribution, where the absolute speeds of vehicles were high and the control of vehicles was more difficult, had a more severe influence on accidents than a similar speed spread at lower parts of the speed distribution. The mean speed and the eighty-fifth percentile speed did not show any significant results. This result was supported by studies which were inclined to the opinion that the speed differentials between vehicles (i.e. and excessive vehicle speeds) was the cause of accidents not the mean speed of traffic (e.g. Solomon (1964), Garber and Gadiraju (1990), ITE Metropolitan section of New York and New Jersey Sub-Committee (1977) and ITE Special Technical Council Task Force (1987)). The length of the section had almost a linear relationship with the number of accidents, which was anticipated. This relationship meant that if the length of the section was doubled, for example, double the number of accidents were expected. This was not the case for the relationship between the traffic flow and the number of accidents on a particular length of section which meant that doubling the flow of traffic, for example, did not mean that the number of accidents would double, as was suggested by some studies (see Section 3.2.5). No significant relationship was found between the mean speed of traffic and the severity of personal injury accidents.

The Bahrain data revealed that the speed characteristic which was most related to the number of accidents (i.e. the length of the section was assumed to have a linear relationship with number of accidents) was the mean speed (SP) of traffic. The validation of the results revealed good agreement between the observed data and the number of accidents predicted by the model (see Figures 3.2b). This agreed with the experiences in different countries where changing the speed limit led to a change in the mean speed of traffic which was associated with a change in the number of accidents (see Section 3.2.1). The other influential speed characteristic was the Skewness Index (SI) which agreed with the opinion that the speed differential was related to the number of accidents. Here, also, the relationship between the length of the section, the traffic flow, and the interaction effect of the length of the section and the traffic flow with the frequency of injury accidents had similar characteristics to those found in Tyne & Wear. No significant relationship was found between the mean speed of traffic and the severity of personal injury accidents.

The results of the two sets of data agreed, partially. The speed differential of vehicles was an influential factor when determining the number of accidents in both places (i.e. CUSS and SI), even though, the speed differential in Tyne & Wear was for the upper part of the speed distribution and the speed differential for Bahrain was for the whole distribution. The mean speed of traffic remained the main difference between the results of the two sets of data. The difference could be associated with different environmental conditions prevailing in the two places such as road conditions, vehicles, traffic laws, weather, drivers' education and the cultural background, in general. Each of these factors could have contributed individually or collectively in producing the dissimilarity of the results of the two sets of the data. At this stage, it would be hard to identify the exact reason for the variation in the results.

Generally, the limited data could have affected the results. Ideally, more sites were needed to test the relationships more rigorously. For example, sites of similar lengths but with significantly different speed characteristics would have enhanced the results but, usually, the vehicles attained higher speeds on the longer sections of road with 'higher' speed limits displayed. Also, longer sections of road were needed as the shorter lengths exhibited very few accidents and, after the selection procedure, the number of accidents decreased, even further, which made the significance of the analysis less reliable. In the case of the severity of accidents, many sites exhibited no serious or fatal injury accidents which led to small variations in the severity of injury accidents for different sites. This was reflected in the results from the regression analysis, which explained the variation in the severity of the accidents by the variation in the length of the sections (i.e. in the data collected, most of the severe injury accidents happened on the 'longer' sections of roads) and the traffic volume and, in some other cases, the variation in the accidents was explained by a constant of regression, only, which produced satisfactory statistical results. This was true for both methods of analysis. The random occurrence of accidents could have affected the results, especially, for the serious and fatal accidents on the 'shorter' sections. The accuracy of reporting the accidents could have been another source of error. The assumptions that have been made such as the typical traffic speeds and traffic volumes could have been sources of error and affected the results. The strong indications that the speed differentials was a main source of accidents should influence police enforcement. Drivers who cruise at higher or lower speeds than the mean speed of traffic (e.g. 'aggressive' or 'slow' drivers) should be targeted as a means to reduce accidents.

The following recommendations were suggested to develop further the outcome of the study:

(i) to observe more sites having wider characteristics (i.e. the length of the section, the traffic volume, and the speed distribution characteristics) in order to be able to test the contribution of the variables more closely to the final results;

(ii) to investigate whether the accident statistics were typical for the data collection sites and, if necessary, to choose additional sites with more typical ratios between slight, serious and fatal injury accidents; and

(iii) to develop a number of sites to monitor continuously the speed and flow of traffic on certain sections of motorway (or roads of similar character) in order to build a data base. It was found that there were many DoT monitoring sites on motorways but they do not normally coincide with sites meeting the criteria set for this study.

7.4 Cost-benefit Analysis Applied to the Effect of Changing Speed Limits

Chapter Four discussed cost-benefit analysis in general with a special emphasis on the method published by the Department of Transport U.K. in the COBA manuals. The approach was considered to be suitable to meet the objectives and scope of the study, though, there were some limitations.

In Chapter Five, the cost-benefit analysis method was applied to a typical case study. The potential NPVs of both the net benefits and the total cost were estimated for possible changes in the current speed limit to both 'higher' and 'lower' speed limits.

Positive NPVs of the net benefits were obtained at 'higher' speed limits and negative NPVs for 'lower' speed limits with the assumption that the frequency and severity of personal injury accidents did not change with the changes in the speed limits (i.e. this was assumed due to the uncertainty in the relationship between the mean speed of traffic and the frequency and severity of personal injury accidents). The absolute magnitudes of the NPVs of the net benefits were found to be larger when the current speed limit was lowered than when it was increased by the same amount. There was evidence that the positive net benefits tended to decrease as the speed limits increased beyond 100 mile/h. The assumption that the cost of PIAs were constant at various speed limits could have affected the final economic assessment. The 'break-even' analysis that was performed revealed that a change in the accident cost due to changes in the speed limit of the base case would have affected the final result of the economic assessment but, most probably, it would not have changed the sign of the NPV of the net benefits from lowering the speed limit of the base case. However, when the speed limit of the base case was increased the conclusion was more cautious, even though, any change in the sign of the NPV of the net benefits would still be less likely.

The travel-time cost played a major role in determining the NPV of net benefits which were derived from changing the existing speed limit. This should not be a surprise because shortening journey time has been a quest for mankind since the beginning of history. Lowering the speed limit would work in the opposite direction of this instinct. The large share of travel-time cost within the total cost is a natural reflection of this fact. The environmental effects could not be included in the cost-benefit analysis because they were not assigned monetary values and, it was believed, as explained in Chapter One, they would not change considerably within the ranges of speed investigated and that there impact would not be vital.

The decision making process of selecting an appropriate speed for a particular site limit should not be confined to a single viewpoint (e.g. improving road traffic safety or saving energy). A more comprehensive attitude should be adopted towards such decisions. This study was an attempt to achieve this goal which brought most of the consequences of changing speed limits to a common ground which made the overall assessment more objective. The cost benefit analysis reflects, theoretically, the perception of society to costs and benefits generated by road projects. It might have been accepted in the past not to include the environmental costs but with the rapid increase in awareness of the public to the environmental issues, ignoring the cost of environmental implications of road projects in cost benefit analysis is increasingly unacceptable and forms a major drawback in any analysis in general even though the environmental effects were not significant in this particular study, as it was discussed in Chapter One.

It was concluded from this study that increasing the existing speed limit would bring positive benefits even though the frequency and severity of accidents might increase. This conclusion might sound unethical but the previous argument about the perception of society stands true here, as well. If society rejected such a conclusion, then the cost of accidents should be adjusted to avoid such an outcome but by using the existing values the conclusion should reflect, theoretically, society's opinion.

Another argument which might be raised about the small contribution to the cost of accidents due to the investment that has been made in improving the safety of roads and vehicles and, also, the education of the drivers and that it would be wrong to exploit such improvements by increasing the speed limit. This argument is true to a certain extent but the following should be considered: firstly, there is no firm relationship between increasing the speed limit and reducing the safety on roads; and secondly, the practice of capitalising on the safety improvements is used in other modes of transport to increase their speed or capacity.

The conclusion of this study is true within the base case considered. The results should not be generalised to other situations such as: the motorway network (which includes for example, the merging and diverging areas, sections of lower geometry quality), lower quality of roads, different weather conditions, roads with at-grade intersections and restricted traffic flow. All of these conditions could be areas for further studies.

Though the conclusion was inclined to the opinion that positive net benefits would occur speed limits were increased, this conclusion should not overshadow other factors in the decision making process when deciding the level of a particular speed limit such as political considerations (e.g. the reaction of the public), safety considerations (e.g. the 'spill-over' effect on other types of road), social considerations (e.g. the image of 'fast' drivers), energy considerations (e.g. the global situation of energy supplies), economic considerations (e.g. the effect on the motor industry), environmental considerations (e.g. alternative fuels in the long run), and transportation considerations (e.g. the national transport strategy).

In Chapter Six, the sensitivity of the calculation of the NPV were determined for both the total cost and the net benefits to the variables and the assumptions for the base case were determined to reveal the relative importance of the variables and the significance of the assumptions. The variables tested were: the travel-time cost, the cost of fuel and the non-fuel elements of VOC, the accident cost, the frequency of PIAs, the number of FI casualties per average PIA, the discount rate, the initial traffic flow in the base year, the traffic growth, the initial mean speed of traffic in the base year, the growth of the mean speed of traffic, the combined effect of traffic growth and the decrease in the mean speed of traffic, the traffic composition, and the speed limit effect on the mean speed of traffic.

The initial daily traffic flow for the base year was the most sensitive variable in determining the NPV of the total cost followed by the traffic composition, the travel-time cost, the initial mean speed of traffic for the base year, the speed limit effect, the non-fuel element cost and the discount rate in descending order.

The NPVs of the net benefits were most sensitive to the effect of the speed limit model, the initial mean speed of traffic in the base year, the travel-time cost, the frequency of personal injury accidents (PIAs), and the number of fatal injury (FI) casualties per average PIA. Again, these were listed in descending order (i.e. for most of the speed limits). The sensitivity of the NPV of the net benefits, to some variables, increased as the speed limit increased. For some other variables, which were related to speed limits other than the speed limit of the base case, it was most sensitive at speed limits close to the speed limit of the base case (i.e. 70 mile/h).

These variables all require extra attention when their values are determined because any inaccuracy in their values would lead to significant changes in the outcome. Policy-makers responsible for such decisions should pay extra attention to these variables when a change in speed limit is proposed. Any proposals for changing a speed limit should be accompanied by extensive studies regarding the effect of the change on the mean speed of traffic with precise knowledge of the behaviour of drivers in selecting the desired speed in response to these changes, especially if the change in the current speed limit was 'small' (e.g. ±10 mile/h). The mean speed of traffic should be thoroughly monitored and regularly updated before any decision is made regarding changes in the speed limit. The relationship of the frequency and severity of personal injury accidents with the speed of traffic, in general, and, with the mean speed of traffic, in particular, should be understood and estimated as precisely as possible to avoid false conclusions. This task is not an easy one, especially, when one considers the efforts taken in this study to explore such relationships with results that were no more satisfactory than what existed already. The task would become even more difficult with the effect of safety campaigns that, already, have been launched (e.g. "a one-third reduction in the annual number of injury accidents by the year 2000 in U.K.") and those proposed in the future on road users and the effect of improvements in the safety of vehicles (e.g. the introduction of air bags and better vehicle design in terms of safety). The better estimation of travel-time cost as perceived by road users, especially in the case of changing the speed limit, could enhance the contribution to the analysis of this significant component of cost. Any changes in the travel-time cost due to unexpected changes in the economics or in the perception of road users would have a greater impact on the cost-benefit analysis and, therefore, on the NPV of the net benefits and this would be more than, for example, the cost of fuel, which was the sole reason for changing speed limits in some previous cases. The accurate estimation of other variables within the cost-benefit analysis should not be ignored.

It was worthwhile noticing that the sensitivity of the NPV of the net benefits and the NPV of the total cost to the variables used in the cost-benefit analysis were different. This means that the required accuracy of the variables applied to the cost-benefit analysis differed when determining the NPV of the net benefits derived from changing the current speed limit for the base case compared to determining the NPV of the total cost of changing the speed limit.

7.5 General Comments and Recommendations on Speed Limits

This thesis has considered road traffic on motorways and similar high quality roads where vehicles were segregated, completely, from other users on the road, e.g. pedestrians. In residential areas, for example, the concept of the speed limit should be treated and discussed differently.

The basic instinct of people, generally, is to preserve themselves. Drivers of motor-vehicles are no exception. For example, at traffic signals most drivers stop when the lights are red because they perceive a high risk of an accident if they proceeded into the junction. On the other hand, most drivers exceed the maximum speed limit on roads. It seems that the main reason for this kind of behaviour is that drivers do not perceive a higher risk of an accident if they violate the maximum speed limit which they consider to be unrealistic, as some studies have shown. To encourage drivers to respect speed limits, they should be set at levels to reflect the actual conditions of the driving environment and when that environment changes there should be corresponding changes in the speed limit. Speed limits should respond to changes in the environment such as: traffic conditions (e.g. peak or off-peak hours, and traffic queues due to maintenance work or road accidents), weather conditions (e.g. dry or wet), lighting conditions (i.e. day or night), and road geometry (e.g. sharp bends). 'Responsive' speed limits would lead drivers to observe speed limits more often because they would appreciate the reason for restricting speed. This would require monitoring stations, as can be seen in other modes of transport (e.g. radar control for air traffic). Such an idea needs resources but with both the existing and the future advanced technology, less manpower would be needed to monitor the road traffic environment which would make the monitoring increasingly affordable by road operators.

Safety on motorways and similar 'high-speed roads' could be improved further by means such as:

(i) drivers who use motorways should be given additional education and training;

(ii) vehicles should be checked and tested more rigorously to qualify to use motorways;

(iii) police enforcement should be aimed at abnormal driving behaviour such as 'aggressive' driving and 'slow' driving which causes speed differentials between vehicles which has been shown to be one of the major causes of accidents;

(iv) more resources should be devoted to highway research in areas such as: the relationship between speed limits and the mean speed of traffic, and the effect of changes in the mean speed of traffic on the frequency and severity of personal injury accidents; and

(v) decisions to impose speed limits should be based on economic analysis, or a similar kind of analysis, where the various consequences of imposing the speed limit can be brought to a common ground which would prevent any consequence from imposing a speed limit to overshadow others. Also, the environmental impact of the effect of the speed limit should be considered in quantitative (if possible) and qualitative terms.

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Appendices

Appendix I

The description of the investigated sites, the automatic speed recorder output, and the output of the statistical analysis of the relationship between speed limits and the speed of traffic

Table 2.1a Description of the Sites (Tyne & Wear)

site	heavy vehicle proportion	number of lanes	lane width (metre)	side obstr. dist.+ (metre)	length of the section (metre)	length* of the section category	length** of the trips category	pave-ment cond	land-use active
EA167	4.3	2	3.40	NSH	1130	3	2	good	low
EA1	18.4	2	3.65	3.40	44000	7	4	good	low
E19	6.1	2	3.65	NSH	3890	6	3	good	low
EGHN	5.0	2	3.40	NSH	640	2	2	good	medium
EGHS	5.0	2	3.40	NSH	970	2	3	good	low
EJR	5.0	2	3.65	NSH	1160	3	3	good	low
ELN	4.5	2	3.25	NSH	1250	3	2	good	medium
EGN	5.0	2	3.50	NSH	620	2	2	good	low
E194	4.0	2	3.70	NSH	450	1	2	good	low
EHW	6.1	2	3.50	NSH	470	1	2	good	low
EOC	6.1	2	3.50	NSH	760	2	2	good	low

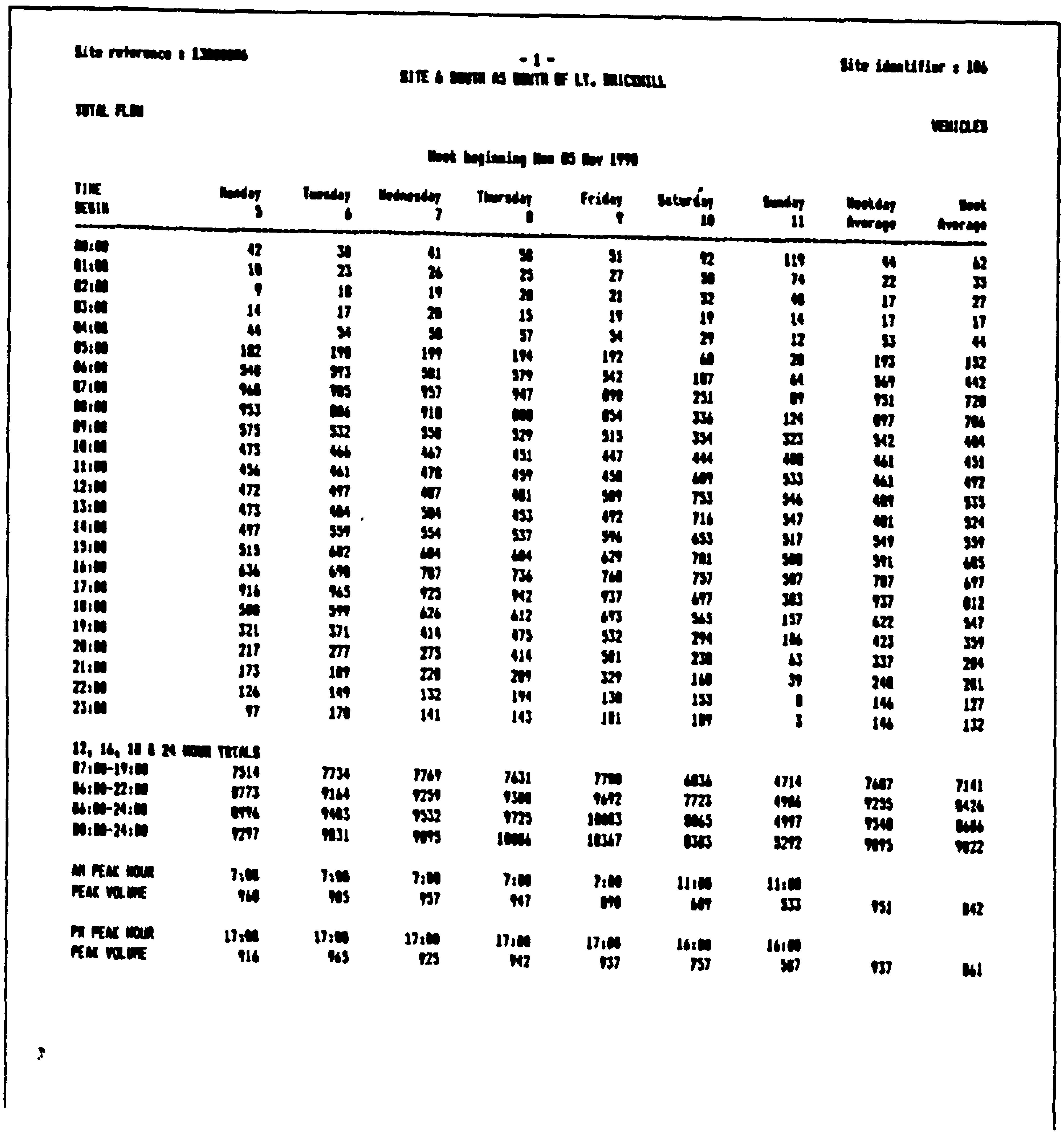
+ NSH: no shoulder exists
* See table 2.6
** See table 2.5

Table 2.1b: Description of the Sites (Bahrain)

site	heavy vehicle proportion	number of lanes	lane width (metre)	side obstr. dist.+ (metre)	length of the section (metre)	length* of the section category	length** of the trip category	pavement condition	landuse activity
BSA50	6.4	2	3.75	NSH	820	2	2	good	low
BKW50	7.5	2	3.75	NSH	1790	4	4	good	low
BBU70	6.4	2	3.75	NSH	1050	3	3	good	low
BSA70	14.0	2	3.75	NSH	1900	4	4	fair	meduim
BSE70	21.1	2	3.75	NSH	550	2	2	fair	low
BFA80	15.9	3	3.75	NSH	800	2	3	v.good	low
BKH80	8	3	3.75	NSH	1680	4	4	v.good	low
BHA80	17.7	3	3.00	NSH	1520	4	4	v.good	low
BGH80	6.5	3	3.75	NSH	1180	3	4	excellent	low
BIS 80	6.9	3	3.75	NSH	1580	4	4	excellent	low
BKH 100	3.9	3	3.75	NSH	2490	5	5	excellent	low
BSA 100	3.5	2	3.75	2.4	2680	5	3	excellent	low
BMU 100	7.9	2	3.75	2.0	840	2	5	excellent	low
BMJ 100	6.9	3	3.75	NSH	1580	4	4	excellent	low

+ NSH: no shoulder exists
* See table 2.6
** See table 2.5

Exhibit 2.1: A Sample of VISA Programme Output



```
Site reference : 13000006                       - 1 -                                    Site identifier : 106
                                SITE 6 SOUTH A5 NORTH OF LT. BRICKHILL

TOTAL FLOW
                                                                                                    VEHICLES

                                   Week beginning Mon 05 Nov 1990

TIME             Monday   Tuesday  Wednesday  Thursday    Friday  Saturday    Sunday   Weekday      Week
BEGIN                 5         6          7         8         9        10        11   Average   Average
-----------------------------------------------------------------------------------------------------------
00:00                42        30         41        56        51        92       119        44        62
01:00                10        23         26        25        27        30        74        22        33
02:00                 9        18         19        20        21        32        48        17        27
03:00                14        17         20        15        19        19        14        17        17
04:00                44        34         50        57        34        29        12        53        44
05:00               182       198        199       194       192        60        20       193       132
06:00               548       593        581       579       542       187        64       569       442
07:00               968       985        957       947       898       231        89       951       720
08:00               953       806        910       888       854       336       126       897       706
09:00               575       532        550       529       515       354       323       542       404
10:00               473       466        467       451       447       444       408       461       431
11:00               456       461        478       459       450       609       533       461       492
12:00               472       497        487       481       509       753       546       489       535
13:00               473       404        504       453       492       716       547       481       524
14:00               497       559        554       537       596       653       517       549       559
15:00               515       602        604       604       629       701       500       591       605
16:00               636       698        787       736       760       737       507       787       697
17:00               916       965        925       942       937       697       383       937       812
18:00               508       599        626       612       693       565       157       622       547
19:00               321       371        414       475       532       294       186       423       359
20:00               217       277        275       414       501       238        63       337       284
21:00               173       189        220       209       329       160        39       248       201
22:00               126       149        132       194       130       153         8       146       127
23:00                97       170        141       143       181       109         3       146       132

12, 16, 18 & 24 HOUR TOTALS
07:00-19:00        7314      7734       7769      7631      7780      6836      4714      7687      7141
06:00-22:00        8773      9164       9259      9300      9672      7723      4986      9235      8426
06:00-24:00        8996      9403       9532      9725     10003      8065      4997      9540      8686
00:00-24:00        9297      9831       9895     10004     10367      8383      5292      9895      9022

AM PEAK HOUR       7:00      7:00       7:00      7:00      7:00     11:00     11:00
PEAK VOLUME         968       985        957       947       898       609       533       951       842

PM PEAK HOUR      17:00     17:00      17:00     17:00     17:00     16:00     16:00
PEAK VOLUME         916       965        925       942       937       757       507       937       861
```

Exhibit 2.2a: The Linear Regression Analysis of the Speed Limit Effect on the Mean Speed of Traffic (Tyne & Wear)

```
***********************************
* Regression of all the variables *
***********************************
MTB > Regress 'SPD' 4 'SPL' 'HV' 'LENGTH' 'O/D'.
The regression equation is
SPD = 15.2 + 0.362 SPL - 0.284 HV + 1.89 LENGTH + 4.82 O/D

Predictor     Coef      Stdev    t-ratio      p
Constant     15.187     3.881      3.91   0.006
SPL         0.36174   0.05732      6.31   0.000
HV          -0.2844    0.2157     -1.32   0.229
LENGTH       1.8945    0.5438      3.48   0.010
O/D           4.817     1.531      3.15   0.016
s = 2.326      R-sq = 96.0%     R-sq(adj) = 93.8%

Analysis of Variance
SOURCE       DF         SS          MS         F       p
Regression    4      919.79      229.95     42.51   0.000
Error         7       37.86        5.41
Total        11      957.65

SOURCE       DF      SEQ SS
SPL           1      628.45
HV            1       20.08
LENGTH        1      217.74
O/D           1       53.53

*******************************************
* Regression of the significant variables *
*******************************************

MTB > Regress 'SPD' 3 'SPL' 'LENGTH' 'O/D'.
The regression equation is
SPD = 14.6 + 0.363 SPL + 1.87 LENGTH + 4.06 O/D
Predictor     Coef      Stdev    t-ratio      p
Constant     14.593     4.028      3.62   0.007
SPL         0.36341   0.05989      6.07   0.000
LENGTH       1.8722    0.5680      3.30   0.011
O/D           4.065     1.485      2.74   0.026
s = 2.431      R-sq = 95.1%     R-sq(adj) = 93.2%

Analysis of Variance
SOURCE       DF         SS          MS         F       p
Regression    3      910.39      303.46     51.36   0.000
Error         8       47.27        5.91
Total        11      957.65

SOURCE       DF      SEQ SS
SPL           1      628.45
LENGTH        1      237.68
O/D           1       44.26
```

Exhibit 2.2b: The Linear Regression Analysis of the Speed Limit Effect on the Mean Speed of Traffic (Bahrain)

```
********************************
* Regression of all variables *
********************************

Worksheet retrieved from file: C:\MINITAB\ARJ\SPD\BAH\BMDL1.MTW
MTB > Regress 'SPD' 5 'SPL' 'HV' 'LANE' 'O/D' 'LENGTH'.
The regression equation is
SPD = 35.0 + 0.235 SPL - 0.232 HV + 2.34 LANE + 4.15 O/D + 1.50
LENGTH

Predictor      Coef       Stdev    t-ratio       p
Constant     34.969       3.786       9.24   0.000
SPL         0.23516     0.04093       5.75   0.000
HV          -0.2321      0.1155      -2.01   0.079
LANE          2.337       1.265       1.85   0.102
O/D          4.1548      0.7759       5.35   0.000
LENGTH       1.4972      0.6220       2.41   0.043
s = 2.016      R-sq = 96.9%     R-sq(adj) = 94.9%
Analysis of Variance
SOURCE       DF        SS          MS         F       p
Regression    5    1006.61     201.32     49.55   0.000
Error         8      32.50       4.06
Total        13    1039.11
SOURCE       DF     SEQ SS
SPL           1     699.93
HV            1      62.42
LANE          1      68.35
O/D           1     152.37
LENGTH        1      23.54

*******************************************
* Regression of the significant variables *
*******************************************
MTB > Regress 'SPD' 3 'SPL' 'O/D' 'LENGTH'.
The regression equation is
SPD = 33.5 + 0.259 SPL + 4.62 O/D + 1.93 LENGTH
Predictor      Coef       Stdev    t-ratio       p
Constant     33.474       3.415       9.80   0.000
SPL         0.25869     0.04626       5.59   0.000
O/D          4.6172      0.8762       5.27   0.000
LENGTH       1.9265      0.6851       2.81   0.018
s = 2.366      R-sq = 94.6%     R-sq(adj) = 93.0%
Analysis of Variance
SOURCE       DF        SS          MS         F       p
Regression    3     983.14     327.71     58.55   0.000
Error        10      55.97       5.60
Total        13    1039.11
SOURCE       DF     SEQ SS
SPL           1     699.93
O/D           1     238.96
LENGTH        1      44.25
```

Exhibit 2.3a: The Linear Regression Analysis of the Speed Limit Effect on the Eighty-Fifth Percentile Speed of Traffic (Tyne & Wear)

```
***********************************
* Regression of all the variables *
***********************************
Worksheet retrieved from file: C:\MINITAB\ARJ\SPD\ENG\EMDL1.MTW
MTB > Regress '85%' 4 'SPL' 'HV' 'LENGHT' 'O/D'.
The regression equation is
85% = 14.6 + 0.497 SPL - 0.468 HV + 2.25 LENGHT + 5.55 O/D
Predictor      Coef       Stdev    t-ratio       p
Constant     14.644       5.952       2.46   0.043
SPL         0.49685     0.08791       5.65   0.000
HV          -0.4685      0.3309      -1.42   0.200
LENGHT       2.2493      0.8339       2.70   0.031
O/D           5.552       2.349       2.36   0.050
s = 3.567      R-sq = 94.2%     R-sq(adj) = 90.8%

Analysis of Variance
SOURCE       DF         SS         MS        F       p
Regression    4    1438.57     359.64    28.27   0.000
Error         7      89.06      12.72
Total        11    1527.63

SOURCE       DF     SEQ SS
SPL           1    1053.93
HV            1      12.64
LENGHT        1     300.91
O/D           1      71.10


*******************************************
* Regression of the significant variables *
*******************************************
MTB > Regress '85%' 3 'SPL' 'LENGHT' 'O/D'.
The regression equation is
85% = 13.7 + 0.500 SPL + 2.21 LENGHT + 4.31 O/D
Predictor      Coef       Stdev    t-ratio       p
Constant     13.666       6.272       2.18   0.061
SPL         0.49959     0.09324       5.36   0.000
LENGHT       2.2125      0.8843       2.50   0.037
O/D           4.312       2.312       1.87   0.099
s = 3.784      R-sq = 92.5%     R-sq(adj) = 89.7%
Analysis of Variance
SOURCE       DF         SS         MS        F       p
Regression    3    1413.07     471.02    32.89   0.000
Error         8     114.57      14.32
Total        11    1527.63

SOURCE       DF     SEQ SS
SPL           1    1053.93
LENGHT        1     309.32
O/D           1      49.81
```

Exhibit 2.3b: The Linear Regression Analysis of the Speed Limit Effect on the Eighty-Fifth Percentile Speed of Traffic (Bahrain)

```
***********************************
* Regression of all the variables *
***********************************
Worksheet retrieved from file: C:\MINITAB\ARJ\SPD\BAH\BMDL1.MTW
MTB > Regress '85' 5 'SPL' 'HV' 'LANE' 'O/D' 'LENGTH'.
The regression equation is
85 = 43.6 + 0.250 SPL - 0.325 HV + 1.77 LANE + 5.92 O/D + 1.83 LENGTH

Predictor      Coef      Stdev   t-ratio      p
Constant     43.594      7.027      6.20  0.000
SPL         0.25004    0.07597      3.29  0.011
HV          -0.3249     0.2144     -1.52  0.168
LANE          1.772      2.348      0.75  0.472
O/D           5.920      1.440      4.11  0.003
LENGTH        1.832      1.155      1.59  0.151
s = 3.742      R-sq = 93.1%     R-sq(adj) = 88.7%

Analysis of Variance
SOURCE        DF         SS         MS       F      p
Regression     5    1501.85     300.37   21.46  0.000
Error          8     111.99      14.00
Total         13    1613.84

SOURCE        DF     SEQ SS
SPL            1     956.87
HV             1     128.12
LANE           1      80.83
O/D            1     300.80
LENGTH         1      35.23

*******************************************
* Regression of the significant variables *
*******************************************
MTB > Regress '85' 2 'SPL' 'O/D'.
The regression equation is
85 = 41.9 + 0.297 SPL + 7.35 O/D

Predictor      Coef      Stdev   t-ratio      p
Constant     41.933      6.271      6.69  0.000
SPL         0.29708    0.08561      3.47  0.005
O/D           7.355      1.554      4.73  0.000
s = 4.434      R-sq = 86.6%     R-sq(adj) = 84.2%

Analysis of Variance
SOURCE        DF         SS         MS       F      p
Regression     2    1397.53     698.77   35.53  0.000
Error         11     216.31      19.66
Total         13    1613.84
SOURCE        DF     SEQ SS
SPL            1     956.87
O/D            1     440.66
```

Exhibit 2.4a: The Predictions of the Linear Speed Limit Effect model on the Mean Speed of Traffic (Tyne & Wear)

```
************************************************
* The predicted values of the observed sites *
************************************************
Worksheet retrieved from file: C:\MINITAB\ARJ\SPD\ENG\EMDL1.MTW
MTB > Regress 'SPD' 3 'SPL' 'LENGTH' 'O/D';
SUBC>   Predict 'SPL' 'LENGTH' 'O/D'.

The regression equation is
SPD = 14.6 + 0.363 SPL + 1.87 LENGTH + 4.06 O/D

    Fit  Stdev.Fit        95% C.I.           95% P.I.
 53.777      1.477  ( 50.370, 57.185)  ( 47.216, 60.338)
 69.395      1.890  ( 65.035, 73.755)  ( 62.293, 76.497)
 63.458      1.554  ( 59.874, 67.042)  ( 56.804, 70.113)
 50.033      1.649  ( 46.229, 53.836)  ( 43.258, 56.808)
 55.970      1.579  ( 52.327, 59.613)  ( 49.283, 62.656)
 50.574      0.969  ( 48.338, 52.809)  ( 44.538, 56.609)
 44.637      0.964  ( 42.413, 46.861)  ( 38.605, 50.669)
 48.701      1.215  ( 45.899, 51.503)  ( 42.433, 54.969)
 39.131      1.149  ( 36.480, 41.781)  ( 32.929, 45.332)
 42.875      1.462  ( 39.502, 46.248)  ( 36.332, 49.418)
 45.067      1.429  ( 41.771, 48.364)  ( 38.563, 51.571)
 41.003      1.186  ( 38.267, 43.738)  ( 34.764, 47.241)
```

```
**********************************************
* The predicted values of new speed limits *
* for the site: EA1                         *
**********************************************
MTB > Regress 'SPD' 3 'SPL' 'LENGTH' 'O/D';
SUBC>   Predict 'SPLA1' 'LNGA1' 'O-DA1'.

The regression equation is
SPD = 14.6 + 0.363 SPL + 1.87 LENGTH + 4.06 O/D

    Fit  Stdev.Fit        95% C.I.           95% P.I.
 62.127      2.234  ( 56.974, 67.280)  ( 54.512, 69.742)
 63.944      2.090  ( 59.124, 68.764)  ( 56.550, 71.338)
 65.761      1.981  ( 61.192, 70.329)  ( 58.529, 72.993)
 67.578      1.913  ( 63.166, 71.989)  ( 60.444, 74.712)
 69.395      1.890  ( 65.035, 73.755)  ( 62.293, 76.497)
 71.212      1.915  ( 66.795, 75.629)  ( 64.075, 78.349)
 73.029      1.985  ( 68.451, 77.607)  ( 65.791, 80.267)
 74.846      2.096  ( 70.012, 79.680)  ( 67.443, 82.249)
 76.663      2.241  ( 71.493, 81.833)  ( 69.037, 84.290)
```

Exhibit 2.4b: The Predictions of the Linear Speed Limit Effect Model on the Mean Speed of Traffic (Bahrain)

```
**********************************************
* The predicted values of the observed sites *
**********************************************
MTB > Retrieve 'C:\MINITAB\ARJ\SPD\BAH\BMDL1.MTW'.
 WORKSHEET SAVED  2/27/1994

Worksheet retrieved from file: C:\MINITAB\ARJ\SPD\BAH\BMDL1.MTW
MTB > Regress 'SPD' 3 'SPL' 'O/D' 'LENGTH';
SUBC>   Predict 'SPL' 'O/D' 'LENGTH'.
The regression equation is
SPD = 33.5 + 0.259 SPL + 4.62 O/D + 1.93 LENGTH

    Fit  Stdev.Fit        95% C.I.           95% P.I.
  92.061      1.339   ( 89.077, 95.046)  ( 86.002, 98.120)
  82.827      1.856   ( 78.691, 86.963)  ( 76.125, 89.528)
  86.282      1.897   ( 82.054, 90.510)  ( 79.523, 93.040)
  78.417      0.776   ( 76.688, 80.146)  ( 72.868, 83.966)
  85.517      1.061   ( 83.154, 87.881)  ( 79.739, 91.296)
  71.874      1.127   ( 69.363, 74.384)  ( 66.034, 77.713)
  80.344      0.768   ( 78.632, 82.055)  ( 74.800, 85.887)
  80.344      0.768   ( 78.632, 82.055)  ( 74.800, 85.887)
  78.417      0.776   ( 76.688, 80.146)  ( 72.868, 83.966)
  71.213      0.792   ( 69.448, 72.978)  ( 65.653, 76.773)
  77.757      0.982   ( 75.568, 79.945)  ( 72.048, 83.466)
  64.669      1.409   ( 61.529, 67.810)  ( 58.532, 70.807)
  59.496      1.483   ( 56.190, 62.801)  ( 53.272, 65.719)
  72.583      1.731   ( 68.725, 76.441)  ( 66.049, 79.116)


**********************************************
* The predicted values of new speed limits *
* for the site: BKH100                     *
**********************************************
MTB > Regress 'SPD' 3 'SPL' 'O/D' 'LENGTH';
SUBC>   Predict 'SPLKH' 'O-DKH' 'LNGKH'.
The regression equation is
SPD = 33.5 + 0.259 SPL + 4.62 O/D + 1.93 LENGTH

    Fit  Stdev.Fit        95% C.I.           95% P.I.
  81.714      2.063   ( 77.117, 86.310)  ( 74.718, 88.709)
  84.300      1.731   ( 80.442, 88.159)  ( 77.767, 90.834)
  86.887      1.472   ( 83.606, 90.169)  ( 80.677, 93.098)
  89.474      1.329   ( 86.512, 92.437)  ( 83.426, 95.522)
  92.061      1.339   ( 89.077, 95.046)  ( 86.002, 98.120)
  94.648      1.499   ( 91.306, 97.990)  ( 88.406,100.891)
  97.235      1.769   ( 93.292,101.179)  ( 90.651,103.819)
  99.822      2.107   ( 95.125,104.519)  ( 92.761,106.883)
 102.409      2.486   ( 96.868,107.949)  ( 94.760,110.057) X
 X  denotes a row with X values away from the center
```

Exhibit 2.5a: The Predictions of the Linear Speed Limit Effect Model on The Eighty-Fifth Percentile Speed (Tyne & Wear)

```
***********************************************
* The predicted values of the observed sites  *
***********************************************
MTB > Regress '85%' 3 'SPL' 'LENGHT' 'O/D';
SUBC>   Predict 'SPL' 'LENGHT' 'O/D'.
The regression equation is
85% = 13.7 + 0.500 SPL + 2.21 LENGHT + 4.31 O/D

   Fit  Stdev.Fit      95% C.I.          95% P.I.
  63.90      2.30   ( 58.59,  69.20)  ( 53.68,  74.11)
  81.37      2.94   ( 74.59,  88.16)  ( 70.32,  92.43)
  74.85      2.42   ( 69.27,  80.43)  ( 64.49,  85.21)
  59.47      2.57   ( 53.55,  65.40)  ( 48.93,  70.02)
  66.00      2.46   ( 60.33,  71.67)  ( 55.59,  76.41)
  58.22      1.51   ( 54.74,  61.70)  ( 48.82,  67.62)
  51.69      1.50   ( 48.23,  55.16)  ( 42.30,  61.09)
  56.01      1.89   ( 51.64,  60.37)  ( 46.25,  65.76)
  44.49      1.79   ( 40.36,  48.61)  ( 34.83,  54.14)
  48.91      2.28   ( 43.66,  54.16)  ( 38.72,  59.10)
  51.01      2.22   ( 45.88,  56.14)  ( 40.88,  61.14)
  46.70      1.85   ( 42.44,  50.96)  ( 36.99,  56.41)
```

```
***********************************************
* The predicted values of the new speed limits *
* site : EA1                                   *
***********************************************

MTB > Regress '85%' 3 'SPL' 'LENGHT' 'O/D';
SUBC>   Predict 'SPL1' 'LENGTH1' 'O/D1'.

The regression equation is
85% = 13.7 + 0.500 SPL + 2.21 LENGHT + 4.31 O/D

   Fit  Stdev.Fit      95% C.I.          95% P.I.
  71.38      3.48   ( 63.36,  79.40)  ( 59.53,  83.24)
  73.88      3.25   ( 66.37,  81.38)  ( 62.37,  85.39)
  76.38      3.08   ( 69.26,  83.49)  ( 65.12,  87.64)
  78.88      2.98   ( 72.01,  85.74)  ( 67.77,  89.98)
  81.37      2.94   ( 74.59,  88.16)  ( 70.32,  92.43)
  83.87      2.98   ( 77.00,  90.75)  ( 72.76,  94.98)
  86.37      3.09   ( 79.24,  93.50)  ( 75.10,  97.64)
  88.87      3.26   ( 81.34,  96.39)  ( 77.34, 100.39)
  91.37      3.49   ( 83.32,  99.41)  ( 79.49, 103.24)
```

Exhibit 2.5b: The Predictions of the Linear Speed Limit Effect Model on the Eighty-Fifth Percentile Speed of Traffic (Bahrain)

```
*************************************************
* The predicted values of the observed sites *
*************************************************
MTB > Regress '85' 2 'SPL' 'O/D';
SUBC>   Predict 'SPL' 'O/D'.
The regression equation is
85 = 41.9 + 0.297 SPL + 7.35 O/D


   Fit  Stdev.Fit       95% C.I.          95% P.I.
 108.41      2.25  ( 103.45, 113.38)  (  97.46, 119.37)
  93.70      2.72  (  87.72,  99.69)  (  82.25, 105.16)
 108.41      2.25  ( 103.45, 113.38)  (  97.46, 119.37)
  95.12      1.30  (  92.26,  97.97)  (  84.95, 105.29)
 101.06      1.96  (  96.75, 105.37)  (  90.39, 111.73)
  87.76      1.57  (  84.30,  91.22)  (  77.41,  98.12)
  95.12      1.30  (  92.26,  97.97)  (  84.95, 105.29)
  95.12      1.30  (  92.26,  97.97)  (  84.95, 105.29)
  95.12      1.30  (  92.26,  97.97)  (  84.95, 105.29)
  84.79      1.48  (  81.52,  88.06)  (  74.50,  95.09)
  92.15      1.68  (  88.46,  95.83)  (  81.71, 102.58)
  77.44      2.54  (  71.86,  83.02)  (  66.19,  88.68)
  71.50      2.74  (  65.46,  77.53)  (  60.02,  82.97)
  86.21      3.07  (  79.44,  92.97)  (  74.33,  98.09)

**********************************************
* The predicted values of new speed limits *
**********************************************
Worksheet retrieved from file: C:\MINITAB\ARJ\SPD\BAH\BMDL1.MTW

MTB > Regress '85' 2 'SPL' 'O/D';
SUBC>   Predict 'SPLK' 'O/DK'.

The regression equation is
85 = 41.9 + 0.297 SPL + 7.35 O/D

   Fit  Stdev.Fit       95% C.I.          95% P.I.
  96.53      3.50  (  88.84, 104.23)  (  84.10, 108.96)
  99.50      2.87  (  93.18, 105.82)  (  87.87, 111.13)
 102.47      2.39  (  97.21, 107.74)  (  91.38, 113.56)
 105.44      2.16  ( 100.69, 110.20)  (  94.58, 116.30)
 108.41      2.25  ( 103.45, 113.38)  (  97.46, 119.37)
 111.38      2.64  ( 105.57, 117.19)  ( 100.02, 122.75)
 114.35      3.21  ( 107.28, 121.42)  ( 102.30, 126.41)
 117.33      3.89  ( 108.76, 125.89)  ( 104.34, 130.31) X
 120.30      4.63  ( 110.11, 130.48)  ( 106.19, 134.41) XX

 X  denotes a row with X values away from the center
 XX denotes a row with very extreme X values
```

Exhibit 2.6a: The Non-Linear (Multiplicative) Regression Analysis of the Speed Limit Effect on the Mean Speed of Traffic (Tyne & Wear)

```
Worksheet retrieved from file: C:\MINITAB\ARJ\SPD\ENG\EMDLLN.MTW
************************************
* Regression of all the variables *
************************************
MTB > Regress 'LNSPD' 4 'LNSPL' 'LNHV' 'LNLENGTH' 'LNO/D'.
The regression equation is
LNSPD = 1.93 + 0.429 LNSPL - 0.0142 LNHV + 0.0857 LNLENGTH + 0.242
LNO/D
Predictor      Coef       Stdev    t-ratio       p
Constant     1.9297      0.2300       8.39   0.000
LNSPL       0.42937     0.05825       7.37   0.000
LNHV       -0.01422     0.03964      -0.36   0.730
LNLENGTH    0.08570     0.03140       2.73   0.029
LNO/D       0.24159     0.07900       3.06   0.018
s = 0.04513     R-sq = 95.9%     R-sq(adj) = 93.5%
Analysis of Variance
SOURCE       DF         SS          MS        F       p
Regression    4   0.331568    0.082892    40.69   0.000
Error         7   0.014260    0.002037
Total        11   0.345828
SOURCE       DF     SEQ SS
LNSPL         1   0.241620
LNHV          1   0.002125
LNLENGTH      1   0.068771
LNO/D         1   0.019052

********************************************
* Regression of the significant variables *
********************************************
MTB > Regress 'LNSPD' 3 'LNSPL' 'LNLENGTH' 'LNO/D'.
The regression equation is
LNSPD = 1.91 + 0.429 LNSPL + 0.0893 LNLENGTH + 0.228 LNO/D
Predictor      Coef       Stdev    t-ratio       p
Constant     1.9089      0.2102       9.08   0.000
LNSPL       0.42939     0.05499       7.81   0.000
LNLENGTH    0.08931     0.02808       3.18   0.013
LNO/D       0.22803     0.06549       3.48   0.008
s = 0.04261     R-sq = 95.8%     R-sq(adj) = 94.2%

Analysis of Variance
SOURCE       DF         SS          MS        F       p
Regression    3    0.33131     0.11044    60.84   0.000
Error         8    0.01452     0.00182
Total        11    0.34583

SOURCE       DF     SEQ SS
LNSPL         1    0.24162
LNLENGTH      1    0.06768
LNO/D         1     0.0220
```

Exhibit 2.6b: The Non-Linear (Multiplicative) Regression Analysis of the Speed Limit Effect on the Mean Speed of Traffic (Bahrain)

```
Worksheet retrieved from file: C:\MINITAB\ARJ\SPD\BAH\BMDLLN.MTW
***********************************
* Regression of all the variables *
***********************************
MTB > Regress 'LNSPD' 5 'LNSPL' 'LNHV' 'LNLANE' 'LNO/D'  'LNLNGTH'.
The regression equation is
LNSPD = 3.08 + 0.220 LNSPL - 0.0329 LNHV + 0.0505 LNLANE + 0.216
LNO/D
        + 0.0515 LNLNGTH
Predictor      Coef      Stdev   t-ratio       p
Constant     3.0799     0.1630     18.89   0.000
LNSPL       0.21975    0.03909      5.62   0.000
LNHV       -0.03288    0.01529     -2.15   0.064
LNLANE      0.05055    0.04156      1.22   0.259
LNO/D       0.21576    0.03336      6.47   0.000
LNLNGTH     0.05149    0.02691      1.91   0.092
s = 0.02591    R-sq = 97.2%    R-sq(adj) = 95.4%
Analysis of Variance
SOURCE       DF         SS         MS        F      p
Regression    5   0.184805   0.036961    55.05  0.000
Error         8   0.005371   0.000671
Total        13   0.190177

SOURCE       DF     SEQ SS
LNSPL         1   0.119299
LNHV          1   0.009988
LNLANE        1   0.011401
LNO/D         1   0.041660
LNLNGTH       1   0.002457

*********************************************
* Regression of all the significant variables *
*********************************************
MTB > Regress 'LNSPD' 3 'LNSPL' 'LNO/D' 'LNLNGTH';
The regression equation is
LNSPD = 2.91 + 0.245 LNSPL + 0.219 LNO/D + 0.0762 LNLNGTH
Predictor      Coef      Stdev   t-ratio       p
Constant     2.9094     0.1636     17.79   0.000
LNSPL       0.24548    0.04152      5.91   0.000
LNO/D       0.21878    0.03680      5.94   0.000
LNLNGTH     0.07624    0.02770      2.75   0.020
s = 0.02947    R-sq = 95.4%    R-sq(adj) = 94.1%

Analysis of Variance
SOURCE       DF         SS         MS        F      p
Regression    3   0.181490   0.060497    69.64  0.000
Error        10   0.008687   0.000869
Total        13   0.190177
SOURCE       DF     SEQ SS
LNSPL         1   0.119299
LNO/D         1   0.055608
LNLNGTH       1   0.006583
```

Exhibit 2.7a: The Non-Linear (Multiplicative) Regression Analysis of The Speed Limit Effect on the Eighty-Fifth Percentile Speed of Traffic (Tyne & Wear)

```
************************************
* Regression of all the variables *
************************************
Worksheet retrieved from file: C:\MINITAB\ARJ\SPD\ENG\EMDLLN.MTW
MTB > Regress 'LN85%' 4 'LNSPL' 'LNHV' 'LNLENGTH' 'LNO/D'.
The regression equation is
LN85% = 1.86 + 0.493 LNSPL - 0.0286 LNHV + 0.0893 LNLENGTH + 0.231
LNO/D
Predictor      Coef       Stdev    t-ratio       p
Constant      1.8598      0.2862      6.50    0.000
LNSPL         0.49319     0.07246     6.81    0.000
LNHV         -0.02855     0.04931    -0.58    0.581
LNLENGTH      0.08935     0.03906     2.29    0.056
LNO/D         0.23132     0.09826     2.35    0.051
s = 0.05614    R-sq = 94.6%    R-sq(adj) = 91.5%

Analysis of Variance
SOURCE       DF        SS          MS         F       p
Regression    4    0.383935    0.095984    30.45    0.000
Error         7    0.022064    0.003152
Total        11    0.405999

SOURCE       DF    SEQ SS
LNSPL         1    0.296009
LNHV          1    0.000587
LNLENGTH      1    0.069872
LNO/D         1    0.017467

********************************************
* Regression of the significant variables *
********************************************
MTB > Regress 'LN85%' 3 'LNSPL' 'LNLENGTH' 'LNO/D'.
The regression equation is
LN85% = 1.82 + 0.493 LNSPL + 0.0966 LNLENGTH + 0.204 LNO/D
Predictor      Coef       Stdev    t-ratio       p
Constant      1.8182      0.2652      6.86    0.000
LNSPL         0.49323     0.06939     7.11    0.000
LNLENGTH      0.09660     0.03543     2.73    0.026
LNO/D         0.20410     0.08263     2.47    0.039
s = 0.05376    R-sq = 94.3%    R-sq(adj) = 92.2%
Analysis of Variance
SOURCE       DF        SS         MS         F       p
Regression    3     0.38288    0.12763    44.16    0.000
Error         8     0.02312    0.00289
Total        11     0.40600
SOURCE       DF    SEQ SS
LNSPL         1    0.29601
LNLENGTH      1    0.06924
LNO/D         1    0.01763
```

Exhibit 2.7b: The Non-Linear (Multiplicative) Regression Analysis of The Speed Limit Effect on the Eighty-Fifth Percentile Speed of Traffic (Bahrain)

```
*********************************
* Regression of all variables *
*********************************
MTB > Regress 'LN85%' 5 'LNSPL' 'LNHV' 'LNLANE' 'LNO/D' 'LNLNGTH'.
The regression equation is
LN85% = 3.38 + 0.188 LNSPL - 0.0377 LNHV + 0.0240 LNLANE + 0.261
LNO/D
        + 0.0489 LNLNGTH
Predictor      Coef      Stdev    t-ratio      p
Constant     3.3755     0.2637     12.80    0.000
LNSPL        0.18796    0.06323     2.97    0.018
LNHV        -0.03770    0.02474    -1.52    0.166
LNLANE        0.02396    0.06723     0.36    0.731
LNO/D        0.26095    0.05395     4.84    0.000
LNLNGTH       0.04890    0.04354     1.12    0.294
s = 0.04191     R-sq = 93.3%     R-sq(adj) = 89.2%

Analysis of Variance
SOURCE        DF        SS          MS          F        p
Regression     5   0.196773   0.039355     22.40    0.000
Error          8   0.014054   0.001757
Total         13   0.210826

SOURCE        DF      SEQ SS
LNSPL          1    0.112562
LNHV           1    0.013613
LNLANE          1    0.010161
LNO/D          1    0.058220
LNLNGTH          1    0.002216

********************************************
* Regression of the significant variables *
********************************************
MTB > Regress 'LN85%' 2 'LNSPL' 'LNO/D'.
The regression equation is
LN85% = 3.21 + 0.213 LNSPL + 0.303 LNO/D
Predictor      Coef      Stdev    t-ratio      p
Constant     3.2088     0.2640     12.15    0.000
LNSPL        0.21327    0.06697     3.18    0.009
LNO/D        0.30300    0.05323     5.69    0.000
s = 0.04758    R-sq = 88.2%     R-sq(adj) = 86.0%
Analysis of Variance
SOURCE        DF        SS          MS          F        p
Regression     2   0.185925   0.092962     41.06    0.000
Error         11   0.024902   0.002264
Total         13   0.210826
SOURCE        DF      SEQ SS
LNSPL          1    0.112562
LNO/D          1    0.073362
```

Exhibit 2.8a: The Predictions of the Non-Linear (Multiplicative) Speed Limit Effect on the Mean Speed of Traffic (Tyne & Wear)

```
************************************************
* The predicted values of the observed sites *
************************************************
MTB > Regress 'LNSPD' 3 'LNSPL' 'LNLENGTH' 'LNO/D';
SUBC>   Predict 'LNSPL' 'LNLENGTH' 'LNO/D'.

The regression equation is
LNSPD = 1.91 + 0.429 LNSPL + 0.0893 LNLENGTH + 0.228 LNO/D

    Fit  Stdev.Fit        95% C.I.            95% P.I.
  3.9894    0.0276    ( 3.9257, 4.0530)   ( 3.8723, 4.1065)
  4.2231    0.0293    ( 4.1554, 4.2908)   ( 4.1038, 4.3424)
  4.1437    0.0248    ( 4.0865, 4.2010)   ( 4.0300, 4.2575)
  3.8913    0.0320    ( 3.8174, 3.9651)   ( 3.7683, 4.0142)
  4.0456    0.0241    ( 3.9900, 4.1013)   ( 3.9327, 4.1586)
  3.9374    0.0168    ( 3.8986, 3.9762)   ( 3.8317, 4.0430)
  3.8087    0.0174    ( 3.7686, 3.8488)   ( 3.7025, 3.9148)
  3.9011    0.0199    ( 3.8551, 3.9472)   ( 3.7926, 4.0097)
  3.6510    0.0241    ( 3.5954, 3.7065)   ( 3.5381, 3.7639)
  3.7491    0.0272    ( 3.6864, 3.8118)   ( 3.6325, 3.8657)
  3.8053    0.0256    ( 3.7464, 3.8643)   ( 3.6907, 3.9199)
  3.7129    0.0214    ( 3.6635, 3.7623)   ( 3.6029, 3.8229)

**********************************************
* The predicted values of new speed limits *
* for the site: EA1                        *
**********************************************

MTB > Regress 'LNSPD' 3 'LNSPL' 'LNLENGTH' 'LNO/D';
SUBC>   Predict 'LNSPL1' 'LNLNGTH1' 'LNO/D1'.

The regression equation is
LNSPD = 1.91 + 0.429 LNSPL + 0.0893 LNLENGTH + 0.228 LNO/D


    Fit  Stdev.Fit        95% C.I.            95% P.I.
  4.0786    0.0327    ( 4.0030, 4.1541)   ( 3.9546, 4.2025)
  4.1194    0.0307    ( 4.0485, 4.1902)   ( 3.9982, 4.2405)
  4.1567    0.0295    ( 4.0886, 4.2248)   ( 4.0371, 4.2763)
  4.1911    0.0291    ( 4.1239, 4.2582)   ( 4.0720, 4.3101)
  4.2228    0.0293    ( 4.1552, 4.2905)   ( 4.1035, 4.3421)
  4.2525    0.0300    ( 4.1832, 4.3217)   ( 4.1323, 4.3727)
  4.2804    0.0311    ( 4.2087, 4.3521)   ( 4.1587, 4.4020)
  4.3061    0.0324    ( 4.2315, 4.3808)   ( 4.1827, 4.4296)
  4.3310    0.0339    ( 4.2529, 4.4092)   ( 4.2055, 4.4566)
```

Exhibit 2.8b: The Predictions of the Non-Linear (Multiplicative) Speed Limit Effect on the Mean Speed of Traffic (Bahrain)

```
*********************************************
* The predicted values of the observed sites    *
*********************************************
MTB > Regress 'LNSPD' 3 'LNSPL' 'LNO/D' 'LNLNGTH';
SUBC>    Predict 'LNSPL' 'LNO/D' 'LNLNGTH'.

The regression equation is
LNSPD = 2.91 + 0.245 LNSPL + 0.219 LNO/D + 0.0762 LNLNGTH

    Fit  Stdev.Fit        95% C.I.          95% P.I.
 4.51475   0.01495   (4.48143,4.54807)  (4.44109,4.58840)
 4.40299   0.02173   (4.35456,4.45142)  (4.32138,4.48460)
 4.44489   0.02342   (4.39269,4.49709)  (4.36099,4.52879)
 4.37221   0.00952   (4.35098,4.39343)  (4.30317,4.44124)
 4.44892   0.01267   (4.42068,4.47716)  (4.37742,4.52042)
 4.27835   0.01433   (4.24642,4.31029)  (4.20531,4.35139)
 4.39414   0.00966   (4.37261,4.41567)  (4.32501,4.46327)
 4.39414   0.00966   (4.37261,4.41567)  (4.32501,4.46327)
 4.37221   0.00952   (4.35098,4.39343)  (4.30317,4.44124)
 4.27649   0.00928   (4.25581,4.29717)  (4.20762,4.34535)
 4.36136   0.01163   (4.33545,4.38727)  (4.29075,4.43197)
 4.15687   0.01894   (4.11466,4.19907)  (4.07879,4.23494)
 4.07427   0.02009   (4.02950,4.11904)  (3.99478,4.15376)
 4.27876   0.02265   (4.22827,4.32925)  (4.19591,4.36161)
```

```
*******************************************
* The predicted values of new speed limits *
* for the site BKH100                      *
*******************************************
MTB > Regress 'LNSPD' 3 'LNSPL' 'LNO/D' 'LNLNGTH';
SUBC>    Predict 'LNSPLK' 'LNO/DK' 'LNLNGTHK'.
The regression equation is
LNSPD = 2.91 + 0.245 LNSPL + 0.219 LNO/D + 0.0762 LNLNGTH
Predictor       Coef       Stdev    t-ratio        p
Constant      2.9094      0.1636      17.79    0.000
LNSPL        0.24548     0.04152       5.91    0.000
LNO/D        0.21878     0.03680       5.94    0.000
LNLNGTH      0.07624     0.02770       2.75    0.020
s = 0.02947     R-sq = 95.4%     R-sq(adj) = 94.1%
    Fit  Stdev.Fit        95% C.I.          95% P.I.
 4.38938   0.02205   (4.34025,4.43851)  (4.30735,4.47141)
 4.42723   0.01766   (4.38786,4.46660)  (4.35065,4.50381)
 4.46000   0.01509   (4.42638,4.49363)  (4.38621,4.53380)
 4.48903   0.01429   (4.45717,4.52089)  (4.41603,4.56204)
 4.51490   0.01496   (4.48156,4.54825)  (4.44124,4.58857)
 4.53830   0.01657   (4.50138,4.57522)  (4.46295,4.61365)
 4.55966   0.01865   (4.51808,4.60123)  (4.48192,4.63739)
 4.57929   0.02094   (4.53262,4.62597)  (4.49871,4.65988)
 4.59748   0.02329   (4.54559,4.64938)  (4.51377,4.68120)
```

Exhibit 2.9a: The Predictions of the Non-Linear (Multiplicative) Speed Limit Effect on the Eighty-Fifth Percentile Speed of Traffic (Tyne & Wear)

```
**********************************************
* The predicted values of the observed sites *
**********************************************

MTB > Regress 'LN85%' 3 'LNSPL' 'LNLENGTH' 'LNO/D';
SUBC>   Predict 'LNSPL' 'LNLENGTH' 'LNO/D'.

The regression equation is
LN85% = 1.82 + 0.493 LNSPL + 0.0966 LNLENGTH + 0.204 LNO/D


   Fit  Stdev.Fit       95% C.I.           95% P.I.
 4.1613    0.0348   ( 4.0810, 4.2416)  ( 4.0136, 4.3090)
 4.3846    0.0370   ( 4.2993, 4.4700)  ( 4.2341, 4.5352)
 4.3110    0.0313   ( 4.2387, 4.3833)  ( 4.1675, 4.4546)
 4.0552    0.0404   ( 3.9620, 4.1484)  ( 3.9001, 4.2103)
 4.2049    0.0304   ( 4.1347, 4.2751)  ( 4.0624, 4.3474)
 4.0781    0.0212   ( 4.0292, 4.1271)  ( 3.9448, 4.2114)
 3.9562    0.0220   ( 3.9055, 4.0068)  ( 3.8222, 4.0901)
 4.0389    0.0252   ( 3.9809, 4.0970)  ( 3.9020, 4.1759)
 3.7792    0.0304   ( 3.7091, 3.8493)  ( 3.6367, 3.9216)
 3.8853    0.0343   ( 3.8062, 3.9644)  ( 3.7382, 4.0324)
 3.9289    0.0323   ( 3.8545, 4.0033)  ( 3.7843, 4.0735)
 3.8461    0.0270   ( 3.7838, 3.9085)  ( 3.7073, 3.9849)


*******************************************
* The predicted values of new speed limits *
* for the site EA1                         *
*******************************************

MTB > Regress 'LN85%' 3 'LNSPL' 'LNLENGTH' 'LNO/D';
SUBC>   Predict 'LNSPL1' 'LNLNGTH1' 'LNO/D1'.

The regression equation is
LN85% = 1.82 + 0.493 LNSPL + 0.0966 LNLENGTH + 0.204 LNO/D
   Fit  Stdev.Fit       95% C.I.           95% P.I.
 4.2186    0.0413   ( 4.1233, 4.3139)  ( 4.0622, 4.3750)
 4.2655    0.0387   ( 4.1761, 4.3548)  ( 4.1126, 4.4183)
 4.3084    0.0373   ( 4.2224, 4.3944)  ( 4.1575, 4.4593)
 4.3478    0.0367   ( 4.2631, 4.4326)  ( 4.1976, 4.4980)
 4.3843    0.0370   ( 4.2990, 4.4697)  ( 4.2338, 4.5349)
 4.4184    0.0379   ( 4.3310, 4.5057)  ( 4.2667, 4.5701)
 4.4504    0.0392   ( 4.3600, 4.5409)  ( 4.2969, 4.6039)
 4.4800    0.0409   ( 4.3858, 4.5743)  ( 4.3243, 4.6358)
 4.5086    0.0428   ( 4.4100, 4.6073)  ( 4.3502, 4.6671)
```

Exhibit 2.9b: The Predictions of the Non-Linear (Multiplicative) Speed Limit Effect on the Eighty-Fifth Percentile Speed of Traffic (Bahrain)

```
**********************************************
* The predicted values of the observed sites *
**********************************************
MTB > Regress 'LN85%' 2 'LNSPL' 'LNO/D';
SUBC>   Predict 'LNSPL' 'LNO/D'.

The regression equation is
LN85% = 3.21 + 0.213 LNSPL + 0.303 LNO/D

    Fit  Stdev.Fit       95% C.I.            95% P.I.
  4.6786    0.0219   ( 4.6304, 4.7268)  ( 4.5633, 4.7939)
  4.5238    0.0259   ( 4.4668, 4.5809)  ( 4.4045, 4.6431)
  4.6786    0.0219   ( 4.6304, 4.7268)  ( 4.5633, 4.7939)
  4.5634    0.0141   ( 4.5324, 4.5944)  ( 4.4542, 4.6726)
  4.6110    0.0195   ( 4.5680, 4.6540)  ( 4.4978, 4.7242)
  4.4762    0.0160   ( 4.4410, 4.5115)  ( 4.3657, 4.5868)
  4.5634    0.0141   ( 4.5324, 4.5944)  ( 4.4542, 4.6726)
  4.5634    0.0141   ( 4.5324, 4.5944)  ( 4.4542, 4.6726)
  4.5634    0.0141   ( 4.5324, 4.5944)  ( 4.4542, 4.6726)
  4.4478    0.0149   ( 4.4150, 4.4805)  ( 4.3380, 4.5575)
  4.5349    0.0174   ( 4.4967, 4.5732)  ( 4.4234, 4.6464)
  4.3249    0.0300   ( 4.2587, 4.3911)  ( 4.2010, 4.4488)
  4.2531    0.0321   ( 4.1825, 4.3238)  ( 4.1268, 4.3795)
  4.4632    0.0357   ( 4.3846, 4.5417)  ( 4.3322, 4.5941)


*******************************************
* The predicted values of new speed limits *
* for the site BKH100                     *
*******************************************

MTB > Retrieve  'C:\MINITAB\ARJ\SPD\BAH\BMDLLN.MTW'.
 WORKSHEET SAVED  4/11/1994

Worksheet retrieved from file: C:\MINITAB\ARJ\SPD\BAH\BMDLLN.MTW
MTB > Regress 'LN85%' 2 'LNSPL' 'LNO/D';
SUBC>   Predict 'LNSPLK' 'LNO/DK'.
The regression equation is
LN85% = 3.21 + 0.213 LNSPL + 0.303 LNO/D
    Fit  Stdev.Fit       95% C.I.            95% P.I.
  4.5697    0.0336   ( 4.4956, 4.6437)  ( 4.4414, 4.6979)
  4.6025    0.0262   ( 4.5448, 4.6603)  ( 4.4829, 4.7222)
  4.6310    0.0218   ( 4.5830, 4.6791)  ( 4.5158, 4.7463)
  4.6563    0.0206   ( 4.6110, 4.7016)  ( 4.5422, 4.7704)
  4.6788    0.0219   ( 4.6305, 4.7270)  ( 4.5634, 4.7941)
  4.6991    0.0248   ( 4.6444, 4.7538)  ( 4.5809, 4.8173)
  4.7176    0.0285   ( 4.6548, 4.7805)  ( 4.5955, 4.8398)
  4.7347    0.0325   ( 4.6632, 4.8062)  ( 4.6079, 4.8615)
  4.7505    0.0364   ( 4.6703, 4.8307)  ( 4.6186, 4.8825)
```

Exhibit 2.10a: The Non-Linear (Additive form) Regression Analysis Results of the Speed Limit Effect On The Mean Speed of Traffic (Tyne & Wear)

```
                         Nonlinear  Regression
----------------------------------------------------------
Dep. variable:  ENG.SPD

Parameter vector: 10 0.7

Function: PARM[1]+ENG.SPL^PARM[2]


Maximum iterations: 25                Initial Marquardt parameter: 0.01
Maximum function calls: 200            Initial scaling factor: 20
Stopping cond. on res. ss: 1E-4       Max. value of Marquardt parm.: 120
Stopping cond. on estimates: 1E-3

---------------------------------------------------------------------
               Analysis of Variance for the Full Regression
---------------------------------------------------------------------
   source              sum of squares    df    mean square      ratio
   Model                    31092.886     2      15546.443    473.188
   Error                    328.54714    10       32.85471
----------------------------------------------------------
   Total                    31421.433    12
   Total (corr.)            957.65413    11
R-squared  =  0.656925
----------------------------------------------------------
                         Model    Fitting    Results
----------------------------------------------------------
                              estimate   stnd.error       ratio
      Coefficient 1         16.3357849   6.30162334       2.5923
      Coefficient 2           .8816631    .04359330      20.2247

Total iterations = 4                     Total function evaluations = 13
```

Exhibit 2.10b: The Non-Linear (Additive form) Regression Analysis Results of the Speed Limit Effect on the Mean Speed of Traffic (Bahrain)

```
                         Nonlinear   Regression
-----------------------------------------------------------
Dep. variable:  BAH.SPD

Parameter vector: 20 0.5
Function: PARM[1]+BAH.SPL^PARM[2]
Maximum iterations: 25                Initial Marquardt parameter: 0.01
Maximum function calls: 200            Initial scaling factor: 20
Stopping cond. on res. ss: 1E-4       Max. value of Marquardt parm.: 120
Stopping  cond.  on  estimates:  1E-3
-----------------------------------------------------------
            Analysis of Variance for the Full Regression
-----------------------------------------------------------
   source              sum of squares    df    mean square      ratio
   Model                   84289.078      2     42144.539    1477.608
   Error                   342.26559     12      28.52213
-----------------------------------------------------------
   Total                   84631.344     14
   Total (corr.)           1039.1087     13

R-squared  =  0.670616
-----------------------------------------------------------
                        Model Fitting Results
-----------------------------------------------------------
                           estimate   stnd.error        ratio
     Coefficient 1        36.9101921  6.63984188       5.5589
     Coefficient 2          .8462475   .03621120      23.3698
-----------------------------------------------------------
Total iterations = 5                   Total function evaluations = 18
```

Exhibit 2.11a: The Non-Linear (Additive form) Regression Analysis Results of the Speed Limit Effect on the Eighty-Fifth Percentile Speed (Tyne & Wear)

```
                         Nonlinear Regression
Dep. variable:  ENG.EFPS

Parameter vector: 20 0.5
Function: PARM[1]+ENG.SPL^PARM[2]
Maximum iterations: 25                 Initial Marquardt parameter: 0.01
Maximum function calls: 200             Initial scaling factor: 20
Stopping cond. on res. ss: 1E-4        Max. value of Marquardt parm.: 120
Stopping cond. on estimates: 1E-3
               Analysis of Variance for the Full Regression

   source             sum of squares    df    mean square      ratio
   Model                   42193.620     2      21096.810    445.472
   Error                   473.58312    10       47.35831
-----------------------------------------------------------
   Total                   42667.203    12
   Total (corr.)           1527.6312    11
R-squared = 0.689989
                         Model Fitting Results
-----------------------------------------------------------
                          estimate   stnd.error      ratio
     Coefficient 1        16.8354461  7.28657968      2.3105
     Coefficient 2          .9315443   .04124391     22.5862
-----------------------------------------------------------
Total iterations = 5                     Total function evaluations = 18
```

Exhibit 2.11b: The Non-Linear (Additive) Regression Analysis Results of the Speed Limit Effect on the Eighty-Fifth Percentile Speed (Bahrain)

```
                      Nonlinear   Regression
------------------------------------------------------------
Dep. variable:  BAH.EFPS
Parameter vector: 20 0.5
Function: PARM[1]+BAH.SPL^PARM[2]
Maximum iterations: 25                  Initial Marquardt parameter: 0.01
Maximum function calls: 200              Initial scaling factor: 20
Stopping cond. on res. ss: 1E-4         Max. value of Marquardt parm.: 120
Stopping cond. on estimates: 1E-3
------------------------------------------------------------
              Analysis of Variance for the Full Regression
------------------------------------------------------------
    source              sum of squares     df    mean square       ratio
    Model                    120128.35      2       60064.17     1088.67
    Error                    662.06277     12       55.17190
------------------------------------------------------------
    Total                    120790.41     14
    Total (corr.)            1612.6321     13
R-squared = 0.589452
------------------------------------------------------------
                         Model Fitting Results
------------------------------------------------------------
                          estimate    stnd.error        ratio
      Coefficient 1       46.4496065   9.02265535       5.1481
      Coefficient 2         .8751729    .04327739      20.2224
------------------------------------------------------------------------------
Total iterations = 5                          Total function evaluations = 18
```

Appendix II

The accident records of the investigated sites and the output of the statistical analysis of the relationship between the speed of traffic and the frequency and the severity of the personal injury accidents

Table 3.1a: Yearly Injury Accidents and Traffic Flow for the Observation Sites (Tyne & Wear)

Site: EA1 length=44 km

year	flow veh/day	accid.	slight	serious	fatal
1988	9270	19	14	4	1
1989	9949	36	27	8	1
1990	11278	25	18	3	4
1991	11916	29	23	3	3
1992	11883	33	28	4	1
total		142	110	22	10
average	10859	28.4	22	4.4	2

Site: EA19 length=18 km

year	flow veh/day	accid.	slight	serious	fatal
1988	25743	9	4	3	2
1989	28538	18	14	4	0
1990	29951	16	13	2	1
1991	28826	27	22	3	1
1992	23899	24	20	3	1
total		94	73	15	6
average	27392	18.8	14.6	3	1.2

Site: EA167 length=7 km

year	flow veh/day	accid.	slight	serious	fatal
1988	12237	1	1	0	0
1989	12815	10	8	2	0
1990	13818	7	6	0	1
1991	13289	7	6	1	0
1992	13148	12	12	0	0
total		37	33	3	1
average	13061	7.4	6.6	0.6	0.2

Table 3.1: (Continued)

Site: HW length=0.47 km

year	flow veh/day	accid.	slight	serious	fatal
1988	13661	1	1	0	0
1989	141511	0	0	0	0
1990	14616	0	0	0	0
1991	14574	1	0	0	1
1992	14934	1	0	0	0
total		3	2	0	1
average	39859	0.6	0.4	0	0.2

Site: EJR length=1.16 km

year	flow veh/day	accid.	slight	serious	fatal
1988	8831	0	0	0	0
1989	8847	0	0	0	0
1990	8898	0	0	0	0
1991	9074	3	2	1	0
1992	10008	0	0	0	0
total		3	2	1	0
average	9132	0.6	0.4	0.2	0

Site: EGHN length=0.64 km

year	flow veh/day	accid.	slight	serious	fatal
1988	12828	2	2	0	0
1989	13881	0	0	0	0
1990	14053	1	1	0	0
1991	11974	1	0	1	0
1992	11528	0	0	0	0
total		4	3	1	0
average	12853	0.8	0.6	0.2	0

Table 3.1: (Continued)

Site: EGHS length=1.05 km

year	flow veh/day	accid.	slight	serious	fatal
1988	15331	0	0	0	0
1989	16245	0	0	0	0
1990	16053	1	1	0	0
1991	13913	1	1	0	0
1992	12718	0	0	0	0
total		2	2	0	0
average	14852	0.4	0.4	0	0

Site: EGN length=0.62 km

year	flow veh/day	accid.	slight	serious	fatal
1988	14068	0	0	0	0
1989	14832	1	1	0	0
1990	11991	0	0	0	0
1991	10303	0	0	0	0
1992	10153	1	1	0	0
total		2	2	0	0
average	12269	0.4	0.4	0	0

Site: EA194 length=1.03 km

year	flow veh/day	accid.	slight	serious	fatal
1988	6688	0	0	0	0
1989	4812	0	0	0	0
1990	6071	1	1	0	0
1991	7330	0	0	0	0
1992	8589	0	0	0	0
total		1	1	0	0
average	12269	0.2	0.2	0	0

Table 3.1b: Yearly Injury Accidents and Traffic Flow for the Observation Sites (Tyne & Wear)

Site: BMJ100 length=10.67 km

year	accid.	slight	serious	fatal
1987	23	18	5	0
1988	30	19	11	0
1989	23	13	7	3
1990	45	37	7	1
total	121	87	30	4
average	30.25	21.75	7.5	1

Site: BSA100 length=6.27 km flow=9024 veh/day

year	accid.	slight	serious	fatal
1987	14	8	5	1
1988	13	8	4	1
1989	15	11	4	0
1990	7	6	1	0
total	49	33	14	2
average	12.25	8.25	14	0.5

Site: BFA80 length= 0.8 km flow=27144 veh/day

year	accid.	slight	serious	fatal
1987	1	1	0	0
1988	1	1	0	0
1989	1	1	0	0
1990	2	2	0	0
total	5	5	0	0
average	1.25	1.25	0	0

Table 3.1b: (Continued)

Site: BHA80 length=1.52 km flow=23976 veh/day

year	accid.	slight	serious	fatal
1987	5	5	0	0
1988	4	3	1	0
1989	3	3	0	0
1990	5	4	1	0
total	17	15	2	0
average	4.25	3.75	0.5	0

Site: BIS80 length=3.83 km flow= 17280

year	accid.	slight	serious	fatal
1987	6	6	0	0
1988	10	8	2	0
1989	8	5	3	0
1990	2	2	0	0
total	26	21	5	0
average	6.5	5.25	1.25	0

Site: BBU70 length=1.05 km flow=11808

year	accid.	slight	serious	fatal
1987	3	1	2	0
1988	3	3	0	0
1989	2	2	0	0
1990	0	0	0	0
total	8	6	2	0
average	2	1.5	0.5	0

Table 3.1b: (Continued)

Site: BSA70 length=1.90 km

year	accid.	slight	serious	fatal
1987	1	1	0	0
1988	3	3	0	0
1989	2	2	0	0
1990	3	2	0	1
total	9	8	0	1
average	2.25	2	0	0.25

Site: BSE70 length=0.55 km

year	accid.	slight	serious	fatal
1987	0	0	0	0
1988	2	2	0	0
1989	0	0	0	0
1990	2	1	1	0
total	4	3	1	0
average	1.0	0.75	0.25	0

Site: BSA50 length=0.82 km flow=3504 veh/day

year	accid.	slight	serious	fatal
1987	0	0	0	0
1988	0	0	0	0
1989	1	1	0	0
1990	1	1	0	0
total	2	2	0	0
average	0.5	0.5	0	0

Site: BKU50 length=2.59 km flow=8688 veh/day

year	accid.	slight	serious	fatal
1987	2	2	0	0
1988	2	2	0	0
1989	1	1	0	0
1990	2	1	1	0
total	7	6	1	0
average	1.75	1.5	0.25	0

Exhibit 3.1a: The Regression Analysis Results of the Effect of Traffic Speed Characteristics on the Total Number of Accidents Using Poisson Distribution (Tyne & Wear)

```
[o] GLIM 3.77 update 1 (copyright)1985 Royal Statistical Society, London
[o] ? $FIT: +LLG +LFW$
[o] scaled deviance = 562.36 at cycle  5
[o]           d.f. =   8
[o] scaled deviance = 5.1975 (change =  -557.2) at cycle  3
[o]           d.f. = 6      (change =     -2  )
[o]          estimate        s.e.    parameter
[o]    1      -7.933       2.211      1
[o]    2       1.016     0.06554     LLG
[o]    3       2.025      0.5562     LFW
[i] ? $FIT +LSP$
[o] scaled deviance = 5.1350 (change = -0.06253) at cycle  3
[i] ? $FIT +LEF$
[o] scaled deviance = 5.0786 (change = -0.11892) at cycle  3
[i] ? $FIT +LSTD$
[o] scaled deviance = 4.8157 (change = -0.3818) at cycle  3
[i] ? $FIT +LPSI$
[o] scaled deviance = 5.0795 (change = -0.11796) at cycle  3
[i] ? $FIT +LSI$
[o] scaled deviance = 5.0248 (change = -0.17275) at cycle  3
[i] ? $FIT +LCV$
[o] scaled deviance = 4.2458 (change = -0.9517) at cycle  3
[i] ? $FIT +LSS$
[o] scaled deviance = 4.6529 (change = -0.5446) at cycle  3
[i] ? $FIT +LCSS$
[o] scaled deviance = 3.7092 (change =  -1.488) at cycle  3
[i] ? $FIT +LUSS$
[o] scaled deviance = 4.6035 (change = -0.5940) at cycle  3
[i] ? $FIT +LCUSS$
[o] scaled deviance = 3.9516 (change =  -1.246) at cycle  3
[i] ? $FIT: +LFL$
[o] scaled deviance = 562.36 at cycle  5
[o]           d.f. =   8
[o] scaled deviance = 9.0907 (change =  -553.3) at cycle  3
[o]           d.f. = 7      (change =     -1  )
[o]          estimate        s.e.    parameter
[o]    1      -3.836      0.3922      1
[o]    2      0.9744     0.05679     LFL
[i] ? $FIT +LSP$
[o] scaled deviance = 8.7058 (change = -0.3849) at cycle  3
[i] ? $FIT +LEF$
[o] scaled deviance = 7.5467 (change =  -1.544) at cycle  3
[i] ? $FIT +LSTD$
[o] scaled deviance = 5.1851 (change =  -3.906) at cycle  3
[o]          estimate        s.e.    parameter
[o]    1      -5.687       1.035      1
[o]    2      0.9272     0.06263     LFL
[o]    3      0.7931      0.4001     LSTD
[i] ? $FIT +LPSI$
[o] scaled deviance = 7.4860 (change =  -1.605) at cycle  3
```

```
[i] ? $FIT +LSI$
[o] scaled deviance = 9.0891 (change = -0.0016) at cycle  3
[i] ? $FIT +LCV$
[o] scaled deviance = 4.3127 (change =  -4.778) at cycle  3
[o]          estimate       s.e.     parameter
[o]    1      -2.094      0.8846      1
[o]    2       1.026      0.06554     LFL
[o]    3       1.100      0.5039      LCV
[i] ? $FIT +LSS$
[o] scaled deviance = 5.0006 (change =  -4.090) at cycle  3
[o]          estimate       s.e.     parameter
[o]    1      -6.049       1.184      1
[o]    2      0.9064      0.06620     LFL
[o]    3      0.7567      0.3725      LP81
[i] ? $FIT +LCSS$
[o] scaled deviance = 3.8305 (change =  -5.260) at cycle  3
[o]          estimate       s.e.     parameter
[o]    1      -3.037      0.5288      1
[o]    2      0.9852      0.06074     LFL
[o]    3      0.9574      0.4190      LP8C
[i] ? $FIT +LUSS$
[o] scaled deviance = 5.0279 (change =  -4.063) at cycle  3
[o]          estimate       s.e.     parameter
[o]    1      -5.654       1.008      1
[o]    2      0.9281      0.06174     LFL
[o]    3      0.7392      0.3634      LVR
[i] ? $FIT +LCUSS$
[o] scaled deviance = 3.9516 (change =  -5.139) at cycle  3
[o]          estimate       s.e.     parameter
[o]    1      -2.254      0.7863      1
[o]    2       1.020      0.06499     LFL
[o]    3       1.089      0.4828      LCR
[i] ? $CAL OF=T*LG$
[i] ? $OFFSET LOF$
[i] ? $FIT: +LFW$
[o] scaled deviance = 22.434 at cycle  3
[o]            d.f. =  8
[o] scaled deviance = 5.2605 (change =  -17.17) at cycle  3
[o]            d.f. = 7     (change =   -1   )
[o]          estimate       s.e.     parameter
[o]    1      -7.625       1.819      1
[o]    2       1.957      0.4804      LFW
[i] ? $FIT +LSP$
[o] scaled deviance = 5.1470 (change = -0.11354) at cycle  3
[i] ? $FIT +LEF$
[o] scaled deviance = 5.1078 (change = -0.152730) at cycle  3
[i] ? $FIT +LSTD$
[o] scaled deviance = 4.9092 (change = -0.3513) at cycle  3
[i] ? $FIT +LPSI$
[o] scaled deviance = 5.1486 (change = -0.11190) at cycle  3
[i] ? $FIT +LSI$
[o] scaled deviance = 5.2522 (change = -0.0083) at cycle  3
[i] ? $FIT +LCV$
[o] scaled deviance = 4.4254 (change = -0.8351) at cycle  3
```

```
[i] ? $FIT +LSS$
[o] scaled deviance = 4.8514 (change = -0.4092) at cycle  3
[i] ? $FIT +LCSS$
[o] scaled deviance = 3.8635 (change =  -1.397) at cycle  3
[i] ? $FIT +LUSS$
[o] scaled deviance = 4.7461 (change = -0.5145) at cycle  3
[i] ? $FIT +LCUSS$
[o] scaled deviance = 4.0459 (change =  -1.215) at cycle  3
[i] ? $CAL OF=T*FW*LG$
[i] ? $FIT: +LSP$
[o] scaled deviance = 9.2716 (change = -0.0183) at cycle  3
[i] ? $FIT: +LEF$
[o] scaled deviance = 9.1839 (change = -0.10600) at cycle  3
[i] ? $FIT: +LSTD$
[o] scaled deviance = 6.4882 (change =  -2.802) at cycle  3
[i] ? $FIT: +LPSI$
[o] scaled deviance = 7.4860 (change =  -1.804) at cycle  3
[i] ? $FIT: +LSI$
[o] scaled deviance = 9.2120 (change = -0.07789) at cycle  3
[i] ? $FIT: +LCV$
[o] scaled deviance = 4.4716 (change =  -4.818) at cycle  3
[o]         estimate       s.e.    parameter
[o]    1     -2.065     0.8813     1
[o]    2      1.022     0.4638     LCV
[i] ? $FIT: +LSS$
[o] scaled deviance = 6.9196 (change =  -2.370) at cycle  3
[i] ? $FIT: +LCSS$
[o] scaled deviance = 3.8892 (change =  -5.401) at cycle  3
[o]         estimate       s.e.    parameter
[o]    1     -3.127     0.3809     1
[o]    2     0.9706     0.4173     LP8C
[i] ? $FIT: +LCUSS$
[o] scaled deviance = 4.0460 (change =  -5.244) at cycle  3
[o]         estimate       s.e.    parameter
[o]    1     -2.214     0.7723     1
[o]    2      1.034     0.4451     LCR
[i] ? $FIT: +LUSS$
[o] scaled deviance = 6.3284 (change =  -2.961) at cycle  3
```

Exhibit 3.1b: The Regression Analysis Results of the Effect of Traffic Speed Characteristics on the Total Number of Accidents Using Poisson Distribution (Bahrain)

```
[o] GLIM 3.77 update 1 (copyright)1985 Royal Statistical Society, London
[i] ? $FIT: +LLG +LFW$
[o] scaled deviance = 345.17 at cycle  5
[o]          d.f. =   9
[o] scaled deviance = 12.562 (change =  -332.6) at cycle  3
[o]          d.f. =  7     (change =    -2  )
[o]         estimate       s.e.     parameter
[o]    1     -1.705      0.7339      1
[o]    2      1.238     0.08260      LLG
[o]    3     0.5199      0.1888      LFW
[i] ? $FIT +LSP$
[o] scaled deviance = 8.9368 (change =  -3.626) at cycle  4
[o]         estimate       s.e.     parameter
[o]    1     -25.92       12.93      1
[o]    2     0.7651      0.2574      LLG
[o]    3     0.1539      0.2690      LFW
[o]    4      5.996       3.188     LSP
[i] ? $FIT +LEF$
[o] scaled deviance = 12.561 (change = -0.0016) at cycle  3
[i] ? $FIT +LSTD$
[o] scaled deviance = 9.3949 (change =  -3.168) at cycle  3
[o]         estimate       s.e.     parameter
[o]    1      1.920       2.116      1
[o]    2      1.312     0.09501      LLG
[o]    3     0.5343      0.1876      LFW
[o]    4     -1.403      0.7909     LSTD
[i] ? $FIT +LPSI$
[o] scaled deviance = 10.615 (change =  -1.948) at cycle  3
[i] ? $FIT +LSI$
[o] scaled deviance = 8.2273 (change =  -4.335) at cycle  3
[o]         estimate       s.e.     parameter
[o]    1     -1.843      0.7196      1
[o]    2      1.164     0.08507      LLG
[o]    3     0.5605      0.1821      LFW
[o]    4      3.206       1.544     LSI
[i] ? $FIT +LCV$
[o] scaled deviance = 7.4101 (change =  -5.152) at cycle  3
[o]         estimate       s.e.     parameter
[o]    1     -4.417       1.497      1
[o]    2      1.185     0.08397      LLG
[o]    3     0.4291      0.1887      LFW
[o]    4     -1.859      0.8528      LCV
[i] ? $FIT +LSS$
[o] scaled deviance = 7.4047 (change =  -5.158) at cycle  3
[o]         estimate       s.e.     parameter
[o]    1      4.219       2.756      1
[o]    2      1.399      0.1160      LLG
[o]    3     0.5322      0.1887      LFW
[o]    4     -1.806      0.8328      LP81
[i] ? $FIT +LCSS$
```

```
[o] scaled deviance = 5.9939 (change =  -6.568) at cycle  3
[o]          estimate        s.e.     parameter
[o]    1      -2.436      0.8312      1
[o]    2       1.237     0.08242     LLG
[o]    3      0.4191      0.1898     LFW
[o]    4      -1.526      0.6464     LP8C
[i] ? $FIT +LUSS$
[o] scaled deviance = 11.470 (change = -1.0923) at cycle  3
[i] ? $FIT +LCUSS$
[o] scaled deviance = 11.022 (change =  -1.540) at cycle  3
[i] ? $CAL OF=T*LG$
[i] ? $FIT: +LFW$
[o] scaled deviance = 35.344 at cycle  3
[o]            d.f. =  9
[o] scaled deviance = 21.482 (change =  -13.86) at cycle  3
[o]            d.f. =  8     (change =   -1   )
[o]          estimate        s.e.     parameter
[o]    1      -1.747      0.7105      1
[o]    2      0.6290      0.1780     LFW
[i] ? $FIT +LSP$
[o] scaled deviance =  9.757 (change =  -11.72) at cycle  4
[o]          estimate        s.e.     parameter
[o]    1      -14.92       4.152      1
[o]    2      0.3071      0.2104     LFW
[o]    3       3.276       1.012     LSP
[i] ? $FIT +LEF$
[o] scaled deviance = 13.193 (change =  -8.289) at cycle  4
[o]          estimate        s.e.     parameter
[o]    1      -12.82       4.104      1
[o]    2      0.4044      0.2017     LFW
[o]    3       2.608      0.9478     LEF
[i] ? $FIT +LSTD$
[o] scaled deviance = 21.396 (change = -0.0863) at cycle  3
[i] ? $FIT +LPSI$
[o] scaled deviance = 19.958 (change =  -1.524) at cycle  3
[i] ? $FIT +LSI$
[o] scaled deviance = 12.238 (change =  -9.243) at cycle  3
[o]          estimate        s.e.     parameter
[o]    1      -1.794      0.6910      1
[o]    2      0.6094      0.1724     LFW
[o]    3       4.120       1.401     LSI
[i] ? $FIT +LCV$
[o] scaled deviance = 12.600 (change =  -8.882) at cycle  3
[o]          estimate        s.e.     parameter
[o]    1      -5.061       1.442      1
[o]    2      0.5109      0.1782     LFW
[o]    3      -2.227      0.7979     LCV
[i] ? $FIT +LSS$
[o] scaled deviance = 21.475 (change = -0.0066) at cycle  3
[i] ? $FIT +LCSS$
[o] scaled deviance = 14.879 (change =  -6.603) at cycle  3
[o]          estimate        s.e.     parameter
[o]    1      -2.421      0.7937      1
[o]    2      0.5397      0.1788     LFW
```

```
[o]    3     -1.386      0.5773     LP8C
[i] ? $FIT +LUSS$
[o] scaled deviance = 18.169 (change =  -3.313) at cycle  3
[o]          estimate        s.e.     parameter
[o]    1      -4.123        1.526     1
[o]    2      0.5647       0.1830     LFW
[o]    3      0.9446       0.5319     LVR
[i] ? $FIT +LCUSS$
[o] scaled deviance = 21.446 (change = -0.0360) at cycle  3
[i] ? $CAL OF=T*LG*FW$
[i] ? $FIT: +LSP$
[o] scaled deviance = 20.235 (change =  -5.330) at cycle  4
[o]          estimate        s.e.     parameter
[o]    1      -12.03        3.955     1
[o]    2       1.994       0.8949     LSP
[i] ? $FIT: +LEF$
[o] scaled deviance = 21.577 (change =  -3.988) at cycle  4
[o]          estimate        s.e.     parameter
[o]    1      -10.95        3.984     1
[o]    2       1.683       0.8671     LEF
[i] ? $FIT: +LSTD$
[o] scaled deviance = 25.366 (change = -0.1989) at cycle  3
[i] ? $FIT: +LPSI$
[o] scaled deviance = 23.751 (change =  -1.814) at cycle  3
[i] ? $FIT: +LSI$
[o] scaled deviance = 17.059 (change =  -8.506) at cycle  3
[o]          estimate        s.e.     parameter
[o]    1      -3.356      0.08132     1
[o]    2       4.108        1.455     LSI
[i] ? $FIT: +LCV$
[o] scaled deviance = 19.457 (change =  -6.107) at cycle  3
[o]          estimate        s.e.     parameter
[o]    1      -6.466        1.403     1
[o]    2      -1.903       0.8207     LCV
[i] ? $FIT: +LSS$
[o] scaled deviance = 25.561 (change = -0.0034) at cycle  3
[i] ? $FIT: +LCSS$
[o] scaled deviance = 20.971 (change =  -4.593) at cycle  3
[o]          estimate        s.e.     parameter
[o]    1      -4.139       0.4622     1
[o]    2      -1.222       0.6087     LP8C
[i] ? $FIT: +LUSS$
[o] scaled deviance = 23.501 (change =  -2.064) at cycle  3
[i] ? $FIT: +LCUSS$
[o] scaled deviance = 25.456 (change = -0.1089) at cycle  3
[i] ? $OFFSET LT$
[i] ? $FIT: +LFL$
[o] scaled deviance = 345.17 at cycle  5
[o]            d.f. =   9
[o] scaled deviance = 22.859 (change =  -322.3) at cycle  3
[o]            d.f. =  8     (change =    -1  )
[o]          estimate        s.e.     parameter
[o]    1      -3.857       0.3941     1
[o]    2       1.111      0.06829     LFL
```

```
[i] ? $FIT +LSP$
[o] scaled deviance = 16.210 (change =  -6.649) at cycle  4
[o]          estimate        s.e.     parameter
[o]    1      -35.37       12.50    1
[o]    2      0.5265       0.2335    LFL
[o]    3       7.890       3.115     LSP
[i] ? $FIT +LEF$
[o] scaled deviance = 20.321 (change =  -2.538) at cycle  4
[i] ? $FIT +LSTD$
[o] scaled deviance = 21.235 (change =  -1.624) at cycle  3
[i] ? $FIT +LPSI$
[o] scaled deviance = 20.834 (change =  -2.025) at cycle  4
[i] ? $FIT +LSI$
[o] scaled deviance = 16.366 (change =  -6.493) at cycle  4
[o]          estimate        s.e.     parameter
[o]    1      -3.677       0.3986    1
[o]    2       1.058       0.07040    LFL
[o]    3       3.850        1.524    LSI
[i] ? $FIT +LCV$
[o] scaled deviance = 18.864 (change =  -3.995) at cycle  3
[o]          estimate        s.e.     parameter
[o]    1      -6.431        1.424    1
[o]    2       1.055       0.07155    LFL
[o]    3      -1.701       0.8766    LCV
[i] ? $FIT +LSS$
[o] scaled deviance = 21.144 (change =  -1.715) at cycle  3
[i] ? $FIT +LCSS$
[o] scaled deviance = 18.968 (change =  -3.890) at cycle  3
[o]          estimate        s.e.     parameter
[o]    1      -4.666       0.6189    1
[o]    2       1.096       0.06834    LFL
[o]    3      -1.203       0.6466    LP8C
[i] ? $FIT +LUSS$
[o] scaled deviance = 22.789 (change = -0.0702) at cycle  4
[i] ? $FIT +LCUSS$
[o] scaled deviance = 22.823 (change = -0.0363) at cycle  3
```

Exhibit 3.2a(i): The Results of the Regression Analysis of the Effect of Traffic Speed Characteristics on the Slight Injury Accidents Using Poisson Distribution (Tyne & Wear)

```
[o] GLIM 3.77 update 1 (copyright)1985 Royal Statistical Society, London
[i] ? $FIT: +LLG +LFW$
[o] scaled deviance = 435.12 at cycle  5
[o]          d.f. =   8
[o] scaled deviance = 4.3839 (change =  -430.7) at cycle  3
[o]          d.f. = 6      (change =    -2  )
[i] ? $FIT +LSP$
[o] scaled deviance = 4.1094 (change = -0.2745) at cycle  3
[i] ? $FIT +LEF$
[o] scaled deviance = 4.2163 (change = -0.16759) at cycle  3
[i] ? $FIT +LSTD$
[o] scaled deviance = 4.3660 (change = -0.0179) at cycle  3
[i] ? $FIT +LPSI$
[o] scaled deviance = 3.8609 (change = -0.5230) at cycle  3
[i] ? $FIT +LSI$
[o] scaled deviance = 3.8870 (change = -0.4969) at cycle  3
[i] ? $FIT +LCV$
[o] scaled deviance = 4.2167 (change = -0.16715) at cycle  3
[i] ? $FIT +LSS$
[o] scaled deviance = 4.3837 (change = -0.0001) at cycle  3
[i] ? $FIT +LCSS$
[o] scaled deviance = 3.9882 (change = -0.3957) at cycle  3
[i] ? $FIT +LUSS$
[o] scaled deviance = 4.3571 (change = -0.02677) at cycle  3
[i] ? $FIT +LCUSS$
[o] scaled deviance = 3.7425 (change = -0.6413) at cycle  3
[i] ? $FIT: +LFL$
[o] scaled deviance = 435.12 at cycle  5
[o]          d.f. =   8
[o] scaled deviance = 7.7622 (change =  -427.4) at cycle  3
[o]          d.f. = 7      (change =    -1  )
[o]        estimate       s.e.     parameter
[o]    1      -2.310      0.4288      1
[o]    2      0.9524      0.06227     LFL
[i] ? $FIT +LSP$
[o] scaled deviance = 7.7287 (change = -0.03346) at cycle  3
[i] ? $FIT +LEF$
[o] scaled deviance = 7.5193 (change = -0.2429) at cycle  3
[i] ? $FIT +LSTD$
[o] scaled deviance = 5.7171 (change =  -2.045) at cycle  3
[i] ? $FIT +LPSI$
[o] scaled deviance = 6.9466 (change = -0.8156) at cycle  3
[i] ? $FIT +LSI$
[o] scaled deviance = 7.6890 (change = -0.07318) at cycle  3
[i] ? $FIT +LCV$
[o] scaled deviance = 4.2747 (change =  -3.487) at cycle  3
[i] ? $FIT +LSS$
[o] scaled deviance= 5.5958 (change=    -2.166) at cyycle 3
[i] ? $FIT +LCSS$
[o] scaled deviance = 4.0132 (change =  -3.749) at cycle  3
```

```
[o]          estimate        s.e.     parameter
[o]    1       -1.539     0.5883      1
[o]    2       0.9597     0.06602     LFL
[o]    3       0.9005     0.4668      LP8C
[i] ? $FIT +LUSS$
[o] scaled deviance = 5.4440 (change =  -2.318) at cycle  3
[i] ? $FIT +LCUSS$
[o] scaled deviance = 3.7980 (change =  -3.964) at cycle  3
[o]          estimate        s.e.     parameter
[o]    1      -0.7500     0.8767      1
[o]    2       0.9938     0.07054     LFL
[o]    3        1.060     0.5349      LCR
[i] ? $CAL OF=T*LG$
[i] ? $FIT: +LFW$
[o] scaled deviance = 19.467 at cycle  3
[o]          d.f. =  8
[o] scaled deviance = 4.3924 (change =  -15.08) at cycle  3
[o]          d.f. = 7      (change =   -1   )
[i] ? $FIT +LSP$
[o] scaled deviance = 4.2913 (change = -0.10112) at cycle  3
[i] ? $FIT +LEF$
[o] scaled deviance = 4.3111 (change = -0.08130) at cycle  3
[i] ? $FIT +LSTD$
[o] scaled deviance = 4.3678 (change = -0.0246) at cycle  3
[i] ? $FIT +LPSI$
[o] scaled deviance = 3.8620 (change = -0.5303) at cycle  3
[i] ? $FIT +LSI$
[o] scaled deviance = 4.1085 (change = -0.2839) at cycle  3
[i] ? $FIT +LCV$
[o] scaled deviance = 4.2179 (change = -0.1745) at cycle  3
[i] ? $FIT +LSS$
[o] scaled deviance = 4.3877 (change = -0.0047) at cycle  3
[i] ? $FIT +LCSS$
[o] scaled deviance = 4.1538 (change = -0.2386) at cycle  3
[i] ? $FIT +LUSS$
[o] scaled deviance = 4.3904 (change = -0.0020) at cycle  3
[i] ? $FIT +LCUSS$
[o] scaled deviance = 3.7476 (change = -0.6448) at cycle  3
[i] ? $CAL OF=T*LG*FW$
[i] ? $CAL LOF=%LOG(OF)$
[i] ? $FIT: +LSP$
[o] scaled deviance = 7.7529 (change = -0.5727) at cycle  3
[i] ? $FIT: +LEF$
[o] scaled deviance = 8.1993 (change = -0.12636) at cycle  3
[i] ? $FIT: +LSTD$
[o] scaled deviance = 7.2653 (change = -1.0604) at cycle  3
[i] ? $FIT: +LPSI$
[o] scaled deviance = 7.1196 (change =  -1.206) at cycle  3
[i] ? $FIT: +LSI$
[o] scaled deviance = 7.8098 (change = -0.5158) at cycle  3
[i] ? $FIT: +LCV$
[o] scaled deviance = 4.2751 (change =  -4.051) at cycle  3
[o]          estimate        s.e.     parameter
[o]    1       -2.240     0.9900      1
```

```
[o]    2       1.053      0.5211     LCV
[i] ? $FIT: +LSS$
[o] scaled deviance = 7.5479 (change = -0.7777) at cycle  3
[i] ? $FIT: +LCSS$
[o] scaled deviance = 4.3742 (change =  -3.951) at cycle  3
[o]          estimate       s.e.    parameter
[o]    1      -3.394      0.4285     1
[o]    2      0.9331      0.4690     LP8C
[i] ? $FIT: +LUSS$
[o] scaled deviance = 7.0604 (change =  -1.265) at cycle  3
[i] ? $FIT: +LCV$
[o] scaled deviance = 4.2751 (change =  -4.051) at cycle  3
[o]          estimate       s.e.    parameter
[o]    1      -2.240      0.9900     1
[o]    2       1.053      0.5211     LCV
[i] ? $FIT: +LCUSS$
[o] scaled deviance = 3.8058 (change =  -4.520) at cycle  3
[o]          estimate       s.e.    parameter
[o]    1      -2.372      0.8661     1
[o]    2       1.077      0.4993     LCR
```

Exhibit 3.2a(ii): The Results of the Regression Analysis of the Effect of Traffic Speed Characteristics on the Serious Injury Accients Using Poisson Distribution (Tyne & Wear)

```
[o] GLIM 3.77 update 1 (copyright)1985 Royal Statistical Society, London
[i] ? $FIT: +LLG +LFW$
[o] scaled deviance =  94.44 at cycle  5
[o]          d.f. =   8
[o] scaled deviance = 5.3918 (change =  -89.05) at cycle  4
[o]          d.f. = 6     (change =   -2   )
[i] ? $FIT +LSP$
[o] scaled deviance = 3.0364 (change =  -2.355) at cycle  4
[o]          estimate       s.e.    parameter
[o]    1      -25.63      13.45      1
[o]    2      0.5965      0.3422     LLG
[o]    3      0.8339       1.585     LFW
[o]    4       4.980      3.284      LSP
[i] ? $FIT +LEF$
[o] scaled deviance = 2.7631 (change =  -2.629) at cycle  4
[o]          estimate       s.e.    parameter
[o]    1      -21.36      10.44      1
[o]    2      0.6533      0.2954     LLG
[o]    3    0.001412       1.797     LFW
[o]    4       4.558      2.855      LEF
[i] ? $FIT +LSTD$
[o] scaled deviance = 2.1466 (change =  -3.245) at cycle  4
[i] ? $FIT +LPS1$
[o] scaled deviance = 5.1296 (change = -0.2622) at cycle  4
[i] ? $FIT +LSI$
[o] scaled deviance = 5.0255 (change = -0.3663) at cycle  5
[i] ? $FIT +LCV$
[o] scaled deviance = 2.1982 (change =  -3.194) at cycle  4
```

```
[i] ? $FIT +LSS$
[o] scaled deviance = 2.2185 (change =  -3.173) at cycle  4
[i] ? $FIT +LCSS$
[o] scaled deviance = 1.8105 (change =  -3.581) at cycle  4
[o]          estimate        s.e.     parameter
[o]    1        26.03        19.74     1
[o]    2         1.011      0.1723     LLG
[o]    3        -5.519       4.383     LFW
[o]    4         6.385       3.687     LP8C
[i] ? $FIT +LVR$
[o] scaled deviance = 2.3022 (change =  -3.090) at cycle  4
[i] ? $FIT +LCR$
[o] scaled deviance = 2.5033 (change =  -2.888) at cycle  5
[i] ? $FIT: +LFL$
[o] scaled deviance = 5.6690 (change =  -88.77) at cycle  4
[o]          estimate        s.e.     parameter
[o]    1       -4.825        1.162     1
[o]    2        1.072       0.1664     LFL
[i] ? $FIT +LSP$
[o] scaled deviance = 3.0643 (change =  -2.605) at cycle  4
[i] ? $FIT +LEF$
[o] scaled deviance = 2.9260 (change =  -2.743) at cycle  4
[i] ? $FIT +LSTD$
[o] scaled deviance = 3.7116 (change =  -1.957) at cycle  4
[i] ? $FIT +LPS1$
[o] scaled deviance = 5.1334 (change = -0.5356) at cycle  4
[i] ? $FIT +LSI$
[o] scaled deviance = 5.5312 (change = -0.1378) at cycle  4
[i] ? $FIT +LCV$
[o] scaled deviance = 4.5655 (change = -1.1035) at cycle  4
[i] ? $FIT +LSS$
[o] scaled deviance = 3.5766 (change =  -2.092) at cycle  4
[i] ? $FIT +LCSS$
[o] scaled deviance = 4.3197 (change = -1.3493) at cycle  4
[i] ? $FIT +LVR$
[o] scaled deviance = 3.4001 (change =  -2.269) at cycle  4
[i] ? $FIT +LCR$
[o] scaled deviance = 4.0770 (change = -1.5920) at cycle  4
[i] ? $CAL OF=T*LG$
[i] ? $FIT: +LFW$
[o] scaled deviance = 5.7576 (change =  -1.329) at cycle  3
[o]          estimate        s.e.     parameter
[o]    1       -7.489        4.685     1
[o]    2        1.412        1.240     LFW
[i] ? $FIT +LSP$
[o] scaled deviance = 4.2082 (change = -1.5494) at cycle  4
[i] ? $FIT +LEF$
[o] scaled deviance = 3.9023 (change =  -1.855) at cycle  4
[i] ? $FIT +LSTD$
[o] scaled deviance = 2.9376 (change =  -2.820) at cycle  4
[i] ? $FIT +LPS1$
[o] scaled deviance = 5.5810 (change = -0.17658) at cycle  3
[i] ? $FIT +LSI$
[o] scaled deviance = 5.7492 (change = -0.0084) at cycle  4
```

```
[i] ? $FIT +LCV$
[o] scaled deviance = 3.9519 (change =  -1.806) at cycle  3
[i] ? $FIT +LSS$
[o] scaled deviance = 3.1998 (change =  -2.558) at cycle  4
[i] ? $FIT +LCSS$
[o] scaled deviance = 1.8150 (change =  -3.943) at cycle  4
[o]         estimate       s.e.     parameter
[o]    1       24.44       19.48     1
[o]    2      -5.519       4.326     LFW
[o]    3       6.362       3.627     LP8C
[i] ? $FIT +LVR$
[o] scaled deviance = 2.6244 (change =  -3.133) at cycle  4
[i] ? $FIT +LCV$
[o] scaled deviance = 3.9519 (change =  -1.806) at cycle  3
[i] ? $CAL OF=T*LG*FW$
[i] ? $FIT: +LSP$
[o] scaled deviance = 4.6113 (change = -1.2570) at cycle  4
[i] ? $FIT: +LEF$
[o] scaled deviance = 4.0190 (change =  -1.849) at cycle  4
[i] ? $FIT: +LSTD$
[o] scaled deviance = 3.7127 (change =  -2.156) at cycle  4
[i] ? $FIT: +LPS1$
 [o] scaled deviance = 5.5883 (change = -0.2800) at cycle  3
[i] ? $FIT: +LSI$
[o] scaled deviance = 5.8647 (change = -0.0036) at cycle  4
[i] ? $FIT: +LCV$
[o] scaled deviance = 5.2639 (change = -0.6044) at cycle  3
[i] ? $FIT: +LSS$
[o] scaled deviance = 3.6070 (change =  -2.261) at cycle  4
[i] ? $FIT: +LCSS$
[o] scaled deviance = 4.6924 (change =  -1.176) at cycle  3
[i] ? $FIT: +LUSS$
[o] scaled deviance = 3.4035 (change =  -2.465) at cycle  4
[i] ? $FIT: +LCUSS$
[o] scaled deviance = 4.8668 (change = -1.0015) at cycle  3
```

Exhibit 3.2a(iii): The Results of the Regression Analysis of the Effect of the Traffic Speed Characteristics on the Fatal Injury Accidents Using Poisson Distribution (Tyne & Wear)

```
[o] GLIM 3.77 update 1 (copyright)1985 Royal Statistical Society, London
[i] ? $FIT: +LLG +LFW$
[o] scaled deviance = 42.600 at cycle  5
[o]          d.f. =  8
[o] scaled deviance = 4.4511 (change =  -38.15) at cycle  5
[o]          d.f. = 6      (change =   -2  )
[i] ? $d e$
[o]         estimate       s.e.     parameter
[o]    1      -12.88       9.917     1
[o]    2       1.140      0.3148     LLG
[o]    3       2.498       2.460     LFW
[i] ? $FIT +LSP$
[o] scaled deviance = 3.8664 (change = -0.5847) at cycle  5
```

```
[i] ? $FIT +LEF$
[o] scaled deviance = 4.0989 (change = -0.3523) at cycle  5
[i] ? $FIT +LSTD$
[o] scaled deviance = 4.2208 (change =  -0.230) at cycle  5
[i] ? $FIT +LPSI$
[o] scaled deviance = 4.1983 (change =  -0.253) at cycle  5
[i] ? $FIT +LSI$
[o] scaled deviance = 1.5043 (change =  -2.947) at cycle  5
[i] ? $FIT +LCV$
[o] scaled deviance = 4.4510 (change =  -0.000) at cycle  5
[i] ? $FIT +LSS$
[o] scaled deviance = 4.2691 (change =  -0.182) at cycle  5
[i] ? $FIT +LCSS$
[o] scaled deviance = 4.4449 (change =  -0.006) at cycle  5
[i] ? $FIT +LUSS$
[o] scaled deviance = 4.4424 (change =  -0.009) at cycle  5
[i] ? $FIT +LCUSS$
[o] scaled deviance = 2.5496 (change = -1.9016) at cycle  7
[i] ? $FIT: +LFL$
[o] scaled deviance = 4.8291 (change =  -37.77) at cycle  5
[o]         estimate        s.e.     parameter
[o]    1      -7.225        1.758     1
[o]    2       1.064        0.2520    LFL
[i] ? $FIT +LSP$
[o] scaled deviance = 4.0446 (change = -0.7845) at cycle  5
[i] ? $FIT +LEF$
[o] scaled deviance = 4.1419 (change = -0.6872) at cycle  5
[i] ? $FIT +LSTD$
[o] scaled deviance = 4.2279 (change = -0.6012) at cycle  5
[i] ? $FIT +LPSI$
[o] scaled deviance = 4.1989 (change = -0.6302) at cycle  5
[i] ? $FIT +LSI$
[o] scaled deviance = 1.6917 (change =  -3.137) at cycle  5
[i] ? $FIT +LCV$
[o] scaled deviance = 4.4886 (change =  -0.340) at cycle  5
[i] ? $FIT +LSS$
[o] scaled deviance = 4.2692 (change = -0.5599) at cycle  5
[i] ? $FIT +LCSS$
[o] scaled deviance = 4.4648 (change =  -0.364) at cycle  5
[i] ? $FIT +LUSS$
[o] scaled deviance = 4.6239 (change =  -0.205) at cycle  5
[i] ? $FIT +LCUSS$
[o] scaled deviance = 4.8072 (change =  -0.022) at cycle  5
[i] ? $CAL OF=T*LG$
[i] ? $FIT: +LFW$
[o] scaled deviance = 5.6811 at cycle  4
[o]            d.f. = 8
[o] scaled deviance = 4.6796 (change = -1.0016) at cycle  4
[o]         estimate        s.e.     parameter
[o]    1      -10.14        7.261     1
[o]    2       1.888        1.918     LFW
[i] ? $FIT +LSP$
[o] scaled deviance = 4.0734 (change =  -0.606) at cycle  5
[i] ? $FIT +LEF$
```

```
[o] scaled deviance = 4.1689 (change =  -0.511) at cycle  5
[i] ? $FIT +LSTD$
[o] scaled deviance = 4.2237 (change =  -0.456) at cycle  5
[i] ? $FIT +LPSI$
[o] scaled deviance = 4.4692 (change = -0.2104) at cycle  4
[i] ? $FIT +LSI$
[o] scaled deviance = 1.6430 (change =  -3.037) at cycle  5
[i] ? $FIT +LCV$
[o] scaled deviance = 4.6781 (change = -0.0015) at cycle  4
[i] ? $FIT +LUSS$
[o] scaled deviance = 4.5891 (change =  -0.090) at cycle  5
[i] ? $FIT +LCUSS$
[o] scaled deviance = 4.0176 (change = -0.6620) at cycle  4
[i] ? $CAL OF=T*LG*FW$
[i] ? $FIT: +LSP$
[o] scaled deviance = 4.5042 (change =  -0.393) at cycle  5
[i] ? $FIT: +LEF$
[o] scaled deviance = 4.4044 (change =  -0.493) at cycle  5
[i] ? $FIT: +LSTD$
[o] scaled deviance = 4.2281 (change = -0.6689) at cycle  4
[i] ? $FIT: +LPSI$
[o] scaled deviance = 4.4703 (change = -0.42664) at cycle  4
[i] ? $FIT: +LSI$
[o] scaled deviance = 1.9151 (change =  -2.982) at cycle  5
[i] ? $FIT: +LCV$
[o] scaled deviance = 4.7124 (change = -0.1845) at cycle  4
[i] ? $FIT: +LSS$
[o] scaled deviance = 4.2765 (change = -0.6205) at cycle  4
[i] ? $FIT: +LCSS$
[o] scaled deviance = 4.5783 (change = -0.3187) at cycle  4
[i] ? $FIT: +LUSS$
[o] scaled deviance = 4.6336 (change = -0.2634) at cycle  4
[i] ? $FIT: +LCUSS$
[o] scaled deviance = 4.8936 (change = -0.0033) at cycle  4
```

Exhibit 3.2a(iv): The Results of the Regression Analysis of the Effect of Traffic Speed Characteristics on the 'Hazard' Injury Accidents Using Poisson Distribution (Tyne & Wear)

```
[o] GLIM 3.77 update 1 (copyright)1985 Royal Statistical Society, London
[i] ? $FIT: +LLG +LFW$
[o] scaled deviance = 133.11 at cycle  5
[o]          d.f. =   8
[o] scaled deviance = 5.9684 (change =  -127.1) at cycle  4
[o]          d.f. = 6      (change =    -2  )
[o]          estimate       s.e.     parameter
[o]     1      -9.871       5.213     1
[o]     2       1.119       0.1649    LLG
[o]     3       2.039       1.299     LFW
[i] ? $FIT +LSP$
[o] scaled deviance = 3.0667 (change =  -2.902) at cycle  4
[o]          estimate       s.e.     parameter
[o]     1      -26.21       11.18     1
```

```
[o]    2      0.6355      0.2913     LLG
[o]    3       1.078       1.339     LFW
[o]    4       4.614       2.730     LSP
[i] ? $FIT +LEF$
[o] scaled deviance = 3.1384 (change =  -2.830) at cycle  4
[o]          estimate        s.e.     parameter
[o]    1      -21.35       8.621      1
[o]    2      0.7115      0.2558     LLG
[o]    3      0.4096       1.516     LFW
[o]    4       3.938       2.355     LEF
[o]    scale parameter taken as  1.000
[i] ? $FIT +LSTD$
[o] scaled deviance = 2.8437 (change =  -3.125) at cycle  4
[i] ? $FIT +LPSI$
[o] scaled deviance = 5.4682 (change = -0.5002) at cycle  4
[i] ? $FIT +LSI$
[o] scaled deviance = 5.6946 (change = -0.2739) at cycle  4
[i] ? $FIT +LCV$
[o] scaled deviance = 3.7460 (change =  -2.222) at cycle  4
[i] ? $FIT +LSS$
[o] scaled deviance = 2.9885 (change =  -2.980) at cycle  4
[i] ? $FIT +LCSS$
[o] scaled deviance = 3.3528 (change =  -2.616) at cycle  4
[i] ? $FIT +LVR$
[o] scaled deviance = 3.8378 (change =  -2.131) at cycle  4
[i] ? $FIT +LCUSS$
[o] scaled deviance = 5.0257 (change = -0.94274) at cycle  4
[i] ? $FIT: +LFL$
[o] scaled deviance = 133.11 at cycle  5
[o] scaled deviance = 6.5707 (change =  -126.5) at cycle  4
[o]          d.f. = 7      (change =    -1  )
[o]          estimate        s.e.     parameter
[o]    1      -6.061      0.9697      1
[o]    2       1.070      0.1389     LFL
[i] ? $FIT +LSP$
[o] scaled deviance = 3.2041 (change =  -3.367) at cycle  4
[o]          estimate        s.e.     parameter
[o]    1      -25.29       10.88      1
[o]    2      0.5962      0.2653     LFL
[o]    3       4.832       2.665     LSP
[i] ? $FIT +LEF$
[o] scaled deviance = 3.1882 (change =  -3.382) at cycle  4
[i] ? $FIT +LSTD$
[o] scaled deviance = 4.0264 (change =  -2.544) at cycle  4
[i] ? $FIT +LPSI$
[o] scaled deviance = 5.4724 (change = -1.0983) at cycle  4
[i] ? $FIT +LSI$
[o] scaled deviance = 6.1004 (change = -0.4703) at cycle  4
[i] ? $FIT +LCV$
[o] scaled deviance = 5.1347 (change = -1.4359) at cycle  4
[i] ? $FIT +LSS$
[o] scaled deviance = 3.9469 (change =  -2.624) at cycle  4
[i] ? $FIT +LCSS$
[o] scaled deviance = 4.8751 (change = -1.6956) at cycle  4
```

```
[i] ? $FIT +LVR$
[o] scaled deviance = 4.2960 (change =  -2.275) at cycle  4
[i] ? $FIT +LCUSS$
[o] scaled deviance = 5.2878 (change = -1.2829) at cycle  4
[i] ? $CAL OF=T*LG$
[i] ? $FIT: +LFW$
[o] scaled deviance = 8.8399 at cycle  3
[o]            d.f. = 8
[o] scaled deviance = 6.5526 (change =  -2.287) at cycle  3
[o]          estimate        s.e.    parameter
[o]    1      -7.668        3.939     1
[o]    2       1.553        1.042     LFW
[i] ? $FIT +LSP$
[o] scaled deviance = 4.4032 (change =  -2.149) at cycle  4
[i] ? $FIT +LEF$
[o] scaled deviance = 4.2193 (change =  -2.333) at cycle  4
[i] ? $FIT +LSTD$
[o] scaled deviance = 3.4509 (change =  -3.102) at cycle  4
 [i] ? $FIT +LPSI$
[o] scaled deviance = 6.1871 (change = -0.3655) at cycle  3
[i] ? $FIT +LCV$
[o] scaled deviance = 5.2640 (change =  -1.289) at cycle  3
[i] ? $FIT +LSI$
[o] scaled deviance = 5.7288 (change = -0.8238) at cycle  4
[i] ? $FIT +LSS$
[o] scaled deviance = 3.7469 (change =  -2.806) at cycle  4
[i] ? $FIT +LCSS$
[o] scaled deviance = 3.3638 (change =  -3.189) at cycle  4
[i] ? $FIT +LVR$
[o] scaled deviance = 3.9719 (change =  -2.581) at cycle  4
[i] ? $FIT +LCUSS$
[o] scaled deviance = 5.8418 (change = -0.7108) at cycle  3
[i] ? $CAL OF=T*LG*FW$
[i] ? $FIT: +LSP$
[o] scaled deviance = 5.1966 (change =  -1.640) at cycle  4
[i] ? $FIT: +LEF$
[o] scaled deviance = 4.5249 (change =  -2.312) at cycle  4
[i] ? $FIT: +LSTD$
[o] scaled deviance = 4.0276 (change =  -2.810) at cycle  4
[i] ? $FIT: +LPSI$
[o] scaled deviance = 6.1951 (change = -0.6420) at cycle  3
[i] ? $FIT: +LSI$
[o] scaled deviance = 6.1028 (change = -0.7343) at cycle  4
[i] ? $FIT: +LCV$
[o] scaled deviance = 6.0525 (change = -0.7846) at cycle  3
[i] ? $FIT: +LSS$
[o] scaled deviance = 3.9848 (change =  -2.852) at cycle  4
[i] ? $FIT: +LCSS$
[o] scaled deviance = 5.3572 (change =  -1.480) at cycle  3
[i] ? $FIT: +LUSS$
[o] scaled deviance = 4.3035 (change =  -2.534) at cycle  4
[i] ? $FIT: +LCUSS$
[o] scaled deviance = 6.0764 (change = -0.7607) at cycle  3
```

Exhibit 3.2b(i): The Results of the Regression Analysis of the Effect of Traffic Speed Characteristics on the Slight Injury Accidents Using Poisson Distribution (Bahrain)

```
[o] GLIM 3.77 update 1 (copyright)1985 Royal Statistical Society, London
[i] ? $FIT: +LLG +LFW$
[o] scaled deviance = 231.26 at cycle  4
[o]          d.f. =   9
[o] scaled deviance = 7.5936 (change =  -223.7) at cycle  3
[o]          estimate       s.e.    parameter
[o]    1      -2.300      0.8520     1
[o]    2       1.131      0.09034     LLG
[o]    3      0.6428      0.2169      LFW
[i] ? $FIT +LSP$
[o] scaled deviance = 5.3013 (change =  -2.292) at cycle  4
[o]          estimate       s.e.    parameter
[o]    1      -23.27      14.05      1
[o]    2      0.7194      0.2822      LLG
[o]    3      0.3120      0.3077      LFW
[o]    4       5.205      3.473      LSP
[i] ? $FIT +LEF$
[o] scaled deviance = 7.5875 (change = -0.0062) at cycle  3
[i] ? $FIT +LSTD$
[o] scaled deviance = 5.9264 (change =  -1.667) at cycle  3
[i] ? $FIT +LPSI$
[o] scaled deviance = 5.5293 (change =  -2.064) at cycle  3
[i] ? $FIT +LSI$
[o] scaled deviance = 4.5721 (change =  -3.022) at cycle  3
[o]          d.f. = 6      (change =  -1    )
[o]          estimate       s.e.    parameter
[o]    1      -2.340      0.8295     1
[o]    2       1.070      0.09255     LLG
[o]    3      0.6554      0.2083      LFW
[o]    4       2.956      1.706      LSI
[i] ? $FIT +LCV$
[o] scaled deviance = 4.7251 (change =  -2.869) at cycle  3
[i] ? $FIT +LSS$
[o] scaled deviance = 4.7153 (change =  -2.878) at cycle  3
[i] ? $FIT +LCSS$
[o] scaled deviance = 3.9456 (change =  -3.648) at cycle  3
[o]          estimate       s.e.    parameter
[o]    1      -2.871      0.9411     1
[o]    2       1.128      0.09018     LLG
[o]    3      0.5547      0.2194      LFW
[o]    4      -1.248      0.6957     LP8C
[i] ? $FIT +LUSS$
[o] scaled deviance = 7.0580 (change = -0.5356) at cycle  3
[i] ? $FIT +LCUSS$
[o] scaled deviance = 6.8595 (change = -0.7342) at cycle  3
[i] ? $FIT: +LFL$
[o] scaled deviance = 231.26 at cycle  4
[o]          d.f. =   9
[o] scaled deviance = 11.357 (change =  -219.9) at cycle  3
[o]          d.f. =  8     (change =     -1  )
```

```
[o]        estimate      s.e.    parameter
[o]   1     -3.795     0.4422     1
[o]   2      1.049     0.07728    LFL
[i] ? $FIT +LSP$
[o] scaled deviance = 7.8704 (change =  -3.486) at cycle  4
[o]        estimate      s.e.    parameter
[o]   1     -28.83      13.65     1
[o]   2     0.5761      0.2619    LFL
[o]   3      6.280      3.410     LSP
[i] ? $FIT +LEF$
[i] ? $FIT +LSTD$
[o] scaled deviance = 10.352 (change = -1.0050) at cycle  3
[i] ? $FIT +LPSI$
[o] scaled deviance = 9.2356 (change =  -2.121) at cycle  3
[i] ? $FIT +LSI$
[o] scaled deviance = 7.6234 (change =  -3.733) at cycle  3
[o]        estimate      s.e.    parameter
[o]   1     -3.626     0.4471  · 1
[o]   2      1.002     0.07992    LFL
[o]   3      3.259      1.695     LSI
[i] ? $FIT +LCV$
[o] scaled deviance = 9.0166 (change =  -2.340) at cycle  3
[i] ? $FIT +LSS$
[o] scaled deviance = 10.068 (change =  -1.289) at cycle  3
[i] ? $FIT +LCSS$
[o] scaled deviance = 8.9594 (change =  -2.397) at cycle  3
[i] ? $FIT +LUSS$
[o] scaled deviance = 11.357 (change = -0.0001) at cycle  3
[i] ? $FIT +LCUSS$
[o] scaled deviance = 11.277 (change = -0.0794) at cycle  3
[i] ? $CAL OF=T*LG$
[i] ? $FIT: +LFW$
[o] scaled deviance = 22.229 at cycle  3
[o]          d.f. =  9
[o] scaled deviance = 9.7616 (change =  -12.47) at cycle  3
[o]          d.f. = 8     (change =  -1  )
[o]        estimate      s.e.    parameter
[o]   1     -2.302     0.8362     1
[o]   2     0.6963     0.2091     LFW
[i] ? $FIT +LSP$
[o] scaled deviance = 6.2723 (change =  -3.489) at cycle  3
[o]        estimate      s.e.    parameter
[o]   1     -10.27      4.501     1
[o]   2     0.5037     0.2397     LFW
[o]   3      1.981      1.096     LSP
[i] ? $FIT +LEF$
[o] scaled deviance = 7.8046 (change =  -1.957) at cycle  3
[i] ? $FIT +LSTD$
[o] scaled deviance = 9.4969 (change = -0.2646) at cycle  3
[i] ? $FIT +LPSI$
[o] scaled deviance = 7.9438 (change =  -1.818) at cycle  3
[i] ? $FIT +LSI$
[o] scaled deviance = 5.1594 (change =  -4.602) at cycle  3
[o]        estimate      s.e.    parameter
```

```
[o]    1     -2.305      0.8145    1
[o]    2     0.6721      0.2033    LFW
[o]    3      3.339       1.596    LSI
[i] ? $FIT +LCV$
[o] scaled deviance = 5.6147 (change =  -4.147) at cycle  3
[i] ? $d e$
[o]          estimate       s.e.     parameter
[o]    1     -4.835       1.604     1
[o]    2     0.5956       0.2113    LFW
[o]    3     -1.728       0.8911    LCV
[i] ? $FIT +LSS$
[o] scaled deviance = 9.5973 (change = -0.16427) at cycle  3
[i] ? $FIT +LCSS$
[o] scaled deviance = 6.0367 (change =  -3.725) at cycle  3
[o]          estimate       s.e.     parameter
[o]    1     -2.862       0.9209    1
[o]    2     0.6138       0.2110    LFW
[o]    3     -1.198       0.6572    LP8C
[i] ? $FIT +LUSS$
[o] scaled deviance = 9.2039 (change = -0.5577) at cycle  3
[i] ? $FIT +LCUSS$
[o] scaled deviance = 9.7348 (change = -0.02674) at cycle  3
[i] ? $FIT +LSI$
[o] scaled deviance = 4.5721 (change =  -3.022) at cycle  3
[i] ? $CAL OF=T*LG*FW$
[i] ? $FIT: +LSP$
[o] scaled deviance = 10.439 (change = -1.3303) at cycle  3
[i] ? $FIT: +LEF$
[o] scaled deviance = 11.072 (change = -0.6969) at cycle  3
[i] ? $FIT: +LSTD$
[o] scaled deviance = 11.374 (change = -0.3950) at cycle  3
[i] ? $FIT: +LPSI$
[o] scaled deviance = 9.7557 (change =  -2.013) at cycle  3
[i] ? $FIT: +LSI$
[o] scaled deviance = 7.6240 (change =  -4.145) at cycle  3
[o]          estimate       s.e.     parameter
[o]    1     -3.615      0.09154    1
[o]    2      3.268       1.647     LSI
[i] ? $FIT: +LCV$
[o] scaled deviance = 9.0167 (change =  -2.752) at cycle  3
[i] ? $FIT: +LSS$
[o] scaled deviance = 11.500 (change = -0.26859) at cycle  3
[i] ? $FIT: +LCSS$
[o] scaled deviance = 9.1631 (change =  -2.606) at cycle  3
[i] ? $FIT: +LUSS$
[o] scaled deviance = 11.530 (change = -0.23882) at cycle  3
[i] ? $FIT: +LCUSS$
[o] scaled deviance = 11.764 (change = -0.0048) at cycle  3
```

Exhibit 3.2b(ii): The Results of the Regression Analysis of the Effect of Traffic Speed Characteristics on the Serious Injury Accidents Using Poisson Distribution (Bahrain)

```
[i] ? $FIT: +LLG +LFW$
[o] scaled deviance = 112.08 at cycle  5
[o]          d.f. =   9
[o] scaled deviance = 10.705 (change = -101.38) at cycle  4
[o]          d.f. =  7     (change =   -2  )
[o]         estimate        s.e.     parameter
[o]    1      -2.149       1.549      1
[o]    2       1.654       0.2236     LLG
[o]    3     0.06087       0.4187     LFW
[i] ? $FIT +LSP$
[o] scaled deviance =  9.484 (change =  -1.222) at cycle  5
[i] ? $FIT +LEF$
[o] scaled deviance = 10.660 (change =  -0.046) at cycle  4
[i] ? $FIT +LSTD$
[o] scaled deviance = 8.0672 (change =  -2.638) at cycle  4
[i] ? $FIT +LPSI$
[o] scaled deviance = 10.699 (change =  -0.006) at cycle  4
[i] ? $FIT +LSI$
[o] scaled deviance = 10.009 (change =  -0.697) at cycle  4
[i] ? $FIT +LCV$
[o] scaled deviance = 7.0721 (change =  -3.633) at cycle  4
[o]         estimate        s.e.     parameter
[o]    1      -8.783       4.526      1
[o]    2       1.564       0.2202     LLG
[o]    3    -0.07096       0.4059     LFW
[o]    4      -4.281       2.595      LCV
[i] ? $FIT +LSS$
[o] scaled deviance = 7.4447 (change =  -3.261) at cycle  4
[o]         estimate        s.e.     parameter
[o]    1       10.58       7.996      1
[o]    2       2.038       0.3637     LLG
[o]    3      0.1361       0.4165     LFW
[o]    4      -3.962       2.533      LP81
[i] ? $FIT +LCSS$
[o] scaled deviance = 6.8526 (change =  -3.853) at cycle  4
[o]         estimate        s.e.     parameter
[o]    1      -4.260       2.280      1
[o]    2       1.674       0.2261     LLG
[o]    3    -0.05339       0.4067     LFW
[o]    4      -3.366       2.186      LP8C
[i] ? $FIT +LUSS$
[o] scaled deviance =  9.190 (change = -1.5158) at cycle  4
[i] ? $FIT +LCUSS$
[o] scaled deviance =  8.841 (change = -1.8642) at cycle 4
[i] ? $FIT: +LFL$
[o] scaled deviance = 112.08 at cycle  5
[o]          d.f. =   9
[o] scaled deviance = 19.732 (change =  -92.35) at cycle  4
[o]          d.f. =  8     (change =   -1  )
[o]         estimate        s.e.     parameter
```

```
[o]    1     -6.497     0.9263     1
[o]    2      1.307     0.1565     LFL
[i] ? $FIT +LSP$
[o] scaled deviance = 15.564 (change = -4.1685) at cycle  5
[o]          estimate       s.e.     parameter
[o]    1     -69.93      32.58      1
[o]    2     0.2053      0.5507     LFL
[o]    3      15.78      8.042      LSP
[i] ? $FIT +LEF$
[o] scaled deviance = 16.243 (change = -3.4891) at cycle  5
[o]          estimate       s.e.     parameter
[o]    1     -79.06      41.61      1
[o]    2    0.03502      0.7180     LFL
[o]    3      17.37      9.918      LEF
[i] ? $FIT +LSTD$
[o] scaled deviance = 18.555 (change = -1.1768) at cycle  4
[i] ? $FIT +LPSI$
[o] scaled deviance = 19.704 (change =  -0.028) at cycle  4
[i] ? $FIT +LSI$
[o] scaled deviance = 16.637 (change = -3.0947) at cycle  4
[o]          estimate       s.e.     parameter
[o]    1     -6.335      0.9389     1
[o]    2      1.241      0.1589     LFL
[o]    3      6.375      3.720      LSI
[i] ? $FIT +LCV$
[o] scaled deviance = 16.890 (change =  -2.842) at cycle  4
[i] ? $FIT +LSS$
[o] scaled deviance = 19.100 (change =  -0.632) at cycle  4
[i] ? $FIT +LCSS$
[o] scaled deviance = 17.604 (change = -2.1276) at cycle  4
[i] ? $FIT +LUSS$
[o] scaled deviance = 19.548 (change =  -0.184) at cycle  4
[i] ? $FIT +LCUSS$
[o] scaled deviance = 19.732 (change =  -0.000) at cycle  4
[i] ? $CAL OF=T*LG$
[i] ? $FIT: +LFW$
[o] scaled deviance = 23.476 at cycle  4
[o]           d.f. =  9
[o] scaled deviance = 21.802 (change = -1.6735) at cycle  4
[o]           d.f. =  8     (change = -1     )
[i] ? $FIT +LSP$
[o] scaled deviance =  9.495 (change = -12.307) at cycle  4
[o]          estimate       s.e.     parameter
[o]    1     -36.00      11.24      1
[o]    2    -0.3713      0.4708     LFW
[o]    3      8.307      2.736      LSP
[i] ? $FIT +LEF$
[o] scaled deviance = 11.539 (change = -10.263) at cycle  4
[o]          estimate       s.e.     parameter
[o]    1     -32.78      10.88      1
[o]    2    -0.1868      0.4536     LFW
[o]    3      7.128      2.529      LEF
[i] ? $FIT +LSTD$
[o] scaled deviance = 21.799 (change =  -0.004) at cycle  4
```

```
[i] ? $FIT +LPSI$
[o] scaled deviance = 21.800 (change = -0.0024) at cycle  4
[i] ? $FIT +LSI$
[o] scaled deviance = 16.863 (change =  -4.939) at cycle  4
[o]         estimate       s.e.    parameter
[o]    1      -2.800       1.400     1
[o]    2      0.4603       0.3485     LFW
[o]    3       6.552       3.138     LSI
[i] ? $FIT +LCV$
[o] scaled deviance = 15.353 (change =  -6.449) at cycle  3
[o]         estimate       s.e.    parameter
[o]    1      -9.532       3.681     1
[o]    2      0.3004       0.3495     LFW
[o]    3      -4.444       2.013     LCV
[i] ? $FIT +LSS$
[o] scaled deviance = 21.357 (change = -0.4453) at cycle  4
[i] ? $FIT +LCSS$
[o] scaled deviance = 18.557 (change =  -3.246) at cycle  3
[o]         estimate       s.e.    parameter
[o]    1      -3.737       1.705     1
[o]    2      0.3486       0.3567     LFW
[o]    3      -2.137       1.321     LP8C
[i] ? $FIT +LUSS$
[o] scaled deviance = 17.109 (change =  -4.694) at cycle  4
[o]         estimate       s.e.    parameter
[o]    1      -9.106       3.622     1
[o]    2      0.2732       0.3822     LFW
[o]    3       2.597       1.292     LVR
[i] ? $FIT +LCUSS$
[o] scaled deviance = 21.525 (change = -0.2771) at cycle  4
[i] ? $CAL OF=T*LG*FW$
[i] ? $FIT: +LSP$
[o] scaled deviance = 17.593 (change =  -6.314) at cycle  4
[o]         estimate       s.e.    parameter
[o]    1      -27.30       9.808     1
[o]    2       5.105       2.213     LSP
[i] ? $FIT: +LEF$
[o] scaled deviance = 18.112 (change =  -5.796) at cycle  4
[o]         estimate       s.e.    parameter
[o]    1      -26.45       9.695     1
[o]    2       4.723       2.104     LEF
[i] ? $FIT: +LSTD$
[o] scaled deviance = 23.905 (change =  -0.002) at cycle  4
[i] ? $FIT: +LPSI$
[o] scaled deviance = 23.882 (change =  -0.026) at cycle  4
[i] ? $FIT: +LSI$
[o] scaled deviance = 19.078 (change =  -4.829) at cycle  4
[o]         estimate       s.e.    parameter
[o]    1      -4.965       0.1886     1
[o]    2       6.865       3.311     LSI
[i] ? $FIT +LCV$
[o] scaled deviance = 15.710 (change =  -3.369) at cycle  4
[o]         estimate       s.e.    parameter
[o]    1      -11.87       4.250     1
```

```
[o]   2     6.152      3.660    LSI
[o]   3    -4.053      2.468    LCV
[i] ? $FIT: +LCV$
[o] scaled deviance = 18.789 (change =  -5.118) at cycle  4
[o]         estimate      s.e.    parameter
[o]   1     -12.01      3.715    1
[o]   2     -4.261      2.160    LCV
[i] ? $FIT: +LSS$
[o] scaled deviance = 23.538 (change =  -0.369) at cycle  4
[i] ? $FIT: +LCSS$
[o] scaled deviance = 21.484 (change =  -2.424) at cycle  4
[i] ? $FIT: +LUSS$
[o] scaled deviance = 20.449 (change =  -3.458) at cycle  4
[o]         estimate      s.e.    parameter
[o]   1     -10.80      3.469    1
[o]   2      2.168      1.233    LVR
[i] ? $FIT: +LCUSS$
[o] scaled deviance = 23.500 (change = -0.4072) at cycle  4
```

Exhibit 3.2b(iii): The Results of the Regression Analysis of the Effect of Traffic Speed Characteristics on the Fatal Injury Accidents Using Poisson Distribution (Bahrain)

```
[i] ? $FIT: +LLG +LFW$
[o] scaled deviance = 18.856 at cycle  4
[o]          d.f. =  9
[o] scaled deviance = 4.3326 (change =  -14.52) at cycle  5
[o]          d.f. = 7      (change =   -2  )
[o]          estimate      s.e.    parameter
[o]   1     -3.523       4.321     1
[o]   2      1.894      0.7273     LLG
[o]   3    -0.2315       1.213     LFW
[i] ? $FIT +LSP$
[o] scaled deviance = 4.2465 (change =  -0.086) at cycle  5
[i] ? $FIT +LEF$
[o] scaled deviance = 4.1574 (change =  -0.175) at cycle  7
[i] ? $FIT +LSTD$
[o] scaled deviance = 4.2038 (change =  -0.129) at cycle  5
 [i] ? $FIT +LPSI$
[o] scaled deviance = 4.2085 (change =  -0.124) at cycle  5
[i] ? $FIT +LSI$
[o] scaled deviance = 4.3323 (change =  -0.000) at cycle  5
[i] ? $FIT +LCV$
[o] scaled deviance = 4.2610 (change =  -0.072) at cycle  5
[i] ? $FIT +LSS$
[o] scaled deviance = 4.3228 (change =  -0.010) at cycle  5
[i] ? $FIT +LCSS$
[o] scaled deviance = 4.2914 (change =  -0.041) at cycle  5
[i] ? $FIT +LUSS$
[o] scaled deviance = 4.3214 (change =  -0.011) at cycle  5
[i] ? $FIT +LCUSS$
[o] scaled deviance = 4.2863 (change =  -0.046) at cycle  5
[i] ? $FIT: +LFL$
```

```
[o] scaled deviance = 18.856 at cycle  4
[o]            d.f. =  9
[o] scaled deviance = 6.1441 (change =  -12.71) at cycle  5
[o]            d.f. = 8      (change =   -1   )
[o]           estimate        s.e.    parameter
[o]    1      -8.975       2.699      1
[o]    2       1.378       0.4524     LFL
[i] ? $FIT +LSP$
[o] scaled deviance = 5.5147 (change =  -0.629) at cycle  6
[i] ? $FIT +LEF$
[o] scaled deviance = 4.2900 (change =  -1.854) at cycle  6
[i] ? $FIT +LSTD$
[o] scaled deviance = 5.7468 (change =  -0.397) at cycle  5
[i] ? $FIT +LPSI$
[o] scaled deviance = 6.0690 (change =  -0.075) at cycle  5
[i] ? $FIT +LSI$
[o] scaled deviance = 5.8066 (change =  -0.337) at cycle  5
[i] ? $FIT +LCV$
[o] scaled deviance = 5.9908 (change =  -0.153) at cycle  5
[i] ? $FIT +LSS$
[o] scaled deviance = 6.0525 (change =  -0.092) at cycle  5
[i] ? $FIT +LCSS$
[o] scaled deviance = 6.1440 (change =  -0.000) at cycle  5
[i] ? $FIT +LUSS$
[o] scaled deviance = 5.8443 (change =  -0.300) at cycle  5
[i] ? $FIT +LCUSS$
[o] scaled deviance = 6.0484 (change =  -0.096) at cycle  5
[i] ? $CAL OF=T*LG$
[i] ? $FIT: +LFW$
[o] scaled deviance = 6.6707 at cycle  4
[o]            d.f. = 9
[o] scaled deviance = 6.5358 (change = -0.1349) at cycle  4
[o]            d.f. = 8      (change = -1     )
[o]           estimate       s.e.     parameter
[o]    1      -4.223       3.917      1
[o]    2      0.3533       0.9901     LFW
[i] ? $FIT +LSP$
[o] scaled deviance = 4.2633 (change = -2.27248) at cycle  5
[i] ? $FIT +LEF$
[o] scaled deviance = 4.1882 (change = -2.34760) at cycle  5
[i] ? $FIT +LSTD$
[o] scaled deviance = 5.9812 (change = -0.5546) at cycle  5
[i] ? $FIT +LPSI$
[o] scaled deviance = 6.4929 (change = -0.0429) at cycle  4
[i] ? $FIT +LSI$
[o] scaled deviance = 5.9200 (change = -0.6158) at cycle  4
[i] ? $FIT +LCV$
[o] scaled deviance = 6.4796 (change = -0.0562) at cycle  4
[i] ? $FIT +LSS$
[o] scaled deviance = 6.0796 (change = -0.4561) at cycle  5
[i] ? $FIT +LCSS$
[o] scaled deviance = 6.4502 (change = -0.0856) at cycle  4
[i] ? $FIT +LUSS$
[o] scaled deviance = 5.1559 (change = -1.3798) at cycle  5
```

```
[i] ? $FIT +LCUSS$
[o] scaled deviance = 6.3019 (change = -0.2339) at cycle  4
[i] ? $CAL OF=T*LG*FW$
[i] ? $FIT: +LSP$
[o] scaled deviance = 5.8035 (change =  -1.116) at cycle  5
[o]          estimate        s.e.    parameter
[o]    1      -34.36        29.02     1
[o]    2       6.232         6.542     LSP
[i] ? $FIT: +LEF$
[o] scaled deviance = 5.6137 (change =  -1.306) at cycle  5
[i] ? $FIT: +LSTD$
[o] scaled deviance = 6.2699 (change =  -0.650) at cycle  5
[i] ? $FIT: +LPSI$
[o] scaled deviance = 6.8615 (change = -0.0584) at cycle  4
[i] ? $FIT: +LSI$
[o] scaled deviance = 6.3163 (change = -0.6037) at cycle  4
[i] ? $FIT: +LCV$
[o] scaled deviance = 6.9143 (change = -0.0057) at cycle  4
[i] ? $FIT: +LSS$
[o] scaled deviance = 6.4327 (change =  -0.487) at cycle  5
[i] ? $FIT: +LCSS$
[o] scaled deviance = 6.8971 (change = -0.0228) at cycle  4
[i] ? $FIT: +LUSS$
[o] scaled deviance = 5.8640 (change =  -1.056) at cycle  5
[i] ? $FIT: +LCUSS$
[o] scaled deviance = 6.6347 (change = -0.2852) at cycle  4
```

Exhibit 3.2b(iv): The Results of the Regression Analysis of the Effect of Traffic Speed Characteristics on the 'Hazard' Injury Accidents Using Poisson Distribution (Bahrain)

```
[o] GLIM 3.77 update 1 (copyright)1985 Royal Statistical Society, London
[i] ? $FIT: +LLG +LFW$
[o] scaled deviance = 123.91 at cycle  5
[o]            d.f. =   9
[o] scaled deviance = 8.1268 (change =  -115.8) at cycle  4
[o]            d.f. = 7      (change =    -2  )
[i] ? $FIT +LSP$
[o] scaled deviance = 6.8122 (change = -1.3145) at cycle  5
[o]            d.f. = 6      (change = -1     )
[i] ? $FIT +LEF$
[o] scaled deviance = 8.1166 (change = -0.0102) at cycle  4
[i] ? $FIT +LSTD$
[o] scaled deviance = 6.1153 (change =  -2.011) at cycle  4
[i] ? $FIT +LPSI$
[o] scaled deviance = 8.0940 (change =  -0.033) at cycle  4
[i] ? $FIT +LSI$
[o] scaled deviance = 7.4719 (change = -0.6549) at cycle  4
[i] ? $FIT +LCV$
[o] scaled deviance = 5.2990 (change =  -2.828) at cycle  4
[i] ? $FIT +LSS$
[o] scaled deviance = 5.1383 (change =  -2.988) at cycle  4
[i] ? $FIT +LCSS$
```

```
[o] scaled deviance = 4.5022 (change =  -3.625) at cycle  4
[o]          estimate        s.e.     parameter
[o]    1      -3.753       2.030      1
[o]    2       1.686      0.2133     LLG
[o]    3    -0.07617      0.3845     LFW
[o]    4      -2.945       1.904     LP8C
[i] ? $FIT +LUSS$
[o] scaled deviance = 6.6872 (change = -1.4395) at cycle  4
[i] ? $FIT +LCUSS$
[o] scaled deviance = 6.2741 (change = -1.8526) at cycle  4
[i] ? $FIT: +LFL$
[o] scaled deviance = 123.91 at cycle  5
[o]            d.f. =  9
[o] scaled deviance = 18.870 (change =  -105.0) at cycle  4
[i] ? $FIT +LSP$
[o] scaled deviance = 14.084 (change =  -4.786) at cycle  5
[o]          estimate        s.e.     parameter
[o]    1      -70.88       30.92      1
[o]    2      0.1976      0.5211     LFL
[o]    3       16.03       7.631     LSP
[i] ? $FIT +LEF$
[o] scaled deviance = 14.040 (change = -4.8300) at cycle  5
[o]          estimate        s.e.     parameter
[o]    1      -88.41       40.00      1
[o]    2     -0.1148      0.6846     LFL
[o]    3       19.62       9.525     LEF
[i] ? $FIT +LSTD$
[o] scaled deviance = 18.190 (change = -0.6798) at cycle  4
[i] ? $FIT +LPSI$
[o] scaled deviance = 18.809 (change =  -0.061) at cycle  4
[i] ? $FIT +LSI$
[o] scaled deviance = 15.439 (change =  -3.431) at cycle  4
[o]          estimate        s.e.     parameter
[o]    1      -6.261      0.8883      1
[o]    2       1.249      0.1502     LFL
[o]    3       6.349       3.519     LSI
[i] ? $FIT +LCV$
[o] scaled deviance = 16.799 (change = -2.0708) at cycle  4
[i] ? $FIT +LSS$
[o] scaled deviance = 18.455 (change =  -0.415) at cycle  4
[i] ? $FIT +LCSS$
[o] scaled deviance = 17.019 (change = -1.8516) at cycle  4
[i] ? $FIT +LUSS$
[o] scaled deviance = 18.529 (change =  -0.341) at cycle  4
[i] ? $FIT +LCUSS$
[o] scaled deviance = 18.863 (change =  -0.007) at cycle  4
[i] ? $CAL OF=T*LG$
[i] ? $FIT: +LFW$
[o] scaled deviance = 23.118 at cycle  4
[o]            d.f. =  9
[o] scaled deviance = 21.318 (change = -1.8000) at cycle  4
[o]            d.f. =  8     (change = -1     )
[o]          estimate        s.e.     parameter
[o]    1      -2.383       1.349      1
```

```
[o]    2      0.4397      0.3401     LFW
[i] ? $FIT +LSP$
[o] scaled deviance = 6.8163 (change =  -14.50) at cycle  4
[o]          estimate        s.e.     parameter
[o]    1      -36.83        10.73     1
[o]    2     -0.4077       0.4447     LFW
[o]    3       8.554        2.611     LSP
[i] ? $FIT +LEF$
[o] scaled deviance =  8.887 (change =  -12.43) at cycle  4
[o]          estimate        s.e.     parameter
[o]    1      -34.06        10.44     1
[o]    2     -0.2306       0.4297     LFW
[o]    3       7.470        2.427     LEF
[i] ? $FIT +LSTD$
[o] scaled deviance = 21.230 (change =  -0.088) at cycle  4
[i] ? $FIT +LPSI$
[o] scaled deviance = 21.305 (change = -0.0133) at cycle  4
[i] ? $FIT +LSI$
[o] scaled deviance = 15.763 (change =  -5.555) at cycle  3
[o]          estimate        s.e.     parameter
[o]    1      -2.638        1.315     1
[o]    2      0.4498       0.3272     LFW
[o]    3       6.537        2.944     LSI
[i] ? $FIT +LCV$
[o] scaled deviance = 15.337 (change =  -5.981) at cycle  3
[o]          estimate        s.e.     parameter
[o]    1      -8.455        3.304     1
[o]    2      0.2942       0.3295     LFW
[o]    3      -3.901        1.810     LCV
[i] ? $FIT +LSS$
[o] scaled deviance = 20.588 (change = -0.7299) at cycle  4
[i] ? $FIT +LUSS$
[o] scaled deviance = 15.414 (change =  -5.905) at cycle  4
[o]          estimate        s.e.     parameter
[o]    1      -9.378        3.455     1
[o]    2      0.2501       0.3600     LFW
[o]    3       2.768        1.235     LVR
[i] ? $FIT +LCUSS$
[o] scaled deviance = 20.885 (change =  -0.433) at cycle  4
[i] ? $CAL OF=T*LG*FW$
[i] ? $FIT: +LSP$
[o] scaled deviance = 16.395 (change =  -7.404) at cycle  4
[o]          estimate        s.e.     parameter
[o]    1      -27.72        9.301     1
[o]    2       5.227        2.098     LSP
[i] ? $FIT: +LEF$
[o] scaled deviance = 16.780 (change =  -7.019) at cycle  4
[o]          estimate        s.e.     parameter
[o]    1      -27.25        9.214     1
[o]    2       4.923        1.999     LEF
[i] ? $FIT: +LSTD$
[o] scaled deviance = 23.756 (change =  -0.043) at cycle  4
[i] ? $FIT: +LPSI$
[o] scaled deviance = 23.745 (change =  -0.054) at cycle  4
```

```
[i] ? $FIT: +LSI$
[o] scaled deviance = 18.366 (change =  -5.433) at cycle  4
[o]         estimate       s.e.     parameter
[o]    1      -4.845      0.1776     1
[o]    2       6.857      3.118      LSI
[i] ? $FIT: +LCV$
[o] scaled deviance = 19.277 (change =  -4.522) at cycle  4
[o]         estimate       s.e.     parameter
[o]    1      -10.83      3.313      1
[o]    2      -3.640      1.929      LCV
[i] ? $FIT: +LSS$
[o] scaled deviance = 23.155 (change = -0.6444) at cycle  4
[i] ? $FIT: +LCSS$
[o] scaled deviance = 21.528 (change =  -2.271) at cycle  4
[i] ? $FIT: +LUSS$
[o] scaled deviance = 19.418 (change =  -4.381) at cycle  4
[o]         estimate       s.e.     parameter
[o]    1      -11.10      3.308      1
[o]    2       2.315      1.174      LVR
[i] ? $FIT: +LCUSS$
[o] scaled deviance = 23.190 (change = -0.6089) at cycle  4
```

Exhibit 3.3a: Accident Severity Analysis Using Bionomial Distribution (Tyne & Wear)

```
[i] ? $YVAR SL5$
[i] ? $d  M$
[o] Current model:
[o]
[o]   number of units is  9
[o]
[o]   y-variate  SL5
[o]   weight     *
[o]   offset     *
[o]
[o]   probability distribution is BINOMIAL
[o]     with binomial denominator AC5
[o]              link function is LOGIT
[o]            scale parameter is 1.000
[o]
[o]   terms =  1
[i] ? $FIT: +LSP$
[o] scaled deviance = 5.8729 at cycle  4
[o]            d.f. = 8
[o]
[o] scaled deviance =  3.365 (change =  -2.508) at cycle  5
[o]            d.f. =  7     (change =  -1    )
[o]           estimate        s.e.     parameter
[o]     1       11.81         7.064     1
[o]     2      -2.251         1.515     LSP
[i] ? $FIT: +LEF$
[o] scaled deviance =  3.393 (change =  -2.479) at cycle  5
[i] ? $FIT: +LSTD$
[o] scaled deviance = 4.8007 (change =  -1.072) at cycle  4
[i] ? $FIT: +LPSI$
[o] scaled deviance = 5.8288 (change =  -0.044) at cycle  4
[i] ? $FIT: +LSI$
[o] scaled deviance = 4.7452 (change =  -1.128) at cycle  4
[i] ? $FIT: +LCV$
[o] scaled deviance = 5.8556 (change =  -0.017) at cycle  4
[i] ? $FIT: +LP81$
[o] scaled deviance = 4.6212 (change =  -1.252) at cycle  4
[i] ? $FIT: +LCSS$
[o] scaled deviance = 5.8412 (change =  -0.032) at cycle  4
[i] ? $FIT: +LUSS$
[o] scaled deviance = 5.0505 (change =  -0.822) at cycle  4
[i] ? $FIT: +LCR$
[o] scaled deviance = 5.8348 (change =  -0.038) at cycle  4
[i] ? $YVAR SR5$
[i] ? $FIT: +LSP$
[o] scaled deviance = 3.3702 (change =  -1.790) at cycle  3
[o]           estimate        s.e.     parameter
[o]     1      -12.12         8.302     1
[o]     2       2.224         1.780     LSP
[i] ? $FIT: +LEF$
[o] scaled deviance = 3.2824 (change =  -1.878) at cycle  4
```

```
[i] ? $FIT: +LSTD$
[o] scaled deviance = 4.3394 (change = -0.8208) at cycle  3
[i] ? $FIT: +LPSI$
[o] scaled deviance = 5.1599 (change = -0.00030) at cycle  3
[i] ? $FIT: +LSI$
[o] scaled deviance = 5.1297 (change = -0.030560) at cycle  3
[i] ? $FIT: +LCV$
[o] scaled deviance = 5.1558 (change = -0.004380) at cycle  3
[i] ? $FIT: +LP81$
[o] scaled deviance = 4.1587 (change = -1.0015) at cycle  3
[i] ? $FIT: +LCSS$
[o] scaled deviance = 5.1133 (change = -0.04691) at cycle  3
[i] ? $FIT: +LUSS$
[o] scaled deviance = 4.1847 (change = -0.9755) at cycle  3
[i] ? $FIT: +LCR$
[o] scaled deviance = 5.1414 (change = -0.01882) at cycle  3
[i] ? $YVAR FT5$
[i] ? $FIT: +LSP$
[o] scaled deviance = 4.1557 (change = -0.5242) at cycle  4
[i] ? $FIT: +LEF$
[o] scaled deviance = 4.6798 (change = -0.4392) at cycle 4
[i] ? $FIT: +LSTD$
[o] scaled deviance = 4.5057 (change = -0.1741) at cycle  4
[i] ? $FIT: +LPSI$
[o] scaled deviance = 4.5741 (change = -0.10576) at cycle  3
[i] ? $FIT: +LSI$
[o] scaled deviance = 1.5089 (change =  -3.171) at cycle  5
[i] ? $FIT: +LCV$
[o] scaled deviance = 4.6645 (change = -0.01533) at cycle  3
[i] ? $FIT: +LP81$
[o] scaled deviance = 4.5019 (change = -0.1779) at cycle  4
[i] ? $FIT: +LCSS$
[o] scaled deviance = 4.6795 (change = -0.00030) at cycle  3
[i] ? $FIT: +LUSS$
[o] scaled deviance = 4.6724 (change = -0.0074) at cycle  4
[i] ? $FIT: +LCR$
[o] scaled deviance = 4.3951 (change = -0.2848) at cycle  3
[i] ? $YVAR HZ5$
[i] ? $FIT: +LSP$
[o] scaled deviance = 5.8729 at cycle  3
[o]           d.f. = 8
[o]
[o] scaled deviance = 3.3650 (change =  -2.508) at cycle  3
[o]           d.f. = 7      (change =  -1    )
[o]          estimate        s.e.    parameter
[o]     1      -11.81       7.062     1
[o]     2       2.251       1.515     LSP
[i] ? $FIT: +LEF$
[o] scaled deviance = 3.3935 (change =  -2.479) at cycle  3
[i] ? $FIT: +LSTD$
[o] scaled deviance = 4.8007 (change =  -1.072) at cycle  3
[i] ? $FIT: +LPSI$
[o] scaled deviance = 5.8288 (change = -0.04402) at cycle  3
[i] ? $FIT: +LSI$
```

```
[o] scaled deviance = 4.7452 (change =  -1.128) at cycle  3
[i] ? $FIT: +LCV$
[o] scaled deviance = 5.8556 (change = -0.017239) at cycle  3
[i] ? $FIT: +LSS$
[o] scaled deviance = 4.6212 (change =  -1.252) at cycle  3
[i] ? $FIT: +LCSS$
[i] ? $FIT: +LUSS$
[o] scaled deviance = 5.0505 (change = -0.8224) at cycle  3
[i] ? $FIT: +LCUSS$
[o] scaled deviance = 5.8348 (change = -0.03806) at cycle  3
```

Exhibit 3.3b: Accident Severity Analysis Using Bionomial Distribution (Bahrain)

```
[o] GLIM 3.77 update 1 (copyright)1985 Royal Statistical Society, London
```

i) Slight Accidents

```
[o]  y-variate  SL4
[o]  weight     *
[o]  offset     *
[o]
[o]  probability distribution is BINOMIAL
[o]    with binomial denominator AC4
[o]             link function is LOGIT
[o]           scale parameter is 1.000
[o]
[o]  terms =  1
[i] ? $FIT: +LSP$
[o] scaled deviance =  10.003 at cycle  4
[o]             d.f. =  9
[o] scaled deviance =  6.934 (change =  -3.069) at cycle  4
[o]             d.f. =  8     (change =  -1    )
[o]          estimate       s.e.     parameter
[o]    1       17.83        10.16     1
[o]    2      -3.783        2.294     LSP
[i] ? $FIT: +LEF$
[o] scaled deviance =  6.758 (change =  -3.245) at cycle  4
[i] ? $FIT: +LSTD$
[o] scaled deviance =  9.730 (change =  -0.273) at cycle  4
[i] ? $FIT: +LPSI$
[o] scaled deviance =  9.679 (change =  -0.324) at cycle  4
[i] ? $FIT: +LSI$
[o] scaled deviance =  8.978 (change =  -1.024) at cycle  4
[i] ? $FIT: +LCV$
[o] scaled deviance =  8.664 (change = -1.3392) at cycle  4
[i] ? $FIT: +LSS$
[o] scaled deviance =  9.045 (change =  -0.958) at cycle  4
[i] ? $FIT: +LP8C$
[o] scaled deviance =  9.702 (change =  -0.301) at cycle  4
[i] ? $FIT: +LVR$
[o] scaled deviance =  7.661 (change =  -2.342) at cycle  4
[i] ? $FIT: +LCR$
[o] scaled deviance =  9.337 (change =  -0.666) at cycle  4
```

ii) Seriuos Accidents

```
[i] ? $YVAR SR4$
[i] ? $FIT: +LSP$
[o] scaled deviance = 11.283 at cycle  2
[o]           d.f. =  9
[o] scaled deviance = 8.8238 (change =  -2.459) at cycle  3
[o]           d.f. = 8      (change =  -1    )
[o]          estimate       s.e.    parameter
[o]    1      -16.85       10.58     1
[o]    2       3.526       2.388     LSP
[i] ? $FIT: +LEF$
[o] scaled deviance = 8.8059 (change =  -2.477) at cycle  3
[i] ? $FIT: +LSTD$
[o] scaled deviance = 11.245 (change = -0.037269) at cycle  3
[i] ? $FIT: +LPSI$
[o] scaled deviance = 10.921 (change = -0.3617) at cycle  3
[i] ? $FIT: +LSI$
[o] scaled deviance = 10.400 (change = -0.8824) at cycle  3
[i] ? $FIT: +LCV$
[o] scaled deviance = 9.2990 (change =  -1.984) at cycle  3
[i] ? $FIT: +LSS$
[o] scaled deviance = 10.744 (change = -0.5387) at cycle  2
[i] ? $FIT: +LP8C$
[o] scaled deviance = 10.823 (change = -0.4594) at cycle  3
[i] ? $FIT: +LVR$
[o] scaled deviance = 9.6057 (change =  -1.677) at cycle  3
[i] ? $FIT: +LCR$
[o] scaled deviance = 10.888 (change = -0.3946) at cycle  3
```

iii) Fatal Accidents

```
[i] ? $YVAR FT4$
[i] ? $FIT: +LSP$
[o] scaled deviance = 5.1651 (change = -0.4476) at cycle  5
[o]           d.f. = 8      (change = -1     )
[o]          estimate       s.e.    parameter
[o]    1      -21.36       29.10     1
[o]    2       4.025       6.560     LSP
[i] ? $FIT: +LEF$
[o] scaled deviance = 4.9887 (change = -0.6239) at cycle  5
[i] ? $FIT: +LSTD$
[o] scaled deviance = 4.6484 (change = -0.9642) at cycle  5
[i] ? $FIT: +LPSI$
[o] scaled deviance = 5.6123 (change = -0.0003) at cycle  4
[i] ? $FIT: +LSI$
[o] scaled deviance = 5.5260 (change = -0.0867) at cycle  4
[i] ? $FIT: +LCV$
[o] scaled deviance = 5.4653 (change = -0.14737) at cycle  4
[i] ? $FIT: +LSS$
[o] scaled deviance = 5.0541 (change = -0.5585) at cycle  5
[i] ? $FIT: +LP8C$
[o] scaled deviance = 5.5591 (change = -0.0535) at cycle  4
[i] ? $FIT: +LVR$
```

```
[o] scaled deviance = 5.0037 (change = -0.6089) at cycle 5
[i] ? $FIT: +LCR$
[o] scaled deviance = 5.2955 (change = -0.3171) at cycle 4
```

iv) Hazard (Serious & Fatal) Accidents

```
[i] ? $YVAR HZ4$
[i] ? $FIT: +LSP$
[o] scaled deviance = 6.9339 (change =  -3.069) at cycle 3
[o]          d.f. = 8     (change =  -1    )
[o]          estimate       s.e.    parameter
[o]    1      -17.84       10.19    1
[o]    2       3.783       2.301    LSP
[i] ? $FIT: +LEF$
[o] scaled deviance = 6.7579 (change =  -3.245) at cycle 3
[i] ? $FIT: +LSTD$
[o] scaled deviance = 9.7303 (change = -0.2726) at cycle 3
[i] ? $FIT: +LPSI$
[o] scaled deviance = 9.6788 (change = -0.3241) at cycle 3
[i] ? $FIT: +LSI$
[o] scaled deviance = 8.9785 (change = -1.0244) at cycle 3
[i] ? $FIT: +LCV$
[o] scaled deviance = 8.6637 (change =  -1.339) at cycle 3
[i] ? $FIT: +LSS$
[o] scaled deviance = 9.0450 (change = -0.9579) at cycle 3
[i] ? $FIT: +LCSS$
[o] scaled deviance = 9.7022 (change = -0.3007) at cycle 3
[i] ? $FIT: +LUSS$
[o] scaled deviance = 7.6613 (change =  -2.342) at cycle 3
[i] ? $FIT: +LCUSS$
[o] scaled deviance = 9.3368 (change = -0.6661) at cycle 3
```

Appendix III

Tables of values of costs of travel time, fuel and non-fuel elements of vehicle operating costs and accidents
(note: all tables have been extracted from COBA10 Manual)
(Department of Transport, 1994a)

Table 1: Values of Time per Person and per Vehicle in COBA (1992 values and prices) (Highways Economic Note 2, National Travel Survey of Department of Transport, and New Earings Survey of Department of Employment)

Type of Vehicle	Occupancy	Time Mode	Value of time (pence/hour)	
			per occupant	per vehicle
working car	1.00 drivers	working	1204.9	1304.9
	0.10 passengers	working	1000.1	
non-working car	1.00 drivers	non-working	294.2	529.6
	0.80 passengers	non-working	294.2	
average car	1.00 drivers	(derived from above assuming 14% of cars in work time)		638.1
	0.70 passengers			
light goods vehicle (LGV)	1.00 drivers	working	937.0	1218.1
	0.30 passengers	working	937.0	
other goods vehicle (OGV)	1.00 drivers	working	882.7	882.7
public service vehicle	1.00 drivers	working	918.3	4556.5
	12.13 passengers	non-working	294.2	
	0.07 passengers	working	994.3	

Table 2: Asssumed Compound Annual Rates of Growth of the Real Value of Time (%) (National Roaf Traffic Forecast, 1989)

Range of Years	Economic Forecast	
	Low Growth (% pa)	High Growth (% pa)
1993-2001	1.625	2.875
2002 onwards	1.805	3.055

Table 3: VOC Formulae Parameters Values (1992 prices)

Vehicle Category	Parameter				
Fuel	a	b	c	m	n
CAR	0.61	21.15	0.0000446	-0.00203	0.000102
LGV	0.96	24.47	0.0000598	-0.00125	0.000067
OGV1	2.01	50.23	0.0002655	0.00346	0.000048
OGV2	1.57	142.91	0.0003749	0.00346	0.000048
PSV	2.97	84.65	0.0002992	0.00346	0.000048
Non-Fuel	a^1	b^1			
CAR	3.18	11.90			
LGV	3.91	39.19			
OGV1	7.96	120.52			
OGV2	8.88	244.14			
PSV	16.48	276.29			

Table 4: Compound Annual Growth Rates (%) in Fuel Resources Costs

	Economic Forecasts	
Range of Years	Low Growth (% pa)	High Growth (% pa)
1993-2000		
Cars/LGVs	5.62	1.54
HGVs/PSVs	6.62	1.54
2001 onwards		
Cars/LGVs	0.77	1.54
HGVs/PSVs	0.77	1.54

Table 5: Components of Accident Costs (1992 values and prices)
(Highways Economic Notes 1 and Overseeing Department)

COST PER CASUALTY, £	
Fatal casualty	715,330
Serious casualty	74,480
Slight casualty	6,080

COST PER PERSONAL INJURY ACCIDENT, £				
	Police and Administration	Damage to Property		
		Urban	Rural	Motorway
Fatal accident	530	1490	4820	4300
Serious accident	420	1610	4300	4180
Slight accident	320	1400	2900	3210
Average accident	340	1470	3480	3530

COSTS PER DAMAGE ONLY ACCIDENT, £	
Urban	960
Rural	1160
Motorway	1380

Table 6: Average Casualities per Injury Accident

<table>
<tr><th colspan="8">LINK ONLY CASUALTIES</th></tr>
<tr><th rowspan="2">ACCIDENT TYPE</th><th rowspan="2">CLASSIFICATION</th><th colspan="6">CASUALTIES PER P.I.A.</th></tr>
<tr><th colspan="6">All Speed Limits</th></tr>
<tr><th colspan="2">Casualty Severity</th><th colspan="2">Fatal (f)</th><th colspan="2">Serious (se)</th><th colspan="2">Slight (sl)</th></tr>
<tr><td>1
2
3</td><td>D2 Motorway
D3 Motorway
D4 Motorway</td><td colspan="2">0.046
0.051
0.051</td><td colspan="2">0.311
0.290
0.290</td><td colspan="2">1.208
1.330
1.330</td></tr>
<tr><th colspan="2">Speed Limit (mph)</th><th colspan="3">30/40 mph</th><th colspan="3">> 40 mph</th></tr>
<tr><th colspan="2">Casualty Severity</th><th>f</th><th>se</th><th>sl</th><th>f</th><th>se</th><th>sl</th></tr>
<tr><td>4</td><td>S2 A Roads</td><td>0.021</td><td>0.267</td><td>0.969</td><td>0.060</td><td>0.462</td><td>1.140</td></tr>
<tr><td>5</td><td>WS2 A Roads</td><td>0.021</td><td>0.267</td><td>0.969</td><td>0.060</td><td>0.462</td><td>1.140</td></tr>
<tr><td>6</td><td>Other S2</td><td>0.014</td><td>0.258</td><td>0.919</td><td>0.032</td><td>0.387</td><td>1.067</td></tr>
<tr><td>7</td><td>D2 A Roads</td><td>0.037</td><td>0.262</td><td>0.944</td><td>0.063</td><td>0.355</td><td>1.119</td></tr>
<tr><td>8</td><td>Other D2</td><td>0.022</td><td>0.268</td><td>0.905</td><td>0.037</td><td>0.275</td><td>1.056</td></tr>
<tr><td>9</td><td>D3+ A Roads</td><td>0.037</td><td>0.258</td><td>0.944</td><td>0.054</td><td>0.307</td><td>1.121</td></tr>
<tr><td>10</td><td>Other D3</td><td>0.030</td><td>0.230</td><td>0.886</td><td>0.042</td><td>0.187</td><td>1.201</td></tr>
<tr><th colspan="8">LINK AND JUNCTION COMBINED CASUALTIES</th></tr>
<tr><th colspan="2" rowspan="2">Casualty Severity</th><th colspan="6">All Speed Limits</th></tr>
<tr><th colspan="2">Fatal (f)</th><th colspan="2">Serious (se)</th><th colspan="2">Slight (sl)</th></tr>
<tr><td>1
2
3</td><td>D2 Motorway
D3 Motorway
D4 Motorway</td><td colspan="2">0.046
0.051
0.051</td><td colspan="2">0.311
0.290
0.290</td><td colspan="2">1.208
1.330
1.330</td></tr>
<tr><th colspan="2">Speed Limit (mph)</th><th colspan="3">30/40 mph</th><th colspan="3">> 40 mph</th></tr>
<tr><th colspan="2">Casualty Severity</th><th>f</th><th>se</th><th>sl</th><th>f</th><th>se</th><th>sl</th></tr>
<tr><td>4</td><td>S2 A Roads</td><td>0.016</td><td>0.236</td><td>0.990</td><td>0.053</td><td>0.436</td><td>1.156</td></tr>
<tr><td>5</td><td>WS2 A Roads</td><td>0.016</td><td>0.236</td><td>0.990</td><td>0.053</td><td>0.436</td><td>1.156</td></tr>
<tr><td>6</td><td>Other S2</td><td>0.012</td><td>0.235</td><td>0.957</td><td>0.030</td><td>0.378</td><td>1.083</td></tr>
<tr><td>7</td><td>D2 A Roads</td><td>0.023</td><td>0.236</td><td>1.001</td><td>0.060</td><td>0.359</td><td>1.142</td></tr>
<tr><td>8</td><td>Other D2</td><td>0.017</td><td>0.234</td><td>0.968</td><td>0.034</td><td>0.273</td><td>1.067</td></tr>
<tr><td>9</td><td>D3+ A Roads</td><td>0.024</td><td>0.226</td><td>1.058</td><td>0.046</td><td>0.291</td><td>1.158</td></tr>
<tr><td>10</td><td>Other D3</td><td>0.019</td><td>0.196</td><td>1.047</td><td>0.037</td><td>0.187</td><td>1.188</td></tr>
</table>

Table 7: Default Accident Rates (personal injury accidents per million vehicle kilometres) (Highways Economic Notes and Overseeing Department)

LINK ONLY RATES					
ACCIDENT TYPE	CLASSIFICATION	ACCIDENT RATES (P.I.A. PER 10^6 VEHICLE KMS)			
	Speed Limit (mph)	50		70	
1	D2 Motorway	0.104		0.104	
2	D3 Motorway	0.104		0.104	
3	D4 Motorway	0.104		0.104	
	Speed Limit (mph)	30	40	50	60/70
4	S2 A Roads	0.319	0.319	0.244	0.244
5	WS2 A Roads	0.319	0.319	0.170	0.170
6	Other S2	0.402	0.402	0.344	0.344
7	D2 A Roads	0.335	0.335	0.165	0.165
8	Other D2	0.335	0.335	0.165	0.165
9	D3+ A Roads	0.335	0.335	0.165	0.165
10	Other D3	0.335	0.335	0.165	0.165
LINK AND JUNCTION COMBINED RATES					
	Speed Limit (mph)	50		70	
1	D2 Motorway	0.104		0.104	
2	D3 Motorway	0.104		0.104	
3	D4 Motorway	0.104		0.104	
	Speed Limit (mph)	30	40	50	60/70
4	S2 A Roads	0.946	0.946	0.355	0.355
5	WS2 A Roads	0.946	0.946	0.250	0.250
6	Other S2	0.997	0.997	0.457	0.457
7	D2 A Roads	1.022	1.022	0.233	0.233
8	Other D2	1.022	1.022	0.233	0.233
9	D3+ A Roads	1.022	1.022	0.233	0.233
10	Other D3	1.022	1.022	0.233	0.233