INFLUENCE OF PARKING ON CONGESTION OF NAIROBI CENTRAL BUSINESS AREA

by

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DECLARATION

This thesis is my original work and has not been submitted for a degree in any other university

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This thesis has been submitted with my approval as the University supervisor.

John A. Okumu

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ABSTRACT

In Nairobi central area, traffic generally flows under congested conditions. Generally, traffic congestion has negative effects on operations of town centers, Nairobi central area included.

Commercial and business life of Nairobi central area, just like any other town centre, usually requires to be served by motor traffic. Traffic congestion impedes operations and efficiency of vehicles involved in business and commercial activity. For example, travel time and fuel are lost while vehicles' engines are running at stationery jam situations caused by traffic congestion. Thus, traffic congestion normally impairs business efficiency in Nairobi central area.

Parking is one factor that causes Nairobi central area's traffic congestion problem. However, information is lacking as to the extend to which parked vehicles contribute to the traffic congestion problem. This study's aim is to find out this missing information, by carrying out surveys of traffic stream characteristics in the area and analyzing the data.

Surveys carried out are traffic flow counts, travel time and parking usage surveys. Data obtained from the surveys was stored and analysed by a computer using packages that were readily available. These packages were Word Perfect 5.1, Lotus 123, Harvard Graphics, grapher and Statgraphics.

Analysis of the data established that:

- Plots of variation of traffic speed with flow were typical speed flow curves.

- For 52% of the study period, demand for on-street parking space exeeded it's supply. The extra demand was catered for by illegal and double parking. Consequently, there were reductions in carriageway widths available for moving traffic, reductions in vehicle overtaking opportunities, reductions in traffic speeds and ultimately, traffic congestion.

- Traffic congestion existed in the area, as evidenced by traffic speeds that were below critical speeds (established by speed flow curves).

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1.0. INTRODUCTION

1.1. General

1.1.1. Location

Nairobi is situated at approximately 1.3 degrees south of the equator and at 36.8 degrees East of Greenwich. It is the present capital city of Kenya, East Africa, geographically located as shown in Fig 1.

1.1.2. Historical development

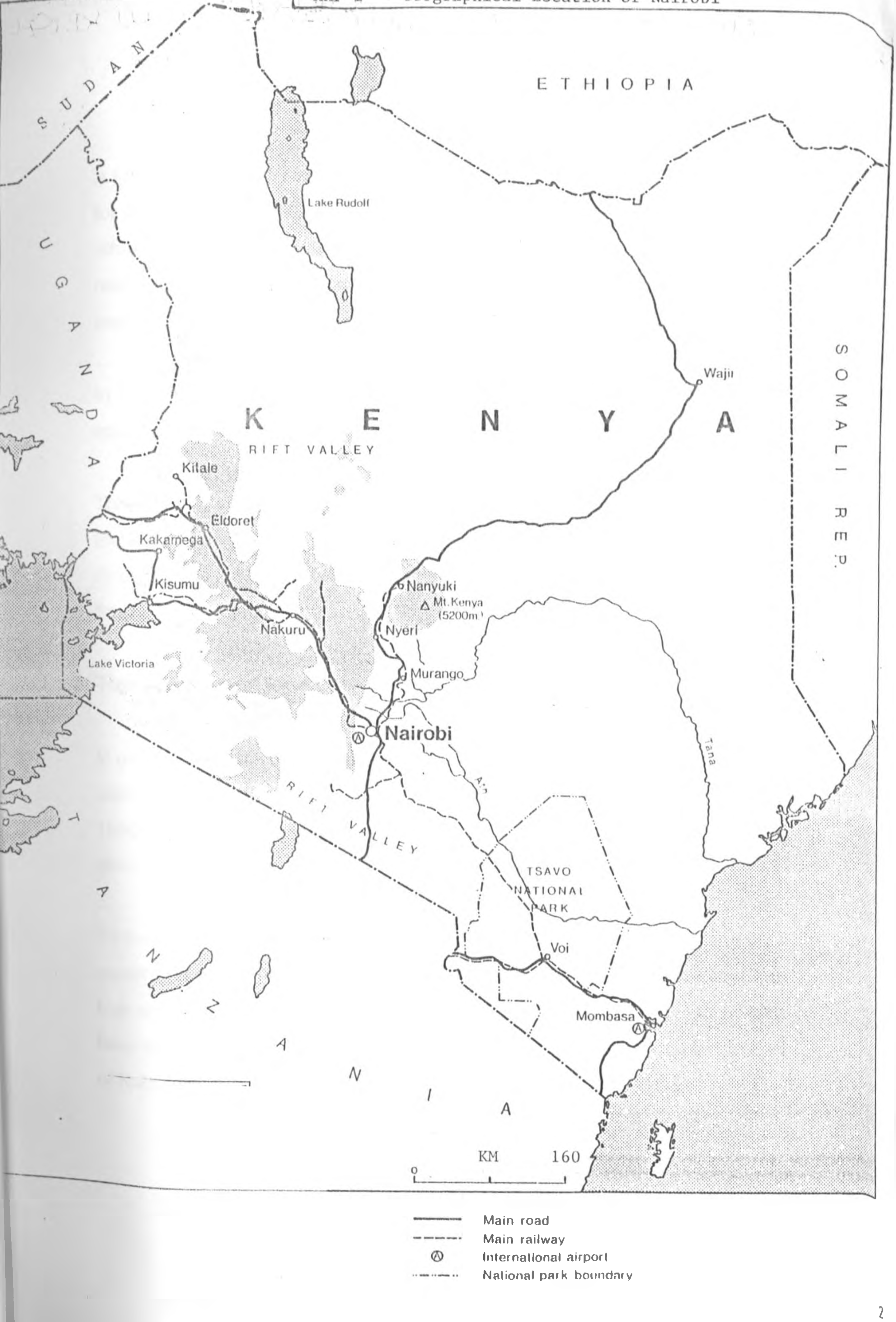
Nairobi started as a stop over facility during construction of Kenya-Uganda railway in 1899. The area's permanence was confirmed in 1905 when it was made the capital town of Kenya. The town became an incorporated municipality in 1919 and finally a City in 1950.

The original township was within the area presently defined as the Central Area - bounded by Uhuru Highway, Nairobi Railway Station, Nairobi River, Pumwani Road and Wakulima Lane.

The early growth of Nairobi was controlled only by economic forces and there was no co-ordination of development other than by a layout of a street pattern in the centre.

In an attempt to order the situation, a town planning consultant was appointed in 1926 to make recommendations on zoning arrangements. However, little was done to curb land speculation with the result of uncontrolled development.

MAP I - Geographical Location of Nairobi



A further master plan study was commissioned in 1948. It laid down guidelines for the following twenty years, earmarking land for residential, industrial and other uses. It also introduced principles of neighbourhood units; it is largely responsible for Nairobi Industrial Area's present layout; and it proposed important extensions to the road network (Nairobi Urban Study Group, 1973).

In 1964, the boundaries of the city were enlarged from the old city area of 90 square kilometres to embrace an area of 690 square kilometres.

This extension aimed at giving the city adequate land for future expansion and included Nairobi's peri-urban settlements, Nairobi Game Park, Embakasi Airport and a large area of ranching land in the east of Nairobi (Nairobi Urban Study Group, 1973).

1.1.3. Topography and land use

In general, the area covered by the city of Nairobi falls from the edge of the Rift Valley in the west, at an average altitude of 2300m, to an average altitude of 1500m on the eastern boundary of the city. The Central Area lies at an average altitude of 1700m.

To the north west of the city and adjacent to the Rift Valley, is a grassland area covering rich, well-drained 'red coffee' soils; to the north and north east, the high and evenly sloping land is dissected by south-east flowing streams which have formed a series of steep-sided parallel valleys and ridges. South and east of Nairobi are grassland plains of poorly drained black cotton clays.

To the north and west of Nairobi are high rainfall areas used for subsistence farming and large tea, coffee and dairy estates; to the east and south are low rainfall areas used for grazing and sisal production.

1.1.4. Population

Nairobi's population changes generally reflect the pattern of agriculture described in the previous section, and an attraction to the central area.

The areas of high rainfall and good soils generally experience large increases in population, whereas the semi-arid areas remain static or, in some cases, even decline in population. Overall, Nairobi's population increased by 5.5% between 1962 and 1969, by 62.54% between 1969 and 1979 and by 60.02% between 1979 and 1989 (Central Bureau of Statistics, 1989).

Population changes are generally due to births, deaths and migration. In the case of Nairobi, being the centre of national and international commerce and administration in Kenya, the most important determinant of future population is the rate of migration from the rural areas. This is despite the Government's policy of decentralization and rural growth.

Nairobi Urban Study Group (1973) states that, due to it's capital status, it is inevitable that the movements of people towards urban concentrations will impinge most heavily on Nairobi.

Nairobi attracted both local and foreign investments, which in turn attracted many job seekers from rural areas. These people generally settled in certain areas of the city in relation to their religion, race and socio-economic factors.

Low density residential areas accommodating high income earners are generally found to the north and west of the city. There is, however, a substantial part of the city's population in high density clusters of low income housing area's in Dagoretti area, which is within this low density residential zone.

To the south and east of Nairobi are generally high density residential areas accommodating middle and low income households.

These residential areas should be the main generators of Nairobi's both pedestrian and vehicular trips. Nairobi Urban Study Group (1973) found out that Nairobi's trips are attracted to work places that are within the Nairobi central and industrial areas.

1.1.5. Economic development

Nairobi is not only the principal urban centre of population, it is also the social, economic and communications hub of the whole country - a classic primate city. It is characterized by a single major employment centre, composed of it's central and an adjacent industrial area (Nairobi Urban Study Group, 1973).

Within the Nairobi central area can be found various land uses. Examples of these land uses are national and local government offices, Nairobi University and Kenya Polytechnic, headquarters of national and international companies, specialist shops, supermarkets and small general stores, hotels and lodging houses, restaurants and bars, and small workshops and warehouses.

The whole spectrum of commercial activity is represented, with the result that a large proportion of the population has to travel to the Nairobi central area for their various needs and employment (Nairobi Urban Study Group, 1973).

1.2. Transportation

1.2.1. Transport demand

Demand for transport derives from needs of people to travel from one place to another, to carry out activities of their daily lives. In general, areas that are used for residential purposes are the most important generators of all journeys, generating between 80 and 90 per cent of all journeys. Employment centres are the next most significant areas in generating traffic (Bruton, 1985).

1.2.2 Transport network

Spatial distribution of areas that are used for various activities within Nairobi necessitates use of transportation facilities, to transfer people and their goods.

Apart from walking and cycling, Nairobi's intra-urban movements are made by use of private vehicles or by public transport. The latter is provided by a commuter rail system, taxis, public and private bus services and minibuses. Kenya Railways, a state corporation, provides the commuter rail system. Nairobi City Council, in collaboration with Government of Kenya, facilitates provision of pedestrian and road network infrastructure.

In addition to catering for intra-urban movement, Nairobi's road network also facilitates inter-urban movements. This is achieved by means of a series of radial routes to other towns such as Thika, Kiambu, Limuru, Kikuyu, Ngong, Athi River and Machakos. Of these, major routes are:

- Uhuru Highway's south easterly extension to Athi River (and further on to Mombasa);

- Uhuru Highway's north westerly extension to Limuru (and further on to western Kenya);

- Muranga Road that extends to Thika (and further on to Muranga, Nanyuki, Embu and Meru); and

- Langata/Magadi Road that extends towards and beyond Magadi.

All but the last of the above named four radial roads run roughly parallel to existing railway lines. In addition to the radial roads, there are also access and non-radial routes such as:

- road connecting Limuru to Rossylyn (an west-east road) and

- Outer Ring Road (a north-south road) linking Ruaraka to Jomo Kenyatta and Embakasi Airports).

1.3. Traffic congestion

Despite it's function of serving inter and intra-urban vehicular traffic movements, Nairobi central area's road network serves traffic inefficiently. Disney (1994) states that this network suffers from traffic congestion. Bruton (1985) states that congestion is an obvious inefficiency of a transport system.

Congestion is inefficient in use of resources (Salter, 1990). For example, congestion wastes an obvious irrecoverable resource, travellers' time (Elliot, 1979).

Consequently, motorists travelling on a road network suffering from traffic congestion loose journey speeds. Lowering of speeds cause economic loss to a community due to time lost by occupants of vehicles and higher vehicle operational costs that result from, for example, fuel lost while vehicle engines are running under stationery traffic jam situations.

1.3.1. Congestion and town centre commercial life

Generally, an efficient system of motor traffic is essential to prosperity of town centres. A great deal of business and commercial life of the town centre can be served only by motor traffic. An inefficient traffic system, such as that suffering from traffic congestion, threatens both prosperity and amenity of a town centre.

Traffic congestion costs money in that travellers loose, for example, time and fuel. Consequently, a centre congested with stationery or slow moving vehicles will loose much of it's attraction for all those who come there whether as workers, shoppers or visitors.

Shoppers are normally essential to the commercial life of town centres. Consequently, if shoppers choose not to visit a town centre (due to traffic congestion), it will be to the detriment of the centre's local prosperity.

.3.2. Traffic congestion solution

Naturally, every town centre, Nairobi central business area included, would like to prosper. Thus, Nairobi central business area would want to encourage visitors and shoppers that bring trade and consequent prospering of the area. The natural desire to have Nairobi central business area prospering raises the need to seek ways of easing the area's traffic congestion.

Anything that can be done to reduce congestion, and allow people to travel to the town centre in a shorter time, will make the central area more accessible- and thus will help people to decide to shop there as against in the suburbs or out of town (O'flaherty, 1986).

Rosenbloom (1978) states that there are basically two alternative solutions to controlling traffic congestion. The solution is either a change in demand to meet system capacity or a change in system capacity to meet demand.

Measures that change system capacity to meet demand normally include provision of more infrastructure and are generally capital intensive.

Moreover, a traffic congestion problem is not solved simply by providing more infrastructure (even if that were feasible in the centres of large cities) because of the way in which users pay for their space. Congestion has to be tackled through means which tailor demand to fit existing road network (Elliot, 1979).

Unlike provision of new infrastructure that generally increases system capacity, traffic management methods (normally referred to as TSM) are best seen as actions or groups of actions that usually produce shifts in supply-demand equilibriums of existing transportation systems (Paquette, 1982).

Fundamentally, the objective of TSM measures is to ensure the overall best use (which may or may not be the maximum use, or that generating the maximum benefits) of the existing urban transport facilities. This best use usually involves imposition upon travellers of rules and regulations governing use of transport facilities (Wells, 1975).

Parking facilities form part of transportation facilities. The imposition of rules governing use of parking facilities, otherwise referred to as parking controls, is one TSM measure that has already been recommended as a solution to Nairobi central area's traffic congestion problem.

1.4. Statement of problem

Disney (1994), Transurb Consult (1986) and Patel (1972) have already established that Nairobi central area's streets suffer from traffic congestion and that on-street parking contributes to this congestion. However, information is lacking as to the extent to which parked vehicles contribute to this congestion.

On-street parking is a modifying factor that generally leads to traffic congestion since the parking causes considerable variation in traffic stream characteristics. The traffic engineer must therefore evaluate modifying factors in order to develop, for example, a high degree of efficiency in traffic stream performance (Matson, 1955).

Traffic streams are generally considered to be efficient in the use of resources, such as travel time and fuel, if they are congestion free.

This study aims at evaluating effects of parked vehicles on Nairobi central business area's traffic stream characteristics and hence establish extent to which parked vehicles contribute to the area's traffic congestion problem, in order to develop efficiency (through parking control) in the area's traffic stream performance, thereby alleviating the area's traffic congestion.

2.0. LITERATURE REVIEW

2.1. Traffic congestion and traffic stream characteristics

As already discussed in chapter 1.0., it has been established that Nairobi central area's road network suffers from traffic congestion. This traffic congestion should be alleviated, if the area's prosperity is not to be impaired.

It should be noted that when planning an improved road system, such as one that is free from traffic congestion, it is necessary to know the distribution and performance of traffic on existing road networks. Not only is this of use in predicting future traffic behaviour, but also in assessing whether alterations are justified, and in deciding priorities for road improvements (O'flaherty, 1986).

Improvements to operations of an area's road network definitely need to be justified if they are to be effective in serving the purpose they are intended for.

To study performance of traffic on existing road networks, it is necessary to investigate the area's traffic speeds and flow. In addition to justifying improvements, a knowledge of existing traffic speed flow relationships generally enables capacity determination of a road network.

Highway Capacity Manual (1988) states that the capacity of a highway is a measure of it's ability to accommodate traffic while traffic flow is a manifestation of traffic demand.

Rosenbloom (1978) states that traffic congestion occurs when travel demand exceeds existing road system's operating capacity.

2.1.1. Speed, flow and density relationships

Traffic flow is the rate at which vehicles pass a point on a roadway and is expressed in number of vehicles per unit of time. The maximum number of vehicles that a highway element can be expected to accommodate under a given set of conditions is referred to as highway capacity (Carter, l982).

One factor that determines traffic flow characteristics is vehicular speeds. There are various types of vehicular speeds, such as spot speeds, space mean speeds and average travel speeds. However, Carter (1982) states that relationships among speed, volume and density (or concentration) are precisely correct only if space mean speed is utilized.

Normally, relationships between variables are expressed in a dimensionally similar way. Thus, values used in the speed, flow and density relationships should be naturally dimensionally similar.

Density and flow are normally expressed in terms of space. In the speed, density and flow relationships, Hobbs (1984) states that flow is taken as the number of vehicles in space at an instant in time. Here, a traffic stream moving along a length of a road is considered to be composed of a series of subsidiary streams, each with it's respective flow and steady speed. The total flow is obtained by summing up flows in the subsidiary streams.

Huber (1982) states that traffic density is the concentration of vehicles on a section of a roadway and that it is expressed as the number of vehicles per length of roadway.

Thus, flow and density are expressed in terms of space and hence the need to express speed in the same units, for the speed, flow and density relationship to be dimensionally similar. The relationships are conceptually but not precisely correct for speed measurements (such as operating speed) normally used in practice.

Highway Capacity Manual (1988) defines space mean speed as the average speed of a specified group of vehicles, based on their average travel time over a section of a roadway.

In summary, space mean speed is expressed in terms of space and is the speed measurement used in speed, flow and density relationships since only spatial measurements can relate space mean speed and concentration to flow (Hobbs, 1984).

2.1.2. General speed flow relationships

Attempts have been made to express, mathematically and diagrammatically, relationships between urban traffic speed and flow.

Highway Capacity Manual (1988) states that speed and flow relationships (and also speed density relationships) are found wherever vehicles regularly follow one another in the same or adjacent lanes. Weaving sections, rotaries, and other types of manoeuvre areas are therefore exceptions. The relationships are found on most typical highways, whether the flows are uninterrupted or interrupted.

Uninterrupted flow is a condition in which a vehicle traversing a section of a lane or a roadway is not required to stop by any cause external to the traffic stream although vehicles may be stopped by causes internal to the traffic stream. On the other hand, interrupted flow is a condition in which a vehicle traversing a section of a lane or a roadway is required to stop by a cause outside the traffic stream, such as signs or signals at an intersection or a junction. Stoppage of vehicles by causes internal to the traffic stream does not constitute interrupted flow.

Thus, one of the difficulties in distinguishing between types of flow is that sooner or later all flows are interrupted. A freeway ends, a rural road enters a town, or a progressive signal system becomes unable to accommodate the demand (Highway Capacity Manual, 1988).

Hobbs's (I984) states that observations of traffic flow under different operating conditions have established speed flow curves that are parabolic and broadly similar, either wholly or in part, to speed flow curves derived theoretically. The typical speed flow curve is presented in Fig. 2.

Huber (1982) gives a general equation of these speed flow curves as follows:

$$q = \frac{Kj.u.(Uf-u)}{Uf}$$

where,

q = observed flow of traffic (vehicles per hour)

Kj = maximum or jam density (vehicles per meter length of roadway)

u = observed vehicular speed (meters per hour)

Uf = free-flow speed (meters per hour)

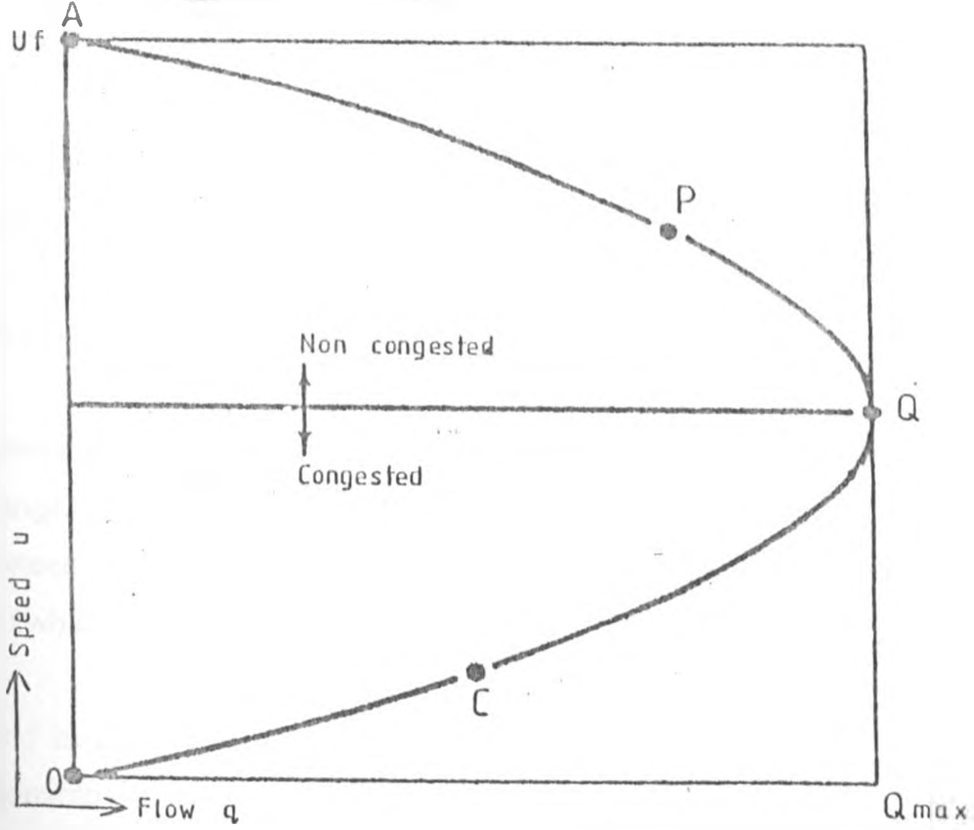
2.1.3. Traffic stream and speed flow curve parts

Traffic stream characteristics generally explain various parts of the speed flow curve presented in Fig.2.

A traffic stream is constituted initially from spatially separated single vehicles, moving at a driver's desired free flow speed. At this stage, the driver is unimpeded and is travelling independent of other traffic. This free-flow conditions that normally constitute initial traffic flow are indicated by point A of the general speed flow curve shown in Fig.2. below.

Fig. 2

GENERAL SPEED FLOW CURVE



Source: Huber (1982).

As traffic flow increases, the average space mean speed usually decreases. The decrease in overall space mean speed is because of the increasing difficulty of overtaking and passing, and the tendency for faster moving vehicles to follow behind slower vehicles (Matson, 1955).

Motorists naturally travel at varying speeds. One effect of these speed differences is that faster vehicles continuously keep on coming close to slower vehicles and overtaking them. However, if conditions prevent faster vehicles from overtaking, moving queues form.

The queues gradually lengthen and separate groups (platoons) coalesce until all vehicles form a single flow. This single flow generally travels at an overall lower speed than that at free-flow conditions. The reduction in speed is caused by factors such as individual driver's inability to choose his own speed. Under these circumstances, a driver's speed is dictated by speed of driver ahead.

The relationship of decreasing speeds with increasing flow holds true throughout the range (of the general speed flow curve in Fig.2.) that starts from free-flow conditions (point A), covers conditions of impeding traffic congestion and terminates at point of critical density or point of maximum flow (point Q).

In summary, the relationship of decreasing speeds with increasing flow covers the range between points A and Q on the typical speed flow curve. This range comprises the upper portion of the speed-flow curve, which is also the range within which traffic flows under non congested conditions.

At and beyond point Q, traffic flows under congested conditions and the relationship that speeds decrease with increasing traffic flows no longer applies. At and beyond point Q, any further increase in flow causes speeds to decrease rapidly, with a marked simultaneous decrease in rate of flow, until the latter becomes zero.

The decrease in speed with decreasing flow is caused by the fact that, at and beyond point Q, any further increase in flow causes concentration to also increase, thereby causing oscillations in traffic flow. The oscillations are caused by factors such as drivers' inability to maintain minimum spacings consistently.

The oscillations consequently result in instabilities and reductions in traffic flows. During these oscillations, actual traffic flows are lower than theoretical maximum traffic flows.

In this condition, where there are oscillations in traffic flow, maximum flow levels cannot be recovered unless there is a reduction in the number of vehicles that are present in the particular road section.

However, if flow continues to increase, it follows that concentration also increases and speeds fall to match reduced spacings available, causing a further reduction in flow. As speeds fall to zero (point 0), concentration rises to its maximum value known as jam concentration (Kj), when vehicles are parked together as closely as possible.

In practice, even when stationery, vehicles do not touch each other. In the stationery jam situation, jam concentration ranges from about 190 to 210 vehicles/km for cars only. The size of each space between vehicles can be seen as a zone of influence ahead of each vehicle which is dependent on both vehicle and driver characteristics (Hobbs, 1984).

Within zone PQC, flows can be very high but driving conditions are very unstable. It is possible for vehicles to be moving under non congested driving conditions (portion PQ). Thereafter, under influence of restricting bottleneck factors (which may or may not be determinable), forced conditions of driving (portion QC) may supervene abruptly, even though the flow may be as before.

2.1.4. Factors affecting speed flow curves

Apart from traffic speeds, there are other factors that affect vehicular flows, and hence traffic stream characteristics. All these factors can be broadly grouped into two categories. The first category is referred to as prevailing conditions, which may further be divided into two groups of prevailing roadway and traffic conditions.

It is seldom that, however, that all roadway and traffic conditions which affect traffic flows are ideal. Hence prevailing roadway and traffic conditions that are actually found on roadways have adverse influences on capacity of the roadways (Highway Capacity Manual, 1988).

Prevailing roadway conditions include factors such as road widths and driveways. These factors primarily affect traffic stream characteristics in the portion AP of the speed flow curve shown in Fig. 2.

As already stated in the preceding section, portion AP represents a range where congestion free driving occurs on a road. Moreover, within the same zone, mean speeds are higher and more variable than in other portions of the speed flow curve. This variability in speeds is caused by factors such as driver freedom in choosing his own speed.

In summary, the higher the standards of highway design, the freer are the driving conditions and the flatter the curve AP. Vice versa, the lower the standards of highway design, the less free are the driving conditions and the steeper is the slope of the curve AP.

In practice, therefore, a designer seeks to insert geometric features into a highway which ensure that curve AP is as flat as is reasonable for the circumstances under consideration. Such a design ensures that there is only a relatively small drop in speed as flow increases, within design limits (O'flaherty, 1986).

Standards of geometrical design of a road hence influence the shape of portion AP of speed flow curve. This is also the portion whereby traffic flows under non congested conditions. However, the geometric design standards of a road have no significant influence on portion OC of the general speed flow curve given in Fig.2. (O'flaherty, 1986).

In portion OC of the general speed flow curve, it is prevailing traffic conditions (such as traffic flow) that influence traffic stream characteristics. Moreover, within this portion OC, mean speeds are much lower than in the portion AP, and vehicles move under conditions of forced driving. As already explained in preceding section, a decrease in speed under these saturated conditions is associated with a decrease in traffic flow.

As already stated elsewhere in this section, the shape of the arm OC depends primarily on interaction between vehicles. Vehicle interaction affects traffic stream characteristics in the portion OC of the general speed flow curve in that vehicle concentration is so high that control exercised on each vehicle by the one in front has a most important influence on the flow (O'flaherty, 1986).

The second category of factors that affect traffic flows are those that comprise ambient conditions that are present during all traffic flows. These conditions, relating primarily to weather and visibility, include measures such as clear, dry, cold, warm, hot and rain.

Rain, which decreases both visibility and surface friction required for breaking, can be expected to lower service volumes at all levels of service. Snow and icy pavements can, in the extreme, lower the capacity of a facility to zero. Any combination of visibility and surface conditions that reduces average speeds to below 64 km/h can be expected to have very significant reducing effects on capacity (Carter, 1982).

In summary, factors that affect traffic stream characteristics vary. While prevailing traffic and ambient conditions may change from hour to hour or during various time periods of a day, none of the prevailing roadway conditions changes, unless some construction or reconstruction is performed.

Due to variability of the factors that affect traffic flow, the latter is inherently variable from any one road section to the next. This characteristic of variability makes it difficult to estimate speed or flow of a road section from speed flow estimates of another road section, unless similar prevailing and ambient conditions exist.

Speed flow relationships could in theory be determined from surveys of journey times over a range of flow conditions. Such an operation would involve either repeated timings of vehicles, or repeated timed runs of a survey vehicle, over sections of route under various flow levels. In practice an exercise of this kind would be prohibitively time consuming and expensive for a whole town centre road network (Cooper, 1976).

Cooper (1976) derived a general speed flow relationship for urban roads by using and expanding on previous studies and by taking into account factors that were felt to have most material influence on the relationships. The factors are road width at exit junction, length of link, type of junction at entrance and exit to the link, carriageway type (single or dual) and land use activity adjacent to the road.

The speed flow curves so derived were generally consistent with the previous studies, which had been used and expanded on.

One factor that determines traffic speeds in freely flowing conditions on urban roads is adjacent land use. For example, shops generate activities such as pedestrians crossing roads and vehicles loading and unloading. Generally, these activities cause greater interference with the flow of traffic than activities generated by open spaces.

Four land uses that are generally associated with urban areas are shopping, residential (includes public open space), not built up (vacant land, agricultural land) and other (industry, offices, schools and institutions).

Type of junction at entrance and exit to a link is another factor that affects urban speed flow curves.

Cooper (1976) states that exit junctions are generally considered to be of the following three kinds:

- Uncontrolled where the link in question is the major road.
- Shared such as in a roundabout, merging sections or traffic signals.

- Minor priority where the link in question is the minor road.

These junction types affect stream characteristics in that motorists within the different junctions are subjected to different driving conditions. For example, a motorist within a traffic signal controlled junction drives under freer conditions than a motorist driving within an uncontrolled junction. Consequently, motorists driving through roads with traffic signal control attain higher journey speeds than motorists driving through roads with uncontrolled junctions.

Road width is another factor that affects traffic stream characteristics. Highway Capacity Manual (1988) states that the standard width of a traffic lane is 3.65m. Width of roads affect traffic stream characteristics in that for traffic lanes less than 3.65m, the narrower a lane is, the more the driving space restrictions a driver is subjected to and the lower the speeds the driver can attain.

Type of carriageway affects stream characteristics in that motorists within a dual carriageway generally attain higher speeds than motorists within single carriageway.

Normally, there is more access control, and hence fewer operations of right turning opposing traffic, on dual a carriageway than on a single carriageway.

Consequently, there are more operations of right turning opposing traffic, and hence more interference to traffic on single two-way carriageways than on dual carriageways. During these operations, motorists giving way to right turning opposing traffic travel at average speeds that are lower than average speeds of motorists on dual carriageways or on one-way carriageways.

2.2. On-street parking and speed flow curve

Highway Capacity Manual (1988) states that, in general, town centre traffic flows under congested conditions. Under such circumstances, traffic stream characteristics are in region QO, of the general speed flow curve shown in Fig.2.

Alleviation of town centre traffic congestion is a growing problem because of its effects on trade (Hobbs, 1984). The alleviation would, for example, permit motorists to travel under free flow conditions indicated by part AQ of the general speed flow curve.

In the TSM context, the objective of parking controls is to enhance free flow of traffic. In the short run, which is the prescribed province of TSM (Wells, 1975), parking policies and good traffic management are widely recognized as the best means of coping with a present and imminent growth of urban traffic.

One of the problems created by road traffic is parking. Not only do vehicles require street space to move about, but also require space to park while occupants are carrying out activities. It is roughly estimated that out of 8670 hours in a year, the car runs on an average for only 400 hours, leaving 8360 hours during which the vehicle is parked (Kadiyali, 1987).

As city size increases, there is generally an increased demand for parking space that results from increases in car traffic (Matson, 1955).

Generally, it is not possible to fully cater for the continuing increases in town centre total car traffic. This inability generally leads to a situation whereby total traffic on town centre road networks is greater than their capacities, thereby causing traffic congestion.

Patel (1972) states that a rapid increase in car ownership, due to increases in real incomes combined with substantial increases in population, resulted in increased demand for movement and parking of private vehicles in almost all large cities in both developed and developing countries. Nairobi, the capital city of a rapidly developing country in Africa, has also experienced the impact of such a rapid increase in private car ownership.

Patel (1972) also established that effects of the increase in car ownership were more pronounced in the Nairobi central area, due to the following factors:

- While vehicular movement had been accommodated to some extent by construction of an improved road network, little or no attention had been paid to provision of a much needed storage space for these vehicles.
- High land costs, combined with the absence of a realistic policy on economic car parking charges, which made provision of parking space unattractive to private investors.

Off-street parking space provision by private enterprise depends upon encouragement offered by a local authority's parking policy. Generally, privately owned commercial car parks will not be built if they are expected to compete with either free and unrestricted on-street parking space or free and heavily subsidized local authority car parks.

Where it is intended to rely on private enterprise to provide parking space, it is necessary to make use of economic charge for off-street parking space, even at parking places provided by the local authority. Such charges ensure continued participation of private enterprise. Moreover, it is generally preferable that, on-street parking charges be higher than those made at off-street parks so as to encourage maximum use of the latter.

At present, parking charges are equal at both off-and on-street parking facilities provided by Nairobi City Council. Such equal parking charges generally lead to a preferred on-street parking space usage, as opposed to off-street parking space usage. This preferred on-street parking space usage results due to the fact that the most convenient place to park for a driver is at the kerbside (Hobbs, 1984).

Preferred usage of on-street parking space has effects on traffic stream characteristics in that the usage suppresses provision and hence usage of commercial privately owned off-street parking facilities, resulting in increased dependence on on-street parking space. Consequently, the number of vehicles on the streets (traffic densities) generally increases, leading to traffic congestion.

It has been established that the effects described in the preceding paragraph have taken place in Nairobi. Patel (1972) expressed fear that, if provision of parking space in Nairobi central area by private enterprise was allowed to continue being unattractive, the Nairobi City Council would either have to provide the required parking space or allow the central area to suffer from congestion caused by illegal indiscriminate parking of vehicles.

The second option, to the detriment of Nairobi central business area's traffic stream characteristics, seems to have taken place. With an upward trend in car ownership rates over the years, it is naturally expected that there be a similar trend in number of parking spaces. On the contrary, provision of off-street parking space facilities by Nairobi City Council has been declining in relation to demand.

The decline in Nairobi City Council provided parking space is due to the following:

- A decreasing supply of land that can be used for off-street parking facilities within the Nairobi central business area. Some parcels of land previously earmarked for Nairobi City Council off-street parking facilities are being developed otherwise. Examples of such parcels are that situated next to Macmillian Library, that fronting Jamia Mosque and that adjacent to the City Market.

- Inability, probably due to financial reasons, of the Nairobi City Council to construct multi-storey parking facilities. The City Council has never constructed a single multi-storey parking facility that is accessible to all motorists desiring usage of the same.

This inability has resulted in surface car parks in parcels of land that were previously reserved for multi-storey car parking facilities. Generally, surface car parks accommodate less parked vehicles than multi-storey car parking facilities.

Due to reasons stated in the preceding paragraphs, there has been an increasing dependence upon on-street parking spaces. Such a practice generally increases total number of vehicles (traffic densities) on the streets, which in turn leads to traffic congestion.

2.3. Nairobi central business area's car parking standards

A parking space facility that is commonly used to provide town centre off-street parking space, and hence reduces on-street parking space usage, is that parking space is generally provided by car parking standards.

This space is usually provided as a condition of planning consent, for all proposed new development within the Nairobi central business area. The condition, often referred to as car parking standards, requires that 10% of total floor area of all proposed new development in the area be reserved for parking purposes only.

Although these standards normally ensure that a new development makes contribution towards meeting the parking demand it generates, they may not practically meet this requirement particularly when the standards do not specify the parking space demand they should cater for. The parking standards should make a clear distinction between operational and non-operational parking space to ensure adequate provision of operational parking purposes if business efficiency in a town centre is not to be impaired.

Operational parking space is the space generally required for cars and other vehicles regularly and necessarily involved in the operation of the businesses of particular building. It includes space for commercial vehicles supplying goods to, or delivering goods from the premises; space for loading and unloading and for picking up and setting down passengers.

Non-operational parking space is the space generally required for traffic that does not have to park at particular premises. It divides roughly into two classes - long-term parking and short- and medium-term parking. Non-operational long-term parking mainly comprises space for cars in which workers in the central area come to work. Short-term parking space covers the needs of shoppers, business callers, sight seers and a host of other requirements arising from visitors who drive to the town centre for many purposes. But the characteristic of all non-operational parking demand (whether it is for essential of optional traffic) is that parking space need not be provided in the particular premises in which the car user's business lies (Her Majesty's Stationery Office, 1965).

Traffic may be either essential in the sense that the use of a vehicle is necessary for the carrying on of a trade or business, or optional in the sense that it was not necessary for the journey to be made by car. For instance, shoppers are necessary for the commercial life of town centres and the car (in comparison to bus and walking modes of transport) has the greatest potential for reaching a wide range of shopping destinations. While walking can also reach various destinations, the mode is naturally only viable for very local journeys.

Overall, local authorities should concentrate revenue support on public transport for actual and potential journeys to work in these locations, give weight to the implications for local firms when designing traffic management schemes which improve access for central area traffic, ensure efficient loading arrangements for goods vehicles, and provide adequate and convenient parking for shoppers.

However, in new developments within the Nairobi central business area, provision of parking space is by car parking standards that do not clearly distinguish between operational and non-operational parking space demand thereby generally denying efficient loading arrangements for goods vehicles that require operational parking space and consequently impairing business efficiency in the area.

There are other disadvantages in the provision of parking space by car parking standards that do not make a distinction between operational and non-operational parking demand in Nairobi central business area in that usage of the space provided generally leads to traffic generation in excess of road capacity, thereby contributing to traffic congestion.

The congestion arises due to the fact that these spaces are not usually available to the general public, but reserved for particular motorists. Such usage of the parking spaces generally results in:

- Under utilization of the same spaces since, for example, a reserved parking space normally remains unoccupied when the motorist for whom it has been reserved for is not using it. While this reserved parking space may be unoccupied due to reasons that have just been stated, it may be possible that there exists no parking space for other motorists in need of the same.

- Traffic congestion since motorists with reserved parking space are generally encouraged to use private cars. Rhodes (1980) states that reserved parking space provision usually encourages use of private motor vehicles since motorists with reserved parking space are assured of availability of parking space for their use. Consequently, the parking space increases total traffic on the streets (traffic densities), leading to traffic congestion.

In summary, parking space provided by implementation of car parking standards is out of Nairobi City Council control once built. This lack of control leads to the parking space being used by specific users. Motorists without prior arrangements for reservation of the parking space provided by implementation of car parking standards have no access to the parking space and have no alternative but to use on-street parking space since the most convenient place to park for a driver is at the kerbside.

2.4. Effects on-street parking

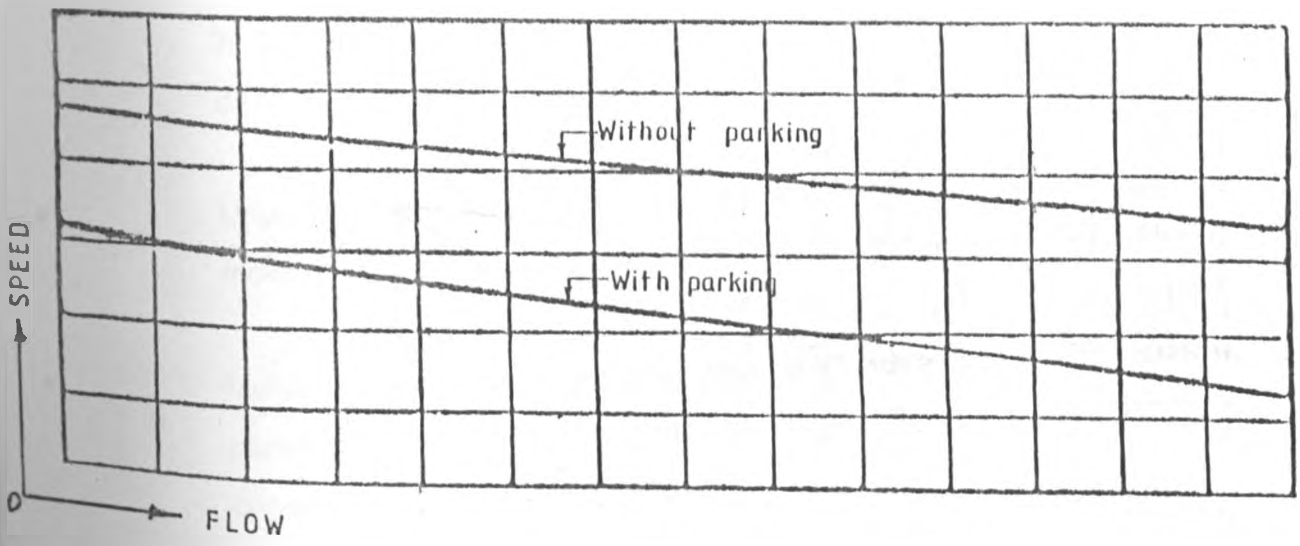
Usage of on-street parking space generally causes operational problems to town centre road network. For example, on-street parking space usage affects speed flow curves, traffic speeds, street operational capacity and traffic flows.

2.4.1. Effects on speed flow curves

Highway Capacity Manual (1988) states that speed flow curve studies done for a composite of 37 test sections with parking permitted were compared with similar studies done for a composite of seven test sections with parking prohibited. It was established that in both studies, typical speed flow relationships existed, results of which are represented in Fig. 3.

FIG.3

EFFECT OF ON-STREET PARKING ON SPEED FLOW CURVES



Source: Highway Capacity Manual (1988)

These results indicate that, for either a fixed value of speed or flow, the corresponding value of flow or speed is higher for test sections where parking was prohibited than where it was permitted. The results support the general phenomena that on-street parking affects traffic stream characteristics.

2.4.2. Effects on traffic speeds

On-street parking process has negative effects on movement of traffic during the whole process. Basically, the process is accomplished in three stages. The first stage is when a motorist is looking for and getting into a parking space. The second stage is when a vehicle is in physical occupation of a parking space. The third and last stage is when a vehicle is pulling out of a parking space. Operations of each of these stages affects traffic stream characteristics in the following manner:

- Motorists in need of parking spaces slow down while looking for and getting into the spaces. When a vehicle slows down, it forces all traffic upstream to also slow down or change lanes (where possible), thus causing delays. Traffic delays result in reduced vehicle speeds, which is in turn an indication of impending or existing traffic congestion (O'flaherty, 1986).

Unparking vehicles, while manoeuvring from parking spaces into moving traffic streams, cause delays to the later due to merging.

Vehicles parked on-street have several disadvantages. For example, parked vehicles generally reduce moving traffic streams' speeds and consequently cause traffic congestion.

Hobbs (1984) states that introduction of on-street unilateral parking shows that traffic flow along the street is hampered with and that the effect of an unbroken line of kerb-parked vehicles is to reduce vehicle speeds by more than 20%. A reduction in vehicle speeds is an indicator of existing or impending traffic congestion.

2.4.3. Effects on street operational capacity

Another disadvantage of on-street parked vehicles, on traffic stream characteristics, is a reduction of effective street widths. On-street parked vehicles inevitably reduce available road widths.

However, what is less well known other than by specialist traffic engineers is the magnitude of the effect of parked vehicles. A 20 meter wide street, with parking on both sides, has the same capacity as a 12 meter street where parking is prohibited (Hobbs, 1984).

Thus, the on-street parking represents a loss in effective width of over 4 meters for each line of parked vehicles. This figure is considerably in excess of the width of a standing vehicle.

The extra loss of street width results due to, for example, the fact that provision of parking lanes wide enough to accommodate parked vehicles physically does not prevent all capacity loss due to parking. This is because on-street parking, like any other obstruction, has an influence range extending beyond its physical limits (Highway capacity Manual, l988).

For example, assuming an 8 feet parking lane, and applying uninterrupted flow principles, the parked cars would constitute an obstruction located about one foot from the edge of the traffic lane, with restrictive effects, even if it were assumed that they were parked very close to the kerb or lane edge (Highway capacity Manual, l988).

In summary, lateral obstructions (such as parked cars), located closer than 1.83m from the edge of a traffic lane reduce the capacity of that lane. However, obstructions such as kerbs that are 15 cm or less in height, have insignificant influence on traffic operations (Kadiyali, 1987).

In addition to being a lateral obstruction greater than 15 cm in height, on-street parked cars reduce street effective widths (and hence reduce operational capacity of the same streets) by measurements greater than vehicle widths due to activities associated with parking.

Traffic flow is normally interfered with by activities associated with parking and the parked vehicle. Examples of such activities are parking manoeuvres, opening of car doors and appearance of pedestrians from behind parked cars.

These activities cause delay and reduce operational capacity of roads (Hobbs, 1984). Traffic delays result in reduced vehicle speeds, which in turn is an indication of impending or existing traffic congestion.

On-street parking supply not only reduces street operational capacity (as a consequence of reductions of effective street widths by measurements greater than widths of vehicles), but also by encouraging double parking.

On-street parking supply, particularly if uncontrolled, generally encourages double parking. Double-parked vehicles definitely reduce operational capacity of roads since the vehicles occupy at least one lane that is intended for moving traffic.

Consequently, on two-lane two-way streets, it may require traffic whose direction of flow has been blocked by double parked vehicles to await gaps in opposing traffic before the former traffic can proceed.

The waiting of gaps constitute delays and consequent reduced vehicular speeds, which is in turn an indication of impending or existing traffic congestion.

Double or illegal parking generally occurs in Nairobi central business area. Transurb Consult (1986) reports that in 1979, the area's demand for on-street parking space exceeded supply by 1930 spaces. This figure represented a 26.6 % deficiency in on-street parking space.

The deficiency in on-street parking supply could have been met by, for example, double parking. This activity is an illegal occupation of part of road intended for moving traffic. Such an activity obviously resulted in a reduction in operational capacity of affected street sections, generally leading to traffic congestion.

2.4.4. Effects on traffic flow

In addition to causing delays to moving traffic streams (due to diverted attention and hence reduced average speeds), motorists in search of parking space remain in circulation thereby increasing traffic flow. Matson (1955) states that a significant factor in the influence of parking on traffic flow is the amount of traffic moving in search of parking places.

The increase in traffic flow ultimately leads to traffic congestion, as is the case in Nairobi central business area.

Disney (1994) states that traffic congestion in Nairobi occurs within the central business area. This area's traffic flows suffer from interruptions that arise from, for example, the lack of a planned provision of parking space. Consequently, vehicles looking for parking space circulate and increase traffic flows within the area, thereby causing traffic congestion.

3.0 TRAFFIC SURVEYS

3.1 Preliminary steps

Before field surveys and data collection were undertaken, organizational and preparatory work was carried out. This work involved:

- delineation of area and roads under study,
- study area block (road link) designation,
- sampling of links to be studied,
- sample link selection,
- scheduling of operations,
- survey personnel mobilization and
- choosing period of aggregation of data.

3.1.1. Delineation of study area and roads

Although it is known that traffic congestion generally exists in Nairobi central area's streets, information is lacking as to the extent to which parked vehicles contribute to this congestion.

Theoretically, information about extent to which congestion is caused by parking only can be obtained by studying effect of parking on traffic stream characteristics, while keeping constant all other variables that affect these characteristics (and hence contributing to congestion).

Apart from parking, there are other factors that have been found to contribute to Nairobi central area's traffic congestion problem. To avoid effects of these other factors, the survey was limited to roads where there was:

- Legal on-street parking. On roads where vehicles are parked illegally, motorists are aware that kerb space usage by parking is illegal and they could be towed away. Such a knowledge is generally, expected to lead to illegal parking space usage that is different from that of legally available kerb parking space. Consequently, data obtained from illegally parked kerb space is expected to affect this study's findings and cannot be used for planning purposes.

- No pubic transport vehicle plying. Situma (1971) found out that Matatus operated on K.B.S. established routes, as well as on other routes where the latter mode was not available, and that the Nairobi City Council together with the Government of Kenya stood to pay heavily in terms of a Matatu caused congestion problem.

This congestion is caused by the fact that Matatus stop anywhere and anytime on the roads while picking up or dropping passengers. Such an activity obviously interferes with traffic flow and generally leads to a Matatu caused congestion, as opposed to congestion caused by parking operations.

- Controlled on-street parking. Generally, more serious traffic congestion results from usage of uncontrolled on-street parking space than would result from usage of controlled on-street parking space. With uncontrolled on-street parking, cars are often parked close together, making it difficult for vehicles to enter or leave the parking spaces.

- Carriageway widths of at least 4.0m and 5.75m on one-way streets and two-way streets respectively, for sufficient room for safe movement and parking (O'flaherty, 1986).

Road links, together with their physical characteristics, which were in the study area are listed in Appendix LUS and presented in Fig.4 which shows the road network within the study area.

3.1.2. Block (road link) designating system

All roads under study were designated into blocks and numbered. A block was considered to be composed of both sides of a road between two intersections (otherwise referred to as a road link), the block area including both kerbs.

Bureau of Public Roads (1957) states that one advantage of this method of block designation is that its blocks are homogeneous as to traffic characteristics.

3.1.3. Sampling

Speed flow relationships could, in theory, be obtained from surveys of journey times over a range of flow conditions. Such an operation would involve either repeated timings of vehicles or repeated timed runs of a survey vehicle, over sections of route under various flow levels. In practice, an exercise of this kind would be prohibitively time consuming and expensive for a whole town centre road network (Cooper, 1976).

Due to naturally limited funds and time, information about Nairobi central area's road network's traffic congestion and traffic stream characteristics was obtained by sampling procedure.

In selecting a sample, Votaw (1962) states that there is criteria to be met, such as follows:

- In designing a sampling procedure the traffic engineer will frequently wish to consider both cost and accuracy of information. Although the information becomes more accurate as the size of the sample increases, survey costs will often increase as the size of the sample increases.

- It is often desirable to determine the sample size so that there is a high probability that the absolute error of a point estimate of a value of a quantity is not more than a preassigned amount. A high probability value that is usually satisfactory in traffic engineering studies is 0.95. Moreover, the absolute error is expected to be a small fraction (for example, 0.10).

Based on the above criteria, Votaw (1962) gives the following equation for calculating the sample size.

$$n = \frac{(Za)^2}{(D)^2} p(1-p)$$

where,

n = required sample size.

Za = the 100a percent point of the standard normal distribution. This equation is based on the normal approximation to the distribution of p.

D = a preassigned bound on absolute error

p = probability that an element drawn at random from the population has a given attribute.

The above equation was adopted for calculating this study's sample size. The sample size (number of links) required for this study is calculated as follows:

$$n = \frac{(1.96)^2 (0.99)(0.01)}{(0.10)^2} = 4$$

Values of the various parameters used in the equation are as follows:

p = 0.99. p should be chosen as large enough as possible in keeping with the investigator's knowledge of the subject matter (Votaw, 1962). In this case, Disney (1994) and Transurb Consult (1986) have already established that there is a general congestion phenomena on Nairobi central area streets.

D = 0.10 Votaw (1962) states that the absolute error is expected to be a small fraction, for example, 0.10

Za = 1.96 This figure is based on a high probability that the absolute error of p is not more than a preassigned amount (d above). A high probability value that is usually satisfactory in traffic engineering studies is 0.95

3.1.4. Sample selection

The sample size was selected from the study road links presented in Table 1. Sample selection was done such that various types of links were represented based on factors that have influence on urban speed flow relationships.

These factors are road width at exit junction, type of junction at entrance and exit to the link, and carriageway type (dual or single). Data on these variables was available at City Hall.

3.1.5. Scheduling of operations

The study surveys were scheduled to be conducted during the period 8.00 a.m. to 5.00 p.m. Selection of the survey time period was based on:

- A requirement that, for planning purposes, future volumes are usually estimated for the peak-hour period (Highway Capacity Manual, 1988).

  The use of the urban transport system is very unevenly distributed in time. Non-operational long-term parkers, who generally come to the central area to work, are of critical interest to the highway planner and designer. The well-known tendency for work trips to happen at the same time results in the creation of peak period travel demands which are usually the focus of attention during the planning and design processes (O'flaherty, 1986).

- General experience that traffic flows and kerb parking space usage were not at their maximum before 8.00 a.m and after 5.00 p.m. As already stated in the preceding paragraph, urban roads need to be designed based on peak hour demands.

  Moreover, to assess accurately the peak demand, the general census of parked vehicles should ideally be completed during the higher of the two levels of parking. Periods of peak parking demand are expected to be in the morning at about 10.00 a.m. and afternoon at about 3.00 p.m..

- A requirement that a minimum of 30 fifteen minute intervals were required for any link data. 30 is the minimum number of points that is required to draw a regression equation (Box, 1982).

Relationships between traffic stream characteristics' variables are normally linear. Sandy (1990) states that where relationships between variables are linear, analysis of the data is usually done by linear regression analysis.

The surveys were also limited to working weekdays, that is, Monday to Friday and to a typical or average season, in the months of September, October and November 1992.

While choosing the above survey period, it was considered that traffic flows and parking demand for the weekdays, Monday to Friday, remain fairly constant and that weekend flows are variable depending on season and weather (Matson, 1955).

Traffic flows and parking usage surveys form part of this study and it is necessary that the surveys be conducted under similar conditions. It is usual to combine traffic survey data collected on different days, for purposes of analysis. Hence, traffic survey data should be collected under similar conditions, so that the combined data (that is to be analyzed) is representative.

3.1.6. Survey personnel mobilization

Surveys were done by experienced traffic enumerators of City Engineer's Department, Nairobi City Council.

3.1.7. Aggregation of data

In defining time periods for aggregation of survey data, there was consideration of the following:

O'flaherty (1986) states that the use of the urban transport system is very unevenly distributed in time, depending on trip purpose for example.

Also, there are short-period fluctuations in traffic flow within the hour and that although hourly volumes are normally used in planning and design, the ability of a highway to accommodate satisfactorily an hourly volume depends primarily on the magnitude and sequence of these short-period fluctuations (Highway Capacity Manual, 1988).

Furthermore, Highway Capacity Manual (1988) states that the shorter the time period over which survey data is aggregated, the more meaningful the results of speed flow relationships established. Vice versa, the longer the time period of observation, the less pronounced the effect of flow on space mean speed.

Salter (1989) states that a 15 minute time interval is the shortest time period over which stable flow exists.

Thus, a 15 minute time period was adopted for aggregating individual link data from field surveys.

The 15 minute time interval enabled, at most, a total of 36 sets of data to be collected. Each set of data represented a point on regression equations that were established during analysis stage. As stated in section 3.1.5., a minimum of 30 points are needed to draw any regression equation.

3.2. Surveys conducted

O'flaherty (1986) states that when planning a new or improved road system, it is necessary to know distribution and performance of traffic on existing roads. Data used in establishing speed flow relationships was obtained by:

- Field confirmation of link data characteristics of widths, lengths and junction types. The link data was available at City Hall.
- Field surveys at sampled links to obtain data on link traffic flows, travel-times and on-street parking usage.

3.2.1. Link data confirmation

Along each study link, a field check was done to confirm Nairobi City Council data (used at sampling stage) on link physical characteristics. This field check was accomplished by myself in a day, by being driven round the Nairobi central area. Moreover, for the sampled links, actual field measurements were done to confirm their physical characteristics. No changes were observed and the sampled links were adopted for field surveys.

3.2.2. Traffic flow counts

Vehicular traffic flow is the number of vehicles which pass a fixed point in unit time. Traffic flow counts may be done either manually (by making use of hand tally counters) or mechanically (by making use of devices such as pneumatic tubes).

In this study, flow counts were done manually, since hand tally counters were readily available at City Hall. The advantages of manual counting are that the counts are more accurate, very specific information is obtained and, in general, office work is simplified (O'flaherty, 1986).

In particular, manual traffic counts are often markedly superior to any mechanical counts since they permit secondary data to be obtained (Box, 1982). Such secondary data that was necessary for this study was, for example, vehicle class.

Traffic using a road is composed of a variety of vehicles, ranging from simple pedal cycles to heavy commercial vehicles. Each type of vehicle has an influence on the performance of traffic on the road in its own way (Kadiyali, 1987).

Thus, it is normal practice to classify traffic into distinct types when carrying out traffic flow counts. Classified counts give data on number of cars, light goods vehicles, buses and trucks within a traffic stream.

The number of light goods vehicles, buses and trucks in a traffic stream is usually required since these vehicles have an effect on service flows, due to their added size and somewhat lower acceleration capabilities (Carter, 1982).

The influence of various vehicle classes on performance of traffic is catered for by applying passenger car unit (pcu) equivalents to the flow counts, so as to convert flows of the various classes of vehicles into passenger cars units.

In other words, passenger cars, lorries, motor cycles and bicycles all have different operating characteristics and hence, for comparison purposes, may be given different weightings to allow for their varied effects within the traffic stream upon traffic movement (O'flaherty, 1986).

Kadiyali (1987) states that the basic consideration behind the application of pcu equivalents is that the different types of vehicles offer different degrees of interference to traffic flows and that it is necessary to bring all types of vehicles to a common unit, the pcu.

Apart from vehicle classification, pcu equivalents also depend on other factors, such as grade and length of grade. An example of effects of grade and length of grade is that trucks with loads travel at lower speeds up grades than on level ground, especially if the up grade is long and steep (Highway Capacity Manual, 1988).

Pcu equivalents that are generally recommended for urban areas are presented in Table 1. below:

TABLE 1

PCU EQUIVALENTS FOR URBAN AREAS

VEHICLE CLASS	PCU EQUIVALENT
Cars and light vans	1
Medium commercial vehicles	1.75
Heavy commercial vehicles	2.5
Buses and coaches	3.0

Source: Wells (1971)

At the sampled links, continuous manual classified directional traffic flow counts were done for the study period, between 8.00 a.m. and 5.00 p.m. Vehicles were classified into 4 groups, that is, whether they are cars, buses, medium commercial vehicles or heavy commercial vehicles. The Highway Code of Kenya (1963) defines these vehicle classes as follows:

- A heavy commercial vehicle is a vehicle whose tare weight exceeds 6720 pounds.
- A light commercial vehicle is one whose tare weight exceeds 4000 pounds but does not exceed 6720 pounds.
- A motor car means a vehicle having a seating accommodation of not more than 10 passengers excluding the driver, but does not include a motor cycle.

Tare weight means the weight of a vehicle when unladen, inclusive of weight of its body and all parts (the heavier being taken when alternative bodies or parts are used) which are necessary to or ordinarily used with the vehicle when used on the road.

At each sampled link, continuous classified vehicle counts were done by three (3) pairs of enumerators, each set being composed of two members. Each pair worked for a maximum of 3 hours a day, at the end of which period it handed over to the next one. This time period was chosen based on the enumerators' previous working programs.

Working of the pairs of enumerators was organised such that, for each sampled link, the first pair started a day's work by stationing at the middle of the link, one enumerator at each kerb line. Each of the two enumerators was equipped with a sound four knobbed tally counter, a watch, a clip board, a recording pen and paper (Form 1).

Once at the desired location, each enumerator positioned so as to face and register traffic in one direction only. This traffic was the one flowing towards the enumerator.

Before the start of a day's counting work, the tally counters had to be confirmed to be sound. A tally counter was considered to be sound if it could be reset to zero and that, after tapping any of the four knobs once, there was only a one digit increase in figures below the tapped knob. A tally counter that did not indicate such an increase was considered to be out of order and replaced with a sound one.

After a tally counter was confirmed to be sound, it's four knobs were labelled differently in order to facilitate counting of vehicles by class. Labelling was done such that each knob recorded either a car, a bus, a light or a heavy goods vehicle.

As already stated in this section, the tally counters were used to record traffic flows, by vehicle class. Every vehicle that passed an enumerator's station, in the desired direction, was registered by tapping once a knob on the tally counter that corresponded to it's class. Such a pass was automatically indicated on the tally counter by a one digit increase under the tapped knob.

At the end of every 15 minute interval, totals were recorded on Form 1, for each class of vehicle that had passed the station in each direction. For each class of vehicle, it's total was indicated on the tally counter under the knob that was tapped for every passage of that class of vehicle.

M 1

ICLE CLASSIFIED COUNTS

K DESCRIPTION: ______________________________
EMENT DESCRIPTION: ______________________________
E ______________ DAY ____________ WEATHER ________________

MERATOR ________________

ME	CARS	LIGHT GOODS VEHICLES	HEAVY GOODS VEHICLES	BUSES AND COACHES	TOTAL PCU
00-8.30					
15-8.30					
30-8.45					
45-9.00					
00-9.15					
15-9.30					
30-9.45					
45-10.00					
.00-10.15					
.15-10.30					
.30-10.45					
.45-11.00					
.00-11.15					
.15-11.30					
.30-11.45					
.45-12.00					
.00-12.15					
.15-12.30					
.30-12.45					
.45-1.00					
00-1.15					
15-1.30					

1.30-1.45					
1.45-2.00					
2.00-2.15					
2.15-2.30					
2.30-2.45					
2.45-3.00					
3.00-3.15					
3.15-3.30					
3.30-3.45					
3.45-4.00					
4.00-4.15					
4.15-4.30					
4.30-4.45					
4.45-5.00					

3.2.3. Travel time surveys

Just like traffic flow data, travel time data was aggregated over 15 minute intervals. A travel time survey measures time required to traverse a route. As the name suggests, travel time is the time spend while travelling from one place to another.

One technique that is used to obtain travel time information is the license plate method. The method was adopted for this study due to the following factors:

- Travel times could be obtained by classes of vehicles.
- Motorists are unaware of being studied, hence results are not expected to be biased.
- Stop watches, the only equipment that are required, were readily available at City Hall.

For each of the 15 minute time interval during which link traffic flow data was recorded, travel time data was obtained and recorded by three sets, of eight traffic enumerators per set, in a day. Each set worked continuously for a maximum of three hours per day, at the end of which time it handed over to the next set.

Four members of the first set (that started a day's work) equipped themselves with sound stop watches. The other four equipped themselves with clip boards, recording pens and paper (Form 2). Moreover, before data recording could start, the stop watches were synchronized and set to read correct time of day.

M 2

VEL TIME SURVEY

K DESCRIPTION ____
EMENT DISCRIPTION ____
E ______________ DAY _________________ WEATHER _______________

MERATOR _________________________ AND _____________________

HICLE GISTRATION	TIME OBSERVED

Each of the enumerators of the first set, two at each location, stationed at predetermined locations on a road link. One of the two enumerators (at each predetermined location) was equipped with a stop watch, while the other enumerator was equipped with a clip board, recording pen and paper (Form 2).

For a sampled two way link, four locations were predetermined and marked so as to be at opposite kerb lines of both entry and exit to the link. The locations were marked so as not to include, in the travel time survey data, time that was spent by vehicles while waiting at junctions. Such time was considered to be delay that is caused by junction operations, as opposed to parking operations.

Travel time data was obtained by sampling since a sample of 50 matches (of travel time data) usually provides sufficient accuracy for most practical purposes (Box, 1982).

Samples of study vehicles were determined by making use of traffic flow data already gathered during the study and sample size selection percentages, based on registration numbers, as presented in Table 2. .

TABLE 2.

VEHICLE SAMPLE SIZE SELECTION PERCENTAGES

SAMPLE SIZE REQUIRED	SAMPLE SIZE GIVEN BY VEHICLE REGISTRATION NUMBER ENDING WITH
100%	All numbers
50%	Odd numbers
30%	2,4 and 7
20%	2 or 7

Source: Her Majesty's Stationery Office (1965)

Sampled vehicles for the travel time surveys at each sampled link are presented in Table 3 below.

TABLE 3.

SELECTED VEHICLES FOR TRAVEL TIME SURVEYS AT SAMPLED LINKS

SAMPLED LINK	15 MINUTE LINK TRAFFIC FLOW (VEHICLES)	% OF VEHICLES REQUIRED FOR STUDY	STUDY VEHICLE REGISTRATION NUMBER ENDING WITH
L1	102	49.02	Even numbers
L2	121	41.32	Even numbers
L3	122	40.98	Even numbers
L4	3	100	All numbers

For link L4, travel time surveys were repeated till at least thirty 15 minute time intervals, each interval having at least 50 matches of travel time data, were obtained.

As already explained in this section, a sample of 50 matches of travel time data usually provides sufficient accuracy for most practical purposes. 15 minute time interval is the time period adopted for the purpose of aggregating this study's data while thirty is the minimum number of points that are required for regression equations, as already stated in section 3.1.5.

For each of the sampled vehicles that passed an enumerator's station, the following details were recorded:

- Registration number (only last five digits, and letter where applicable, since these details were required for identification purposes only).
- Vehicle class; a car was denoted by C, a light goods vehicle by L, a bus by B and a heavy goods vehicle by H.
- Time of day to the nearest second.

For each sampled link, and for each direction of flow, every sampled vehicle's travel-time data was obtained and recorded. The enumerator with the watch read out, only last five digits, approaching vehicle registration number. He then waited till the vehicle reached his marked position and then he read out the time of day. These readings were being recorded simultaneously by his partner.

Travel times were later on obtained by matching vehicle registration numbers. For each direction of flow of traffic and between the two stations marked at entry and exit to a link, a motorist's travel time is the difference between the times recorded against his vehicle.

For each direction of flow within a link, the vehicle should obviously be recorded at the exit marked position at a later time than the time it is recorded at the entry marked position, otherwise the results ought to be discarded.

Other travel time data that was discarded was that of vehicles that parked within the road links under study. Travel time for vehicles that park within a section of a road is usually greater than travel time for vehicles that do not park within the same section of road. Thus, the travel time data for vehicles that parked within the links under study was expected to interfere with this study's findings and was consequently discarded.

Any 15 minute interval link data that did not have at least 50 matches of travel time data was discarded. Travel time surveys were repeated to supplement any link data that did not have a minimum of 30 fifteen minute intervals, each of which interval having at least 50 matches of travel time data.

3.2.4. On-street parking usage survey

Like traffic flow and travel time data, on-street parking usage data was aggregated for 15 minute intervals. On-street parking usage survey generally gives data on the extent of usage of parking spaces on the streets.

A sampled link's parking usage survey was carried out, in a day, by a set of three traffic enumerators. Each enumerator worked continuously for a maximum of three hours a day. At the end of the three hour period, the enumerator on site handed over to the next one.

The first enumerator to start a day's work, equipped with a stop watch, a clip board, a recording pen and paper (Form 3), began a day's survey by recording all vehicles found parked at 8.00 a.m. Henceforth, for every vehicle that parked within his section, he recorded it's registration number and times of it's arrival and departure to the nearest minute.

O'flaherty (1986) states that the most accurate way of carrying out a duration survey is to make continuous observations on parkers at all possible locations.

FORM 3

PARKING USAGE SURVEY

LINK DESCRIPTION ____________________
MOVEMENT DESCRIPTION ____________________
DATE ____________ DAY ________ WEATHER ____________

ENUMERATOR ________________

VEHICLE REGISTRATION	TIME IN	TIME OUT

Thus, the adopted parking usage survey method yielded the most accurate data on all vehicles that parked during the study period. However, since the parking duration survey also obviously measures the degree to which the existing parking regulations are observed, the duration surveys were carried out as inconspicuously as possible to avoid biased results.

For each parked vehicle, only last five digits (and letter where applicable) of the license plate were recorded. The only reason for recording such information was to determine the duration of parking and not for enforcement purposes.

Each vehicle's duration of parking is the difference between the times the vehicle was noted to park and to unpark.

3.3. Computer data storage

All data obtained in the surveys could be summarized and tabulated by manual methods. However, those methods are generally tedious and subject to errors. Thus, for use at analysis stage, computer data storage was adopted. Lotus 123 package was readily available and was used for the data storage. A summary of the data is presented in Appendix DP-T1.

4.0. DATA PRESENTATION AND ANALYSIS

4.1. Parking usage survey data

Parking usage characteristics for the Nairobi central business area were summarised into graphs as shown in Appendix DP-P1. Generally, these curves indicated that the parking usage line graphs rose between 8.00 a.m. and 9.00 a.m. with the entry into the area of people going to work. The curves continued to rise, but less steeply later, as incoming workers were generally replaced by shoppers and people engaged in other journeys or activities.

The curves generally reached their peaks approaching midday, after which the accumulation started to decrease as some people left the area during the lunch period. Between 1.00 p.m. and 2.00 p.m., the curves started to rise again with the return of workers from lunch, and the entry into the area of fresh shoppers. The afternoon generally attracted more visitors than the morning and the accumulation peak for the whole day was generally reached between 2.30 p.m. and 4 p.m. After this time, a major exodus from the area started as people returned home and the accumulation declined.

The parking duration survey provided information regarding the number of motorists parked at particular locations within each link. For example, link L1 data showed that during the time of the survey, characteristics of vehicles parked on-street were as follows:

- 21 number of vehicles parked for the time period between 8.00 a.m. and 8.15 a.m., as presented in Appendix DP-T1.

- These 21 number of vehicles represented 2.6% of the total number of vehicles that parked on that link section during the survey period, as presented in Appendix DP-P2.

- The 21 number of vehicles occupied 117% of the link's legal on-street parking spaces, as shown by parking indices presented in Appendix DP-P3. Parking index is the percentage of theoretically available number of parking bays actually occupied by parked vehicles.

- The parking usage characteristics were also summarised into tables as presented in Table DP-P4 below.

TABLE DP-P4

PARKING USAGE CHARACTERISTICS

LINK	PERCENTAGE OF STUDY TIME DURING WHICH		
	PU <= 0.85 PS	0.85 PS < PU =< PS	PU > PS
L1	5.5555	5.5555	88.889
L2	28.571	48.571	22.857
L3	100.00	0.0000	0.0000
L4	0.0000	3.3333	96.667

Explanations of the symbols used in the tables, for link L1, is as follows:

PU is parking usage in number of spaces
PS is parking supply in number of spaces

PU > PS
88.889%

means that parking space usage for link L1 was greater than supply during 88.889% of the parking usage study period on the link.

The parking usage survey data also included parking duration data and counts of parking volume and parking accumulation.

Parking duration is the length of time spent in a parking space, parking volume is the number of vehicles parked in a particular area over a period of time (usually measured in vehicles per day) and parking accumulation is the number of vehicles parked in an area at a specific moment.

Integration of Nairobi central business area's parking accumulation curves over the survey period, gave the parking load for the period and, hence, the average accumulation. The ratios of each fifteen parking usage to average accumulation were computed and presented in Appendix DP-P5.

The ratios of peak-to-average accumulation (which is a measure of the 'efficiency' with which Nairobi central business area's on-street parking facilities were used) were obtained from Appendix DP-P5 and presented in Table DA-PE1.

TABLE DA-PE1

PARKING 'EFFICIENCY' VALUES

LINK	PEAK PARKING USAGE (A)	AVERAGE PARKING USAGE (B)	'EFFICIENCY' VALUE = A/B
L1	28	22.694	1.234
L2	23	17.943	1.282
L3	17	10.606	1.603
L4	37	33.033	1.120

whereby: both the peak and average parking usages are expressed in number of parking acts.

The ratios of each fifteen minute parking usage to total parking supply, all expressed in number of spaces, were also computed for each link. These ratios, generally referred to as parking indices, were presented in Appendix DP-P5.

Overall, Nairobi central business area's parking indices were greater than one for 52% of the study period. In other words, there was double or illegal parking on Nairobi central business area's links under study for 52% of the study period.

Further analysis of the area's parking indices revealed that, for 34% of the study period, the indices were greater than 0.85. In other words, Nairobi central business area's parking indices exceeded 0.85 during 34% of the study period implying that motorists in need of parking had to spent more time than was expected looking for parking space. This figure (0.85 parking index) represents the objective of parking meter schemes.

4. 2 Speed and flow survey data

As already explained in Chapter 2.0, prevailing traffic conditions are generally not fixed but vary from time to time throughout the day. For example, at any particular time, traffic flows are a function of speeds of vehicles, the composition of the traffic streams, the manner in which the vehicles interact with each other and the physical features of the roadway. Survey data indicated that each of the four Nairobi central business area's links studied portrayed these traffic flow and speed variations as presented in Appendix DP-T1.

The area's variation of traffic speeds and flows with time of day are also presented in Appendices DP-S1 and DP-F1 respectively. Plots of the area's variation of traffic speeds with flow for each fifteen minute time interval during which survey data was aggregated are presented in Appendix DP-SF.

Generally, plots of the area's variation of traffic speeds with flow data were curves. The curves started at maximum speed values, when traffic flows were (theoretically) zero. Thereafter, the speeds decreased from the maximum speed values to zero values. As the speeds continuously decreased, the flows increased from (theoretical values of) zero to their maximum values. Thereafter, both the speeds and flows continuously decreased to (theoretical values of) zero.

4.3. Speed density models

Analysis of the speed and flow data yielded data on traffic densities. Traffic flow values, when divided by their corresponding speed values, yielded traffic concentration. The term concentration used in this text is the same as the term density, and is defined as the number of vehicles occupying a unit length of a traffic lane at a given instant. Concentration is usually expressed in vehicles per kilometre.

The relationship between Nairobi central business area's speed and density data was plotted graphically as presented in Appendix DA-SD. Overall, the speed density graphs indicated that, as the area's traffic concentration increased, the space mean speeds decreased.

These graphs are characteristic of general speed density relationships. Generally, as the concentration of vehicles on a roadway increases, drivers tend to decrease their speeds (Huber, 1982).

On Nairobi central business area's speed density relationships presented in Appendix DA-SD, an increase in concentration represented an increase in the longitudinal arrangement of vehicles in the traffic stream, which consequently gave the road users a sense of hazard and congestion, and naturally continuously affected the motorists' choice of speed and position of their vehicles.

Expressed in other words, increases in concentration resulted in decreases in traffic speeds in that, in a given lane of travel, the faster motorists gradually shortened the space gaps in front of them (thereby increasing concentration at that section of road), continuing operation at their own speed level until it became necessary to reduce speed in order to avoid collision with the vehicles ahead.

Plots of Nairobi central business area's speed density relationships, presented in Appendix DA-SD, were linear. Sandy (1990) states that when there exists a linear relationship between two variables, analysis of the data can be done by linear regression analysis.

Linear regression analysis of Nairobi central business area's speed and density data for the links under study was carried out using Lotus 123 package. Parameters of models derived from the regression analysis were also given in the Appendix DA-SD for speed density relationships and summarised in Table DA-1 below:

TABLE DA-1

SPEED DENSITY MODELS

LINK	SPEED DENSITY MODEL	MODEL COEFFICIENTS		r squared
		Uf (m/s)	Kj (pcu/m)	
L1	U = Uf - 32.4117 k	6.3714	0.19658	0.9426
L2	U = Uf - 100.3511 k	9.2929	0.09260	0.9190
L3	U = Uf - 275.2131 k	17.2600	0.06272	0.9319
L4	U = Uf - 242.2206k	5.9369	0.02451	0.9565

where:

Uf = free flow speed in metres per second (m/s)
U = vehicular speed in metres per second (m/s)
k = density in passenger car units per metre (pcu/m)
Kj = jam density in passenger car units per metre (pcu/m)
r = correlation coefficient

The results of regression analysis of variation of traffic speeds with density data as presented above established that the two variables (traffic speeds and density) were highly correlated, as is evidenced by the high correlation coefficient (r) values.

Bruton (1985) states that the correlation coefficient (r) indicates the degree of association between the independent variable (traffic density in this case) and the dependent variable (traffic speed in this case). This correlation coefficient takes a value between zero and one, and the closer the value of (r) is to one the better the linear relationship between the two variables. The closer the value of (r) is to zero, the worse is the linear relationship between the two variables, although it possible that a non-linear relationship exists. The significance of (r) is that it's square is approximately the decimal fraction of the variation in the dependent variable which is accounted for by the independent variable.

On average, the speed density linear regression models established that traffic densities accounted for 0.9295% of the traffic speeds for the Nairobi central business area's links under study. The part of the regression analysis which was unaccounted for traffic densities was 0.0705% on average. This unaccounted for part was due to other factors that generally affect traffic speeds and densities (effects of all which were not studied) such as pedestrians crossing the links or motorists opening car doors during the study.

Highway Capacity Manual (1988) states that speed distributions and averages vary by hours of the day as the result of many influences. Driver characteristics, trip purposes, visibility, and volume-capacity effects are all related to daily speed variations.

The linear models established during this study were generally in agreement with typical speed density relationships. Huber (1982) states that although no single model is a best model, the linear (Greeenshields) model gives a satisfactory fit to observed data over a sufficient range to make speed density results useful. The model is simple to use and it has been found that there is good correlation between the model and field data.

4.4. Speed flow models

Huber (1982) states that once a speed density model has been determined, a speed flow model can be determined from it. Highway Capacity Manual (1988) states that if the speed density relationship is a straight line, the speed flow relationship will be non-linear and vice versa.

Consequently, Nairobi central business area's free flow speeds (parameters Uf) for the links under study determined from the speed density models were adopted for the speed flow curve and consequently used in derivation of speed flow models.

As already stated in section 4.2 above, plots of Nairobi central business area's speed and flow data indicated that the relationships were generally curves, as presented in Appendix DA-SF.

A general description of these curves is that the free flow speed Uf (at zero levels of flow and concentration), is the maximum obtainable speed. There is second point of zero flow, corresponding to zero speed at maximum density Kj. Between zero and maximum speeds, the speed flow diagram forms some type of loop toward a point defined as that of maximum flow (Qmax) and critical speed (Cs).

The mathematical expression of the general speed flow curve is as follows:

$$q = \frac{Kj.u.(Uf-u)}{Uf}$$

where:

q = observed flow of traffic (in pcu per second)
Kj = maximum or jam density (in vehicles per meter length of roadway)
u = observed vehicular speeds (in meters per second)
Uf = free flow speed (meters per second)

Substitution of these general speed flow curve parameters by their values (as obtained from the speed density models already established in Table DA-1) yielded individual link speed flow relationships as presented in Table SF-CUR-1 .

TABLE SF-CUR-1

SPEED FLOW MODELS

LINK	SPEED FLOW MODEL
L1	$q = 0.030853\, u\, (6.3714 - u)$
L2	$q = 0.009965\, u\, (9.2929 - u)$
L3	$q = 0.003635\, u\, (17.260 - u)$
L4	$q = 0.004128\, u\, (5.9369 - u)$

where:

q = observed flow of traffic (in pcu per second)
u = observed vehicular speeds (in meters per second)

Reorganization and differentiation of the general speed flow curve equation yielded maximum flows and critical speeds, parameters (Qmax) and (Cs) respectively, as follows:

$$q = \frac{Kj.u.(Uf-u)}{Uf}$$

$$q = \frac{Kj.(u.Uf-u)}{Uf}$$

$$dq/du = \frac{Kj.(Uf-2u)}{Uf}$$

For (Qmax) which is the maximum value of (q),

$$dq/du = \frac{Kj}{Uf}.(Uf-2u) = 0$$

Thus (Uf- 2u) = 0 and Uf = 2u

since $\frac{Kj}{Uf}$ has non-zero values as presented in table DA-1 above.

This implies that maximum flows (Qmax) occur when vehicles are moving at critical speeds (Cs) that are equal to half the free flow speeds (Uf).

Substituting the values of the critical speeds (Cs) into each individual link's speed flow models presented in Table SF-CUR-1 above, the maximum flows for each link were computed. The maximum flows (Qmax) and critical speeds (Cs) for each of the links under study were summarised into Table DA-2 below.

TABLE DA-2

CRITICAL SPEEDS AND MAXIMUM FLOWS

LINK	Cs = Uf/2		Qmax	
	m/s	Km/h	pcu/s	pcu/15 minutes
L1	3.1857	11.469	0.31312	282
L2	4.6464	16.727	0.21514	194
L3	8.630	31.068	0.27072	244
L4	2.9685	10.6866	0.03637	33

where:

Cs = critical speed
Qmax = maximum speed

Generally, the critical speed (Cs) is a boundary point that roughly divides the speed flow curve into two zones, as defined here below:

- The zone of non-congested traffic conditions, that is, the upper portion of the curve, and

- the zone of congested traffic conditions, that is, the lower portion of the curve.

Thus, it was possible to determine time periods when there was traffic congestion in Nairobi central business area by examining plots of variation of traffic speeds with time of day in conjunction with the area's speed flow curves.

Link L1's speed flow curve presented in Appendix DP-SF, for example, indicated that critical speed (Cs) was 3.1857 m/s. This speed value was represented by a horizontal straight line in the same link's plot of variation of traffic speeds with time of day data presented in Appendix DP-S1 to facilitate differentiating time periods when traffic was flowing under congested or non-congested situations on the presentations in Appendix DP-S1.

Plots of variation of traffic speeds with time of day, presented in Appendix DP-S1, indicated that for all the links under study, there were:

- speed values below the critical speed (Cs) lines, representing congested traffic flow conditions and

- speed values above the critical speed (Cs) lines, representing non-congested traffic flow conditions.

Overall, there was traffic congestion on the links under study for 48% of the study time and this congestion generally occurred during the time period between 11.00 a.m and 12.45 p.m. and also between 2.00 p.m and 4.00 p.m.

As already stated elsewhere in this section, the speed flow curves' parts above and below the critical speed values (Cs) indicated existence of traffic flowing under non-congested and congested conditions respectively for the links under study.

Hence, for every traffic flow value, the speed flow curves yielded a pair of two different speed data, for the congested and non-congested traffic conditions. The speed data for the non-congested traffic conditions were always higher than speed data for the congested traffic stream situations. The reductions in speeds due to congestion were thus obtained by plotting graphs for congested and non-congested traffic conditions for equal traffic flows, using data obtained from the speed flow curves, and the plots are presented in Appendix SP-RED-CONG-A.

4.5. Parking usage and Nairobi central business area traffic congestion

Individual link reductions in traffic speeds, for equal traffic flows, were an indication of impending or existing traffic congestion as explained in the preceding section.

The area's traffic congestion was attributed to factors related to Nairobi central business area's usage of on-street parking facilities at the time of this study.

Overall, plots of variation of Nairobi central area's parking indices with time of day indicated that parking indices were greater than one for 52% of the study period.

Parking indices greater than one implied that there was double and illegal parking on the links under study. The double or illegal parking occupied physical carriageway space that was meant for moving traffic, thereby interfering with flow of traffic (due to reduced physical capacity of the links under study) and consequently leading to traffic congestion. The links' traffic flows and speeds were practically reduced to zero when there was double parking along both kerbs and leading motorists along the only part of carriageway that was physically available for moving traffic stopped, to allow pedestrians cross for example. This situation led to a stationery jam and congestion.

5.0. DISCUSSION

5.1. Speed flow curves

Speed flow curves obtained during this study, and presented in Appendix DP-SF, indicated that the various links under study had different traffic stream characteristics.

Links L1, L2, L3 and L4 carried maximum flows (Qmax) of 0.31312, 0.21514, 0.27549 and 0.03644 pcu per second respectively. Thus, link L4 carried the least maximum flows while link L1 carried the highest maximum flows. Links L3 and L2 carried maximum flows that were intermediate between those of link L1 and L4.

Link L1 was a two way carriageway 19.0m wide with angle on-street parking space 3.6m wide along one kerbline and 4.0m wide along the opposite kerbline. Illegal parking existed and occupied 2.50m and 2.3m width of carriageway meant for moving traffic alongside the legal on-street parking space.

Thus, Link L1's designed width of carriageway for moving traffic was 11.4m while the width of carriageway physically available for moving traffic was only 6.6m for both directions of flow. Thus, the physical capacity of this link was reduced by 4.8m width of carriageway or to 58% of the design physical capacity, due to the physical occupation of road space intended for moving traffic by double or illegal parking.

Moreover, the reduction in capacity was greater when traffic stream characteristics were considered than when physical width of carriageway was put into consideration. The critical speed (Cs) on Link L1 was 3.18574 m/s and hence the theoretical design capacity (DCt) of this link, based on the design carriageway width for moving traffic and the critical speed, was 0.6635 pcu/m. The ratio of maximum flow (Qmax) to theoretical design capacity (DCt) for this link was thus 0.47 implying that double and illegal parking reduced link capacity to 47% of the design capacity.

Also, a comparison of the value of Qmax to the theoretical capacity of the link's carriageway width physically available for moving traffic (PCt) (when the latter is based on the width of carriageway physically available for moving traffic and the critical speed (Cs) for this link) was made and the ratio of Qmax to PCt was 0.89%. In other words, link L1's maximum flows were reduced to 89% of the link's capacity that could be attained out of the carriageway width physically available for moving traffic and critical speed.

Similarly, reductions in capacities for the other links under study were calculated from their respective carriageway features (widths and type of on-street parking, central median and carriageway widths available for moving traffic) and summarised in a table as presented in Table CAP-RED.

TABLE CAP-RED

REDUCTIONS IN CAPACITIES OF LINKS UNDER STUDY

LINK	P	W1	W2	W3	W4	W5	PCt (A)	DCt (B)	Qmax(C)	C/A(%)	C/B(%)
L1	A A	20.00	3.60 4.00	2.50 2.30	1.00	6.60	0.3507	0.6635	0.3131	89	47
L2	A A	23.15	2.45 4.90	2.30 2.40	0.00	11.1	0.5716	0.8411	0.2151	38	26
L3	F A	18.25	2.50 4.85	2.30 2.30	0.00	6.30	0.3141	0.362	0.27072	86	75
L4	A A	16.50	3.35 4.00	2.30 2.20	1.05	4 60	0.2227	0.5224	0.03637	16	7

Where:

P = Parking type along both kerblines
F = Flush parking
A = Angle parking
P = Perpendicular parking
W1 = Total width of carriageway (m)
W2 = Width of carriageway occupied by legal parking (m)
W3 = Width of carriageway occupied by double or illegal parking (m)
W4 = Width of central median (m)
W5 = W1-(W2 + W3 + W4) = Width of carriageway available for moving traffic (m)
PCt = Theoretical capacity of the link's carriageway width physically available for moving traffic (pcu/s)
DCt = Design theoretical capacity (pcu/s)
Qmax = Maximum flow or Qmax (pcu/s)

Overall, the maximum flow (Qmax) values ascertained that links with higher geometrical features, such as dual carriageway and wider carriageway widths available for moving traffic in link L1, carried higher flows than dual carriageway links with less widths for moving traffic such as link L4.

Availability of wider carriageway widths for moving traffic in link L1 than in link L4 contributed to link L1 having higher a maximum flow (Qmax) value than link L4 despite the fact that both links were dual carriageway and hence had similar geometrical features.

With illegal and double parking that was prevalent during the study period (occurring on this link during 89% of the survey time), Link L1 had in effect 6.6m wide carriageway available for both directions of moving traffic. This 6.6m carriageway was composed of two segregated (by a central median) 3.0m and 3.6m carriageway widths catering for the opposing traffic flows.

On the other hand, there was double and illegal parking on link L4 during 97% of the survey period. Thus, in effect, link L4 had a 4.6m wide carriageway available for both directions of moving traffic. This 4.6m carriageway was composed of two segregated (by a central median) 2.05m and 2.55m carriageway widths catering for the opposing traffic flows.

Carriageway width was a geometrical standard that resulted in link L4 having lower maximum flows than link L1 in that motorists in link L4 hardly had adequate driving space to physically accommodate their vehicles. Thus, fewer motorists entered and left link L4 than link L1 during a given time period, hence the lower maximum flow in link L4 as compared to link L1. Highway Capacity Manual states that a 3.65m width of carriageway is the standard size of a traffic lane required to adequately cater for driving and it's associated activities of manoeuvring for example.

Dual carriageway features of link L1 facilitated higher maximum flows than simple two way unseparated traffic links L2 and L3 under similar prevailing traffic conditions in that the dual carriageways had no right turning traffic. Hence, there was no impedance to traffic flow due to factors such as motorists having to slow down or stop while a leading vehicle was awaiting a gap in the opposing traffic stream so as to make a right turn.

The impedance to traffic flow (due to right turning traffic on two way links L2 and L3 where opposing traffic was not separated) resulted in less maximum flow (Qmax) values than on dual carriageway link L1 in that within the given period of time when a motorist was awaiting to make a right turn on link L2 and L3, the road space available for moving traffic was virtually reduced by one lane at the portion of the road where this motorist was temporarily stopped.

Also, although the widths of carriageway available for moving traffic were similar in links L1 and L3, the maximum flows were less in link L3 than in link L1 due to restrictions of right turning traffic intending to get into parking space along the opposite kerbline on link L3. The right-turning traffic 'locked' and introduced temporary stoppages of all movements through the 'intersections'. Even when locking did not occur, right- turning traffic did cause loss of capacity due to the temporary stoppages.

Despite link L1 having the highest maximum flow (Qmax) value as compared to the other links under study, free flow speed (Uf) value on link L1 was not the highest achieved during the study.

Dual carriageway links L1 and L4 were expected to exhibit higher free flow speeds than simple two way links L2 and L3 where opposing traffic was not segregated since motorists on the dual carriageway links were expected to travel without impedances or temporary stoppages resulting from right turning traffic). The temporary stoppages increased travel time for various drivers and hence reduced traffic speeds.

The lower than expected free flow speed (Uf) exhibited by link L1 was as a result of restrictive prevailing traffic conditions on the link caused by the combination of the high flows and double or illegally parked vehicles. Traffic flow is a prevailing traffic condition and the flows carried on link L1, being higher than those on the other links, caused most interference to traffic stream characteristics on a carriageway width already restricted (to below standard traffic lane widths) by double and illegally parked vehicles.

Higher geometrical standards of link L1 (in terms of dual carriageway and carriageway width available for moving traffic), in comparison with links L2, L3 and L4, were also confirmed by the slopes of the links' speed flow curves. Out of all the links, link L1 had the lowest slope of the speed flow curve.

5.2 Speed density relationships

This study's speed density relationships presented in Appendix DA-SD were similar to the speed flow curves presented in Appendix DP-SF and discussed in the preceding section in that in the upper range speeds decreased with increasing flows and densities. However, densities continued to increase past the points of critical speeds, whereas flows decreased.

Traffic density is the number of vehicles in a particular length of roadway at a particular moment. Usually, it is expressed in vehicles per kilometre. Although an instantaneous value, it is also possible to average successive observations over a period of time. Thus, if vehicle counts were made each minute for an hour, the arithmetic mean would express the average density for the hour.

Overall, the speed density relationships presented in Appendix DA-SD indicated that, as the concentration increased, the speed of traffic decreased. In other words, as the density increased, saturation condition of vehicle road occupancy also increased till each vehicle was nearly bumper to bumper with the vehicle in front. Expressed in terms of vehicle spacings, increases in concentration resulted in decreases in spacings between vehicles. Thus, this study's results were in agreement with the general relationship between spacing and density, which is as follows:

$$\text{Average spacing} = \frac{1}{\text{Density}}$$

where:

> density is expressed in vehicles/unit length of roadway and average spacing is expressed in length of roadway/vehicle.

Thus, each study link's traffic densities, when alternatively expressed in terms of spacing, affected each individual road user in that the spacings gave the driver travelling within the traffic stream his sense of freedom of movement or congestion and of relative safety, and continually affected his choice of speed and position of vehicle.

Each driver's decisions in weaving, merging, passing and car-following operations were thus predicted on his judgement of suitable gaps (spacings) between vehicles. The frequency and length of gaps (spacings) also governed the driver's ability to enter or cross the traffic stream in question.

Because spacings greatly affected the individual vehicle operation, the driver's reactions under various conditions had profound effects on traffic speeds.

Spacing can be measured in terms of either distance or time respectively, known as distance headway and time headway. Headways are fundamental to all traffic operations and control, and to vehicle manoeuvres including those of overtaking, lane changing and intersection operation.

As a faster moving vehicle approaches a slower one, the driver of the rear vehicle will, at some critical point, decide either to reduce speed, until the relative speeds are zero and trailing occurs, or to change lane and overtake if sufficient sized gaps are present in an adjacent lane. The headway at which the following driver is influenced by the preceding vehicle is known as the interference headway (Hobbs, 1974).

Depending on the widths of carriageway available for moving traffic during this study, each of links L1 and L4 was equivalent to a two traffic separated one-way lanes whereby opposing traffic flows did not interfere with each other while links L2 and L3 were, respectively, three-lane and two-lane two-way roads.

Consequently, on links L2 and L3, queues of vehicles started to form behind slower moving vehicles as soon as the headway in the opposing lane fell below a minimum requirement for overtaking. Also, as flows increased, the proportion of suitable sized headway above the required limit also fell. In other words, increasing flow on any lane required more frequent overtaking to maintain individual speeds but there was a reduction in the availability of headway gaps to accommodate these.

Overall, traffic speeds decreased with increasing densities for all the links under study as described in the preceding paragraphs. However, the rates of speed decrease with concentration varied from link to link as presented in Table SD-PAR.

TABLE SD-PAR

LINK SPEED DENSITY CHARACTERISTICS

LINK	Uf	Kj	dU/dK
L1	6.3714	0.19658	32.4127
L2	9.2929	0.09260	100.3511
L3	17.260	0.06272	275.2131
L4	5.9369	0.02451	242.2206

where:

Uf = Free flow speed (m/s)
Kj = Jam concentration (pcu/m)
dU/dK = rate of decrease of speed with density

As already stated elsewhere in this section, traffic speeds decreased with increasing concentrations for all the links under study. However, the rates of speed decrease with increasing concentration varied from link to link in accordance with the physical features of the road. For example, the slopes were steeper for link L3 which was two-way and narrower (carriageway width available for moving traffic being 6.3m), but more gradual for link L1 which was a dual carriageway and wider (carriageway width available for moving traffic being 6.6m).

Table SD-PAR indicated that this study's speed density relationships not only showed link to link variations of rate of decrease of traffic speeds with density, but also link to link variations in stationery jam concentrations (Kj).

The jam concentrations ranged from 0.02451 to 0.19658 pcu/m in links L4 and L1 respectively. O'flaherty (1986) states that when a traffic jam is stationery, vehicles actually don't touch each other physically and the jam concentration under this situation is 190 to 210 vehicles per kilometre (or 0.271 to 0.300 pcu/m). Thus, this study's established jam concentrations were in agreement with past studies on speed density relationships.

Except for link L1 which showed exceptionally high jam densities, there were link to link variations in jam concentrations. Link L2, L3 and L4 jam concentrations were 0.09260, 0.06272 and 0.02451 pcu/m respectively while the carriageway widths available for moving traffic were 11.1m, 6.3m and 4.6m respectively. Thus, the jam concentrations for these three links varied in accordance with link carriageway widths physically available for moving traffic. The higher the carriageway width available (and hence the more the physically available road space) for moving traffic the higher the stationery jam concentrations.

The speed density models established during this study and presented in Table DA-SD were also in agreement with past studies findings. Highway Capacity Manual (1988) states that speed density relationships are generally linear for densities of 20 to 160 vehicles per mile (or 0.01786 to 0.14286 pcu/m). This study's speed density relationships were linear and the densities were within this range.

Table SD-PAR also indicated that this study's speed density relationships not only showed link to link variations of rate of decrease of traffic speeds with density, but also link to link variations in free flow speeds (Uf).

As already discussed elsewhere in this section, drivers' reactions under various conditions have effects on vehicular speeds. Thus, drivers on carriageways that were dual and wide such as link L1 expected less marginal interferences and maintained shorter headway than drivers on two-lane two-way carriageways such as link L3. Consequently, speeds of vehicles on the former carriageway decreased less rapidly with increasing flow than on the latter carriageway.

Speeds of vehicles also decreased less rapidly with increasing widths of carriageway available for moving traffic. Vice versa, enhanced restrictions of carriageway width available for moving traffic resulted in enhanced decreases in traffic speeds. For example, although both were two-way links, the rate of decrease of traffic speeds with densities was greater for link L3 as compared to link L2.

These links' carriageways widths available for moving traffic were 6.3m and 11.1m for links L3 and L2 respectively. Thus, link L3 had the lesser carriageway width available for moving traffic and hence higher traffic densities (and lesser vehicle spacings). Consequently, link L3 vehicles in the opposing traffic had more difficulty in overtaking than vehicles in link L2 resulting in enhanced rates of decreases of traffic speeds with density in link L3 than in link L2.

5.3 Speed density models

The speed density regression models in Appendixes DA-M1 indicated that:

- Overall, 93% of the study area's traffic speeds were accounted for by the area's traffic densities.

Sandy (1990) states that when data that is obtained by field observations accounts for at least 50% of a regression model, the results are generally acceptable. Hence this study's regression models were generally acceptable.

The regression models presented in Appendixes DA-M1 had unexplained parts or parts that were not accounted for by the regression variables. The unexplained part of a regression model is obtained by subtracting the (r) squared value from 1. The (r) refers to simple linear regression analyses correlation coefficients, as stated in the data analysis chapter.

The unexplained parts of the speed density regression models were due to factors such as differing human characteristics. This study's data included both peak and off-peak traffic, hence contained a variety of drivers, some driving intently on rush hour trips and others driving more casually on midday errands.

Thus, this study's traffic streams were not homogeneous with regard to drivers' differing characteristics. The study's traffic streams were also not homogeneous with regard to influences of vehicle performance characteristics, operational controls and environmental factors. Consequently, all flow rates for each of the links under study, including maximum flows, were affected by a number of other factors in addition to the differing human characteristics.

However, the basic determinant of the traffic stream characteristics is the driver and the summation of control decisions made by a group of drivers under the particular roadway, traffic stream, and environmental conditions (Carter, 1982).

For the same regression models presented in Appendices DA-M1, analysis of variance showed that t-ratios for all independent variables were greater than 2. Thus, all independent variables in these models had significant effects on the dependent variables.

Evaluation of the overall performance of the speed density regression models showed that, apart from the regression variables, there were no other unique characteristics during the study period that affected traffic stream characteristics. Existence of such unique characteristics would have required separate analysis of the particular data that showed deviation, so as to establish causes of the deviation.

5.4. Parking indices and traffic congestion

The speed density and speed flow models described in the preceding sections were derived by analyzing speed and flow data. Analysis was also done for the parking usage data and the results indicated that, overall, Nairobi central area's parking indices were greater than one for 52% of the survey time for the links under study.

Parking indices greater than one indicated that, on the links under study, there existed double or illegal parking. Moreover, the objective of parking meter schemes is a peak occupancy (parking index) of 85%, implying that Nairobi central business area's parking meter scheme had failed.

Existence of parking indices greater than one was caused by factors related to Nairobi central business area's parking policy during the study period. For example, the area's parking policy encouraged long-term parking, resulted in preferred usage of on-street parking space as opposed to off-street parking space and was not adequately enforced, all of which factors contributed to Nairobi central business area's traffic congestion as discussed below.

The parking duration survey indicated that 78% of the legal on-street parking space on the links under study was occupied by long-term parkers while the remaining 22% legal parking space was occupied by medium- and short-term parkers.

Long-term parkers are generally car commuters that travel to and from their work places in the central business areas during the morning and evening peak periods thereby increasing total traffic on the streets and consequently contributing to the areas' peak traffic congestion, as already stated in section 2.3.

Long-term parkers generally remain in physical occupation of parking space for time periods of up to eight hours and they are normally people who drive their cars to and from work places at peak periods with no use of the cars in between these times. On the other hand, short- and medium-term parkers generally remain in physical occupation of parking space for time periods of up to four hours and are composed of shoppers and visitors whose trips to the centre means added prosperity to the centre.

Long-term parkers occupied 78% of the legal parking space on the links under study. In the Nairobi central business area, office activities generally start earlier than short- and medium-term parking related activities such as shopping. Thus, long-term parkers generally arrived in the Nairobi central business area earlier than medium- and short-term parkers. Consequently, the long-term parkers had an advantage over medium- and short-term parkers in getting legal parking space.

The above mentioned long-term parking activity on the links under study resulted in only 22% of the legal parking space being available to medium- and short-term parkers. Consequently, the medium- and short-term parkers were not adequately catered for by the legal parking space, as manifested in the total parking usage that was greater than supply for 52% of the study time.

Thus, Nairobi central business area's parking policy promoted long-term parking with the result that, for 52% of the study period, short- and medium-term parkers had either to keep moving on the area's roads looking for legal parking space or illegally parked all of which factors contributed to traffic congestion.

Usage of the area's road network by motorists in search of legal parking space increased total numbers of vehicles on the streets (traffic densities) while the double and illegally parked vehicles interfered with the flow of traffic all of which factors ultimately led to traffic congestion.

The Nairobi central business area's parking policy resulted into traffic congestion not only by encouraging long-term parking, but also by resulting in preferred usage of Nairobi City Council on-street, as opposed to off-street, parking space.

This parking policy's charges were equal at both Nairobi City Council operated on- and off-street parking facilities during the study period. These charges encouraged preferred usage of on-street, as opposed to off-street parking space, since the kerb was the most convenient place to park for the driver.

This preferred usage of on-street parking space increased the total number of vehicles, or traffic densities, on the streets thereby contributing to Nairobi central business area's traffic congestion.

Nairobi central business area's parking policy also contributed to the area's traffic congestion by not having adequate enforcement mechanisms to address to illegal or double parking that was prevalent during the time of this study as a result of unavailability of legal parking space.

The area's parking policy's enforcement level was inadequate in that there was double and illegal parking on the links under study. Elliot (1979) states that where meter schemes have been introduced, enforcement of a reasonably high standard can be achieved. Also, Her Majesty's Stationery Office (1965) states that the best method of enforcing rules in controlled parking zones is by traffic wardens.

Nairobi City Council's traffic wardens, commonly referred to as city askaris, supervised on-street controlled parking spaces within the Nairobi central business area and issued fixed penalty notices. However, during the study period, the askaris had no powers over towing away of vehicles that were double and illegally parking, and hence causing traffic congestion by obstructing moving traffic.

Towing away of vehicles that were double and illegally parked was under the jurisdiction of the traffic police, and they were hardly available so as to ensure that there were no illegally parked vehicles. Consequently, illegal parking in Nairobi central area was rampant as evidenced by parking indices that were greater that one for 52% of the time under study.

Parking indices greater than one not only indicated that the parking policy had failed and that there was double and illegal parking on the links under study, but also a general congestion phenomena.

Existence of double or illegal parking generally lead to traffic congestion since the parked vehicles occupied at least one lane of road space meant for moving traffic. This activity created an impedance to traffic flow since only 6.6m, 11.1m, 6.3m and 4.6m wide carriageways were available for moving traffic along links L1, L2, L3 and L4 respectively.

Overall, double and illegal parking reduced the capacities of the links under study to 63% of the design capacity. This figure was based on widths of carriageway physically available to moving traffic.

Restrictions of carriageway widths available for moving traffic, due to parking related activities, decreased overtaking opportunities which consequently reduced speeds of vehicles. For example, on dual carriageway links L1 and L4, motorists desiring to overtake could not do so in practice since the carriageways available for moving traffic only ranged from 2.05m to 3.6m.

These widths of carriageways could only practically accommodate a single traffic lane and hence trailing had to take place and at the speed of the leading vehicle. Consequently, the times lost while drivers desiring to overtake could not do so amounted to losses in average speeds. Trailing not only led to reduced average traffic speeds, but also resulted in increased traffic densities and ultimately led to traffic congestion. Whenever the average vehicular speeds fell below critical speed (Cs) values, motorists were driving under conditions of traffic congestion.

The effects of on-street parking usage (when measured in terms of parking indices) on traffic speeds on the links under study are presented in Appendix PI-SP-RED.

Overall, there were speed decreases with increasing parking indices. Increasing parking indices were an indication of decreasing carriageway widths available for moving traffic and hence increasing traffic densities. Consequently, increasing parking indices decreased spacings between vehicles which in turn decreased opportunities for overtaking and ultimately decreased average vehicular speeds. When the parking indices exceeded one, the speeds fell below critical speed (Cs) values and the motorists drove under conditions of traffic congestion.

6.0 CONCLUSION

Nairobi central business area's parking policy was not adequate during the study time. One objective of parking controls is to ensure that unoccupied parking space exists and is spread evenly so that motorists are not frustrated by being unable to find space to park. Parking meter schemes' objective is a parking peak occupancy, or peak parking index, of 85%.

However, this study established that Nairobi central business area's parking indices were less than this figure for only 34% of the time under study. Thus, motorists in need of parking were frustrated in that they had to travel extra mileage and loose time while looking for parking space.

Moreover, for 52% of the time, motorists in need of parking on the links under study could not get any legal parking space and hence had no choice but to illegally or double park contributing to traffic congestion.

This latter activity resulted in reductions in physical carriageway widths intended for moving traffic, reductions in traffic speeds, reductions in traffic capacities of links under study all of which factors resulted into the Nairobi central business area traffic congestion.

The double and illegal parking of vehicles, the cruising vehicles awaiting an opportunity to park and the high occupancy of kerb space was an indication of the need to impose in the study area improved parking management measures. Occupation of 78% of legal on-street parking space by long-term parking should be discouraged and on-street parking space be rationed so that preference is given to the people who are normally the life-blood of the Nairobi central business area, that is the shoppers and visiting business people.

The parking policy should also be strictly enforced to ensure that the illegal and double parking that occurred during 52% of the study time is discouraged. Consequently, physical widths of carriageway that were being occupied by double and illegal parking will be available for moving traffic and capacities of the links will on average increase by 37% of design capacity.

Relationships between parking usage (when expressed in terms of parking indices) and vehicular speeds generally indicated that when the parking indices exceeded one, the traffic speeds consequently decreased to below critical speed (Cs) values and motorists were driving under conditions of traffic congestion.

In summary, Nairobi central business area did not have an adequately positive policy for parking in that the parking indices were greater than one during 52% of the study period. Consequently, the results were increasing violation of traffic laws, increasing frustration to motorists due to inability to secure legal parking space, an environmental "disamenity" (or aesthetic deterioration) resulting from streets cluttered with stopped cars and traffic congestion.

APPENDIX LUS LINKS UNDER STUDY

LINK NAME	START	END	DIR	JN	SAMPLE LINK	LINK PREFIX
BANDA ST	LOITA ST	KOINANGE ST	2	SS		
BANDA ST	KOINANGE ST	MARKET LN	2	SM		
BANDA ST	MARKET LN	MU.MBINGU ST	2	MS		
BANDA ST	MU.MBINGU ST	P.HOUSE LN	2	SM		
BANDA ST	P.HOUSE LN	JAMIA ST	2	MM		
BANDA ST	JAMIA ST	WABERA ST	2	MM		
BANDA ST	WABERA ST	LIBRARY ST	2	MM		
BANDA ST	LIBRARY ST	KIMATHI ST	2	MS		
BIASHARA ST	KOINANGE ST	MU.MBINGU ST	2	SS		
BIASHARA ST	MU.MBINGU ST	MOI AVENUE	2	SS		
COUNTY RD	HARAMBEE AV.	COUNTY LN	2	SM		
COUNTY RD	COUNTY LN	REDCROSS LN	2	MM		
COUNTY LN	COUNTY RD	PARLIAMENT RD	1	SS		
H.SELASSIE LN	HARAMBEE AV	GICHAMU LN	1	SS		
H.SELASSIE LN	GICHAMU LN	H.SELASSIE AV	1	SS		
HARAMBEE AV	HARAMBEE LN	LT.TUMBO AV	2	MM	*	L3
HARAMBEE AV	LT.TUMBO AV	TAIFA RD	2	MM	*	L2
HARAMBEE AV	TAIFA RD	NKRUMAH LN	2	MM		
HARAMBEE AV	NKRUMAH LN	MOI AV	2	MH		
HARAMBEE LN	HARAMBEE AV	VV1	1	SM		
HARAMBEE LN	VV1	H.SELASSIE AV	1	MS		
KAUNDA ST	POSTA RD	PARLIAMENT RD	2	MM		
KAUNDA ST	KOINANGE ST	MU.MBINGU ST	2	MS		
KAUNDA ST	GEN.KAGO ST	WABERA ST	1	MS		
KAUNDA ST	WABERA ST	KIMATHI ST	1	SS		
KIMATHI LN	TUBMAN ST	KENYATTA AV	1	MM		
KIGALI ST	MU.MBINGU ST	P.HOUSE LN	1	SM		
KIGALI ST	P.HOUSE LN	KIMATHI ST	1	MH		

KOINANGE LN	LOITA ST	KOINANGE ST	1	SS		
KOINANGE ST	UNIVERSITY WAY	MONROVIA ST	2	HM		
KOINANGE ST	MONROVIA LN	MONROVIA ST	2	MM		
KOINANGE ST	MONROVIA ST	MO.DADDAH ST	2	MM		
KOINANGE ST	MO.DADDAH ST	NJUGU LN	2	MM		
KOINANGE ST	NJUGU LN	BIASHARA ST	2	MM		
KOINANGE ST	BIASHARA ST	TUBMAN ST	2	MM		
KOINANGE ST	MARKET ST	BANDA ST	2	MM		
LOITA ST	MONROVIA ST	KOINANGE LN	2	SM		
LOITA ST	KOINANGE ST	MARKET ST	2	MM		
LOITA ST	MARKET ST	BANDA ST	2	MM		
LOITA ST	BANDA ST	KENYATTA AV	2	MS		
LT.TUMBO AV	HARAMBEE AV	VV1	2	SM		
LT.TUMBO AV	VV1	H.SELASSIE AV	2	MS		
MAMA NGINA ST	MU.MBINGU ST	GEN.KAGO ST	2	MM		
MAMA NGINA ST	GEN.KAGO ST	WABERA ST	2	MS		
MAMA NGINA ST	WABERA ST	SIMBA ST	2	SM		
MARAGWA LN	TOM MBOYA ST	MOI LN	1	SS		
MARKET LN	MARKET ST	BANDA ST	1	SS		
MO.DADDAH ST	KOINANGE ST	MU.MBINGU ST	2	SS		
MO.DADDAH ST	MU.MBINGU ST	MOI AVENUE	1	SH		
MONROVIA ST	UU	LOITA ST	2	SM		
MONROVIA ST	LOITA ST	KOINANGE ST	2	MS		
MONROVIA ST	KOINANGE ST	MU.MBINGU ST	2	SS		
MONROVIA ST	MU.MBINGU ST	MOI AVENUE	2	SS		
MONROVIA LN	KOINANGE ST	MU.MBINGU ST	1	SS		
MONROVIA LN	MU.MBINGU ST	MOI AVENUE	1	SS		
MUINDI M.	UNIVERSITY WAY	MONROVIA LN	2	SM		
MUINDI M.	MONROVIA LN	MONROVIA ST	2	MM		
MUINDI M.	MONROVIA ST	MO.DADDAH ST	2	MM		
MUINDI M.	MO.DADDAH ST	NJUGU LN	2	MM		
MUINDI M.	NJUGU LN	BIASHARA ST	2	MM		

MUINDI M.	BIASHARA ST	TUBMAN ST	2	MM		
MUINDI M.	TUBMAN ST	KIGALI ST	2	MM		
MUINDI M.	KIGALI ST	MARKET ST	22	MM		
MUINDI M.	MARKET ST	BANDA ST	22	MM		
MUINDI M.	BANDA ST	KENYATTA AV	22	MH		
MUINDI M.	KENYATTA AV	STANDARD ST	22	HM		
MUINDI M.	STANDARD ST	KAUNDA ST	22	MM		
MUINDI M.	KAUNDA ST	MAMA NGINA ST	2	MM		
MARKET ST	KOINANGE ST	MARKET LN	1	SM		
MARKET ST	MARKET LN	MU.MBINGU ST	1	MS		
NJUGU LN	KOINANGE ST	MU.MBINGU ST	1	SS		
NJUGU LN	MU.MBINGU ST	MOI AVENUE	1	SS		
NKRUMAH LN	NKRUMAH AV	HARAMBEE AV	1	SS		
PARLIAMENT RD	HARAMBEE AV	COUNTY LN	2	HM		
PARLIAMENT RD	COUNTY LN	ST.JOHN'S GATE	2	MM		
PARLIAMENT RD	ST.JOHN'S GATE	RED CROSS LN	2	MM		
PARLIAMENT RD	RED CROSS LN	H.SELSSIE AV	2	MH		
PARLIAMENT RD	HARAMBEE AV	GICHAMU LN	1	SM		
PARLIAMENT LN	GICHAMU LN	H.SELASSIE AV	1	MS		
POSTA RD	KENYATTA AV	KUNDA ST	1	HM		
PLAY HOUSE LN	KIGALI ST	BANDA ST	1	SS		
RONALD NGALA LN	MOI AVENUE	TOM MBOYA ST	1	SS		
RED CROSS LN	COUNTY RD	PARLIAMENT RD	1	SS		
STANDARD ST	KOINANGE ST	MU.MBINGU ST	1	SS		
STANDARD ST	MU.MBINGU ST	WABERA ST	1	SS		
STANDARD ST	WABERA ST	KIMATHI ST	1	MS		
TAIFA RD	CITY HALL WAY	X7	2	SM		
TAIFA RD	X7	HARAMBEE AV	2	MS		
WABERA ST	BANDA ST	KENYATTA AV	2	MH		
WABERA ST	KENYATTA AV	STANDARD ST	22	MH	*	L4
WABERA ST	STANDARD ST	KAUNDA ST	22	MM		

WABERA ST	KAUNDA ST	MAMA NGINA ST	22	MM	*	L1
WABERA ST	MAMA NGINA ST	CITY HALL WAY	22	MH	"	"
TUBMAN RD	KOINANGE ST	MU.MBINGU ST	1	SS		
TUBMAN RD	MU.MBINGU ST	KIMATHI ST	1	SH		
TUBMAN RD	KIMATHI ST	KIMATHI LN	1	SM		
TUBMAN RD	KIMATHI LN	MOI AVENUE	1	MS		

KEY:

* - Sampled link
AV - Avenue
DIR - Direction of flow such that:
 2 - Two way link
 1 - One way link
 22 - Dual carriageway
GEN. - General
H. - Haille
JN - Junction types at end of link. Letters in this column stand for type of link at end junctions (at both ends of link). The letters mean the following:-
 S - Minor
 M - Major
 H - Shared
 For example, MS implies that a link is a major raod at one junction and a minor road at the other junction.
LN - Lane
LT. - Lieutenant
MO. - Moktar
MU. - Muindi
P. - Play
RD. - Road
ST - Street

APPENDIX DP – T1

Summary of Survey Data for Link L1

TIME START	TIME END	FLOW (pcu)	SPEEDS (m/s)	PARKING USAGE (spaces)
8.00	8.15	219	4.131	21
8.15	8.30	209	5.007	23
8.30	8.45	174	5.524	26
8.45	9.00	218	5.15	25
9.00	9.15	136	5.938	23
9.15	9.30	172	5.355	24
9.30	9.45	186	4.324	28
9.45	10.00	139	5.388	25
10.00	10.15	104	5.856	22
10.15	10.30	102	5.354	23
10.30	10.45	131	5.451	22
10.45	11.00	118	5.505	23
11.00	11.15	255	4.823	23
11.15	11.30	162	5.185	24
11.30	11.45	197	1.974	22
11.45	12.00	164	1.493	22
12.00	12.15	224	1.826	26
12.15	12.30	279	2.494	27
12.30	12.45	226	1.741	24
12.45	1.00	256	2.139	15
1.00	1.15	199	4.843	16

1.15	1.30	217	4.218	13
1.30	1.45	256	2.812	17
1.45	2.00	207	5.447	19
2.00	2.15	270	2.245	20
2.15	2.30	302	3.251	21
2.30	2.45	283	2.346	21
2.45	3.00	207	1.736	25
3.00	3.15	302	3.116	25
3.15	3.30	318	3.258	27
3.30	3.45	221	2.446	28
3.45	4.00	249	2.107	27
4.00	4.15	277	2.435	22
4.15	4.30	280	2.605	23
4.30	4.45	296	3.371	23
4.45	5.00	272	1.914	22

Appendix DP-T1

Summary of Survey Data for Link L2

TIME START	TIME END	FLOW (pcu)	SPEEDS (m/s)	PARKING USAGE (spaces)
8.00	8.15	159	3.411	12
8.15	8.30	179	6.51	15
8.30	8.45	219	4.658	17
8.45	9.00	198	5.599	19
9.00	9.15	172	6.328	19
9.15	9.30	230	4.597	18
9.30	9.45	204	3.518	19
9.45	10.00	190	3.914	16
10.00	10.15	209	4.157	19
10.15	10.30	219	5.076	19
10.30	10.45	212	4.894	18
10.45	11.00	208	4.6	20
11.00	11.15	224	4.762	20
11.15	11.30	191	3.884	23
11.30	11.45	152	6.281	22
11.45	12.00	178	5.937	19
12.00	12.15	211	4.497	16
12.15	12.30	206	4.794	18
12.30	12.45	202	4.302	15
12.45	1.00	132	6.878	14
1.00	1.15	124	7.068	15

1.15	1.30	120	7.502	13
1.30	1.45	151	6.073	15
1.45	2.00	179	5.924	17
2.00	2.15	142	6.2	17
2.15	2.30	139	2.446	19
2.30	2.45	128	2.101	23
2.45	3.00	126	2.099	18
3.00	3.15	121	2.001	19
3.15	3.30	123	1.997	21
3.30	3.45	126	2.018	18
3.45	4.00	133	2.223	21
4.00	4.15	139	2.387	19
4.15	4.30	158	3.331	20
4.30	4.45	163	3.029	15

Appendix DP-T1

Summary of Survey Data for Link L3

TIME START	TIME END	FLOW (pcu)	SPEEDS (m/s)	PARKING USAGE (spaces)
8.00	8.15	249	9.442	4
8.15	8.30	242	9.731	1
8.30	8.45	247	9.61	9
8.45	9.00	232	10.26	9
9.00	9.15	177	11.95	9
9.15	9.30	231	9.902	9
9.30	9.45	243	9.91	11
9.45	10.00	149	3.412	15
10.00	10.15	170	4.112	14
10.15	10.30	196	4.726	14
10.30	10.45	202	5.2	11
10.45	11.00	188	4.5	10
11.00	11.15	187	4.45	9
11.15	11.30	179	4.526	9
11.30	11.45	146	3.3	14
11.45	12.00	182	4.201	14
12.00	12.15	143	3.398	15
12.15	12.30	122	2.551	15
12.30	12.45	182	4.814	9
12.45	1.00	138	3.204	7
1.00	1.15	180	4.992	7

1.15	1.30	164	3.896	9
1.30	1.45	134	2.735	8
1.45	2.00	128	2.711	8
2.00	2.15	236	9.931	7
2.15	2.30	199	10.517	10
2.30	2.45	251	9.444	13
2.45	3.00	300	8.061	13
3.00	3.15	261	6.797	17
3.15	3.30	247	6.323	13
3.30	3.45	279	8.987	14
3.45	4.00	283	8.795	12
4.15	4.30	247	9.322	11

Appendix DP-T1

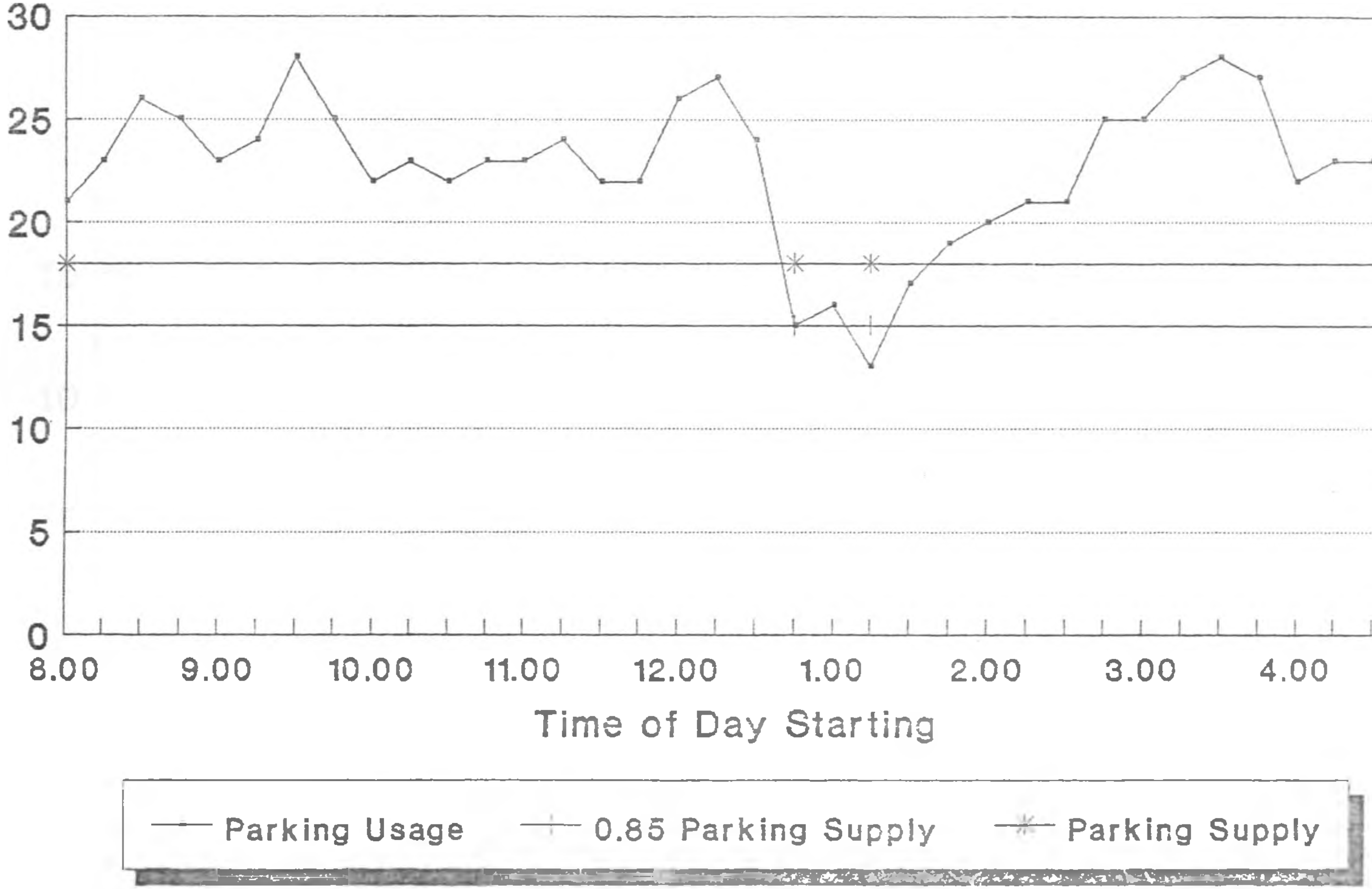
Summary of Survey Data Link L4

TIME START	TIME END	FLOW (pcu)	SPEED (m/s)	PARKING USAGE (spaces)
8.00	8.15	16	4.908	19
8.15	8.30	10	5.696	21
8.30	8.45	12	5.206	26
8.45	9.00	12	5.351	29
9.00	9.15	11	5.231	29
9.15	9.30	14	4.912	33
9.30	9.45	16	4.908	33
9.45	10.00	9	5.719	35
10.00	10.15	9	5.447	34
10.15	10.30	3	5.924	34
10.30	10.45	8	5.621	36
10.45	11.00	6	5.497	34
11.00	11.15	36	3.508	35
11.15	11.30	37	3.318	36
11.30	11.45	20	4.759	35
11.45	12.00	37	2.601	34
12.00	12.15	36	2.605	34
12.15	12.30	33	2.305	33
12.30	12.45	35	3.406	33
12.45	1.00	31	3.494	32
1.00	1.15	39	2.911	36

1.15	1.30	31	2.216	36
1.30	1.45	38	2.71	37
1.45	2.00	18	1.056	34
2.00	2.15	22	1.558	34
2.15	2.30	21	1.326	34
2.30	2.45	28	2.243	36
2.45	3.00	23	1.615	36
3.00	3.15	30	2.058	36
3.15	3.30	21	1.568	37

Appendix DP-P1

Variation of Parking Usage with Time
Link L1



All expressed in number of spaces

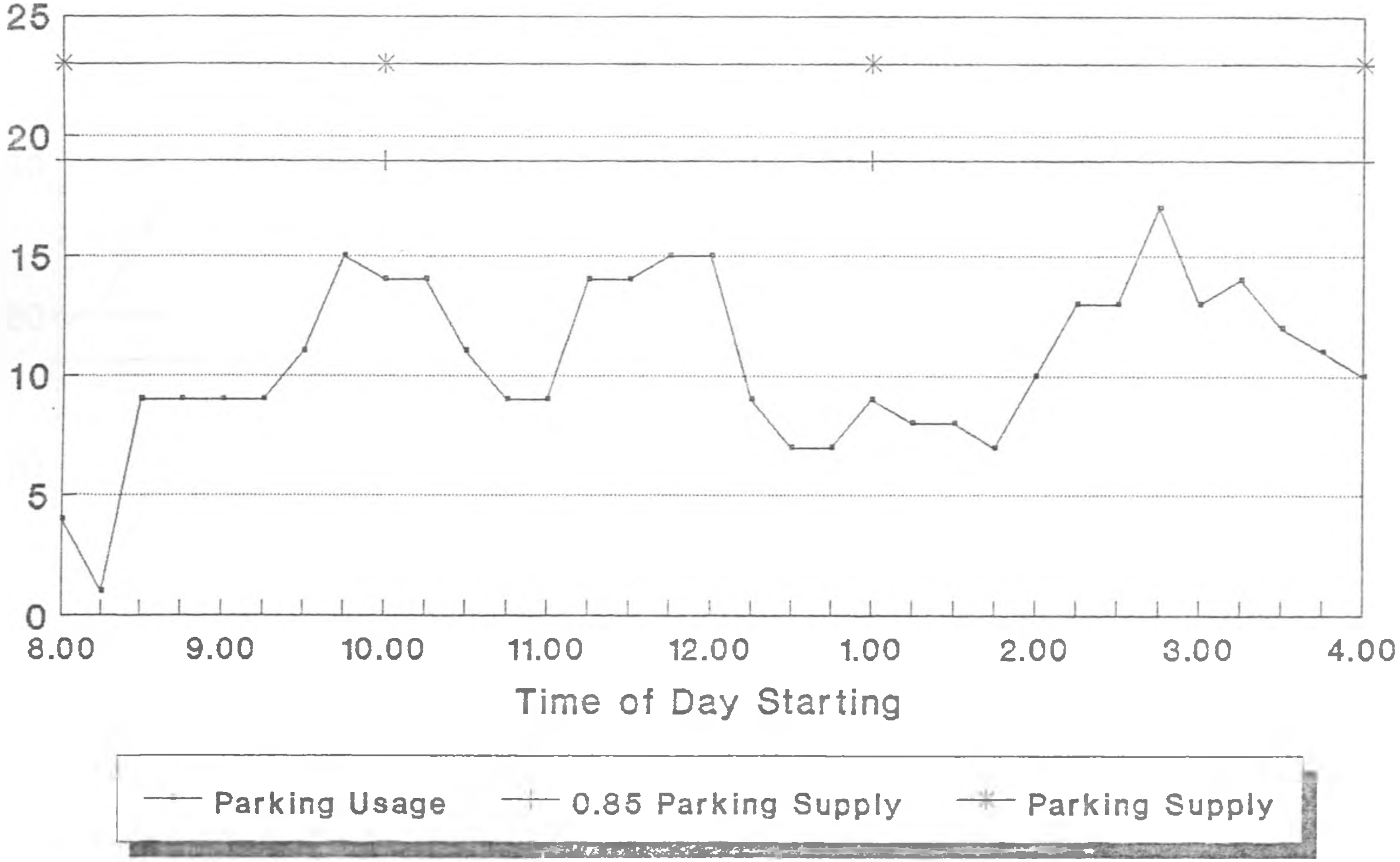
Appendix DP-P1

Variation of Parking Usage with Time Link L2

All expressed in number of spaces

Appendix DP-P1

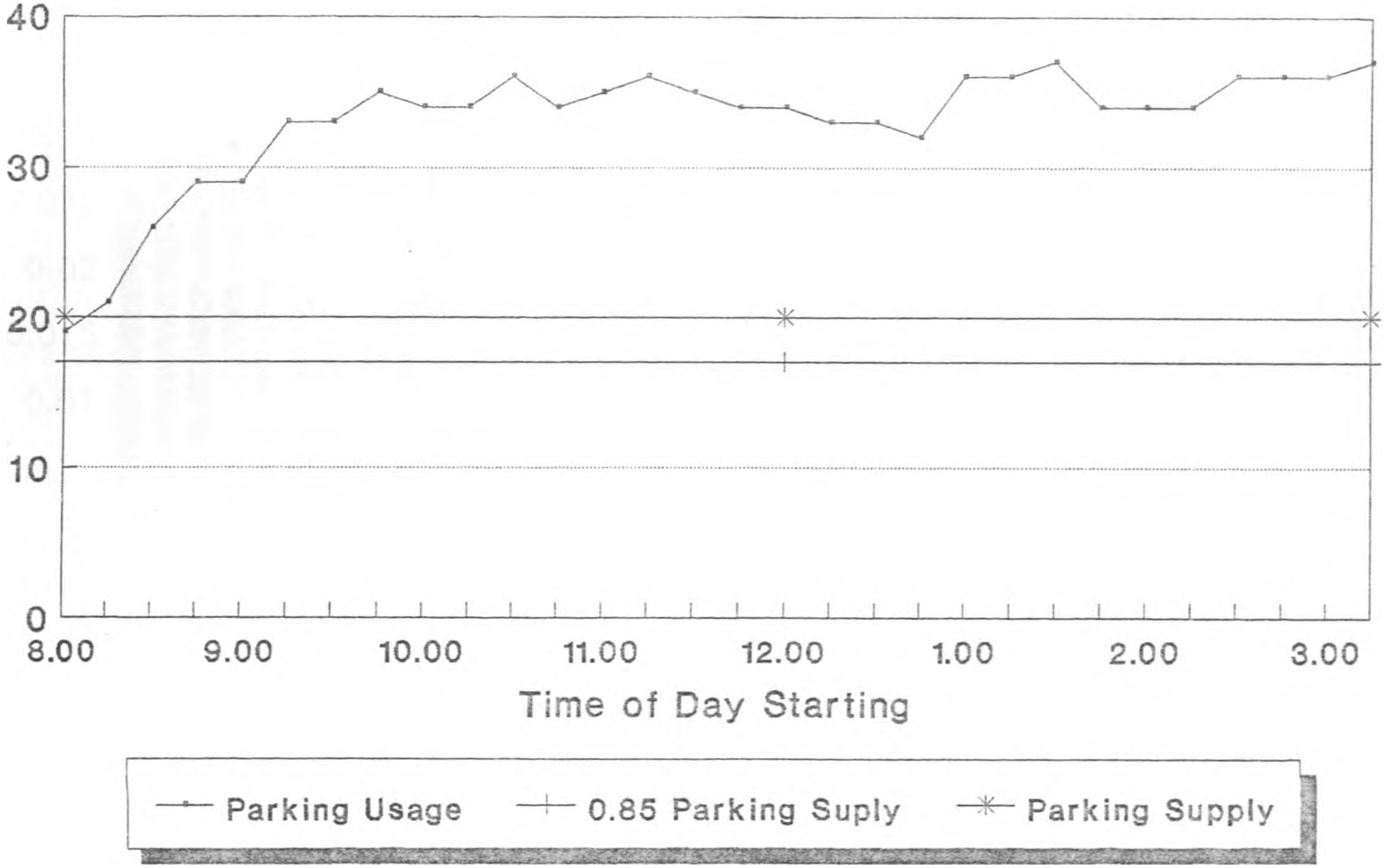
Variation of Parking Usage with Time
Link L3



All expressed in number of spaces

Appendix DP-P1

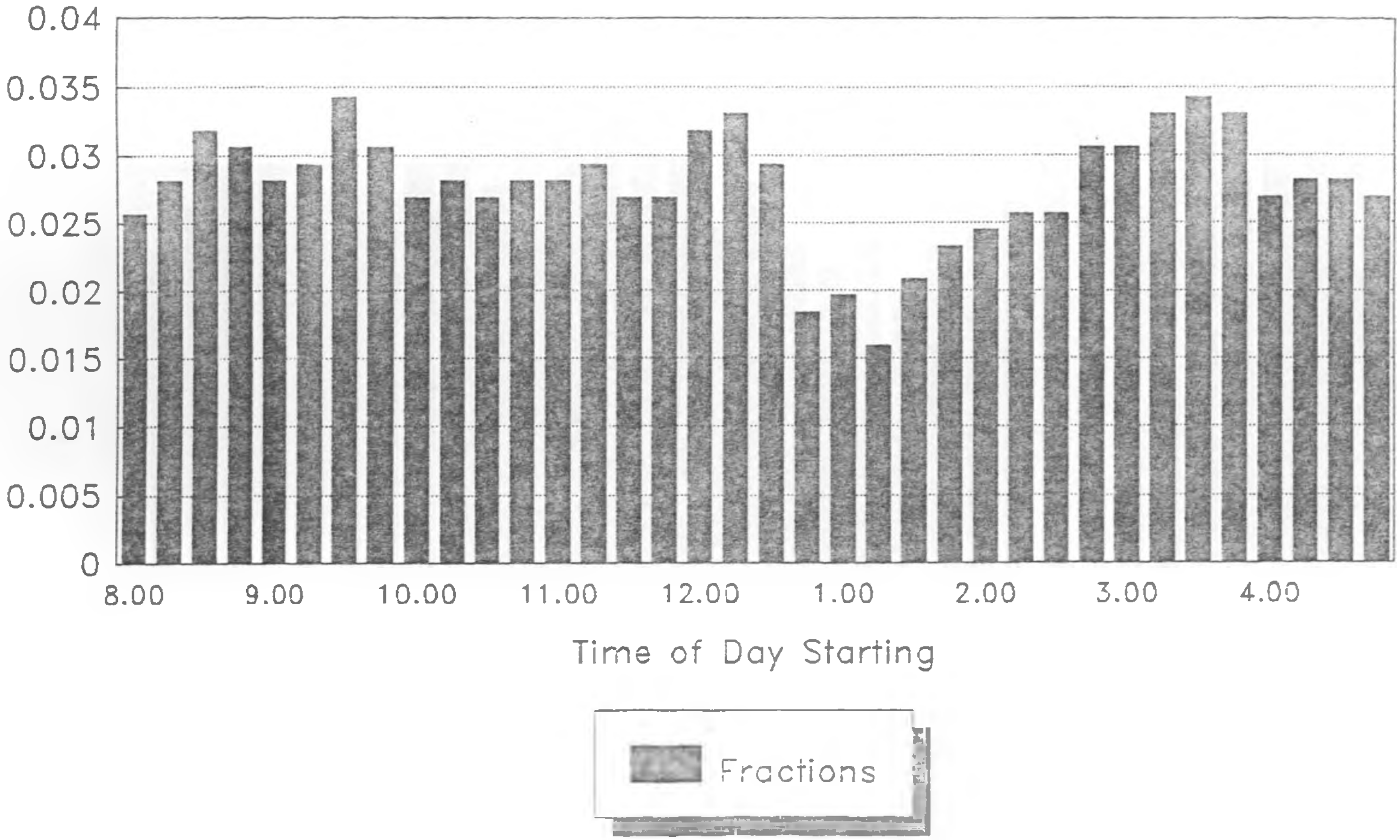
Variation of Parking Usage with Time
Link L4



All expressed in number of spaces

Appendix DP-P2

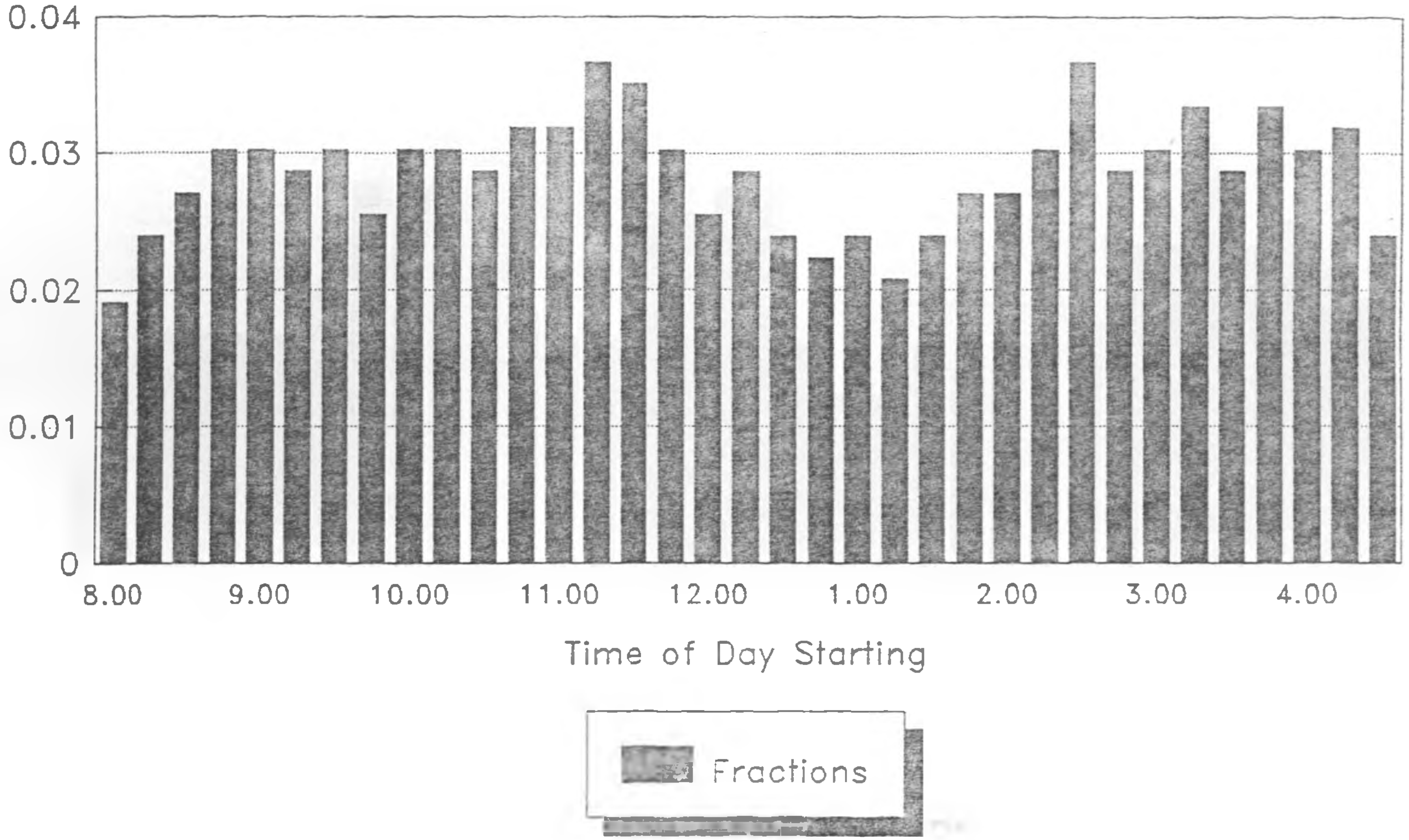
Fractions of Parked Vehicles
Link L1



Fractions are for vehicles parked during 15 minute period, in relation to total vehicles parked during the study period.

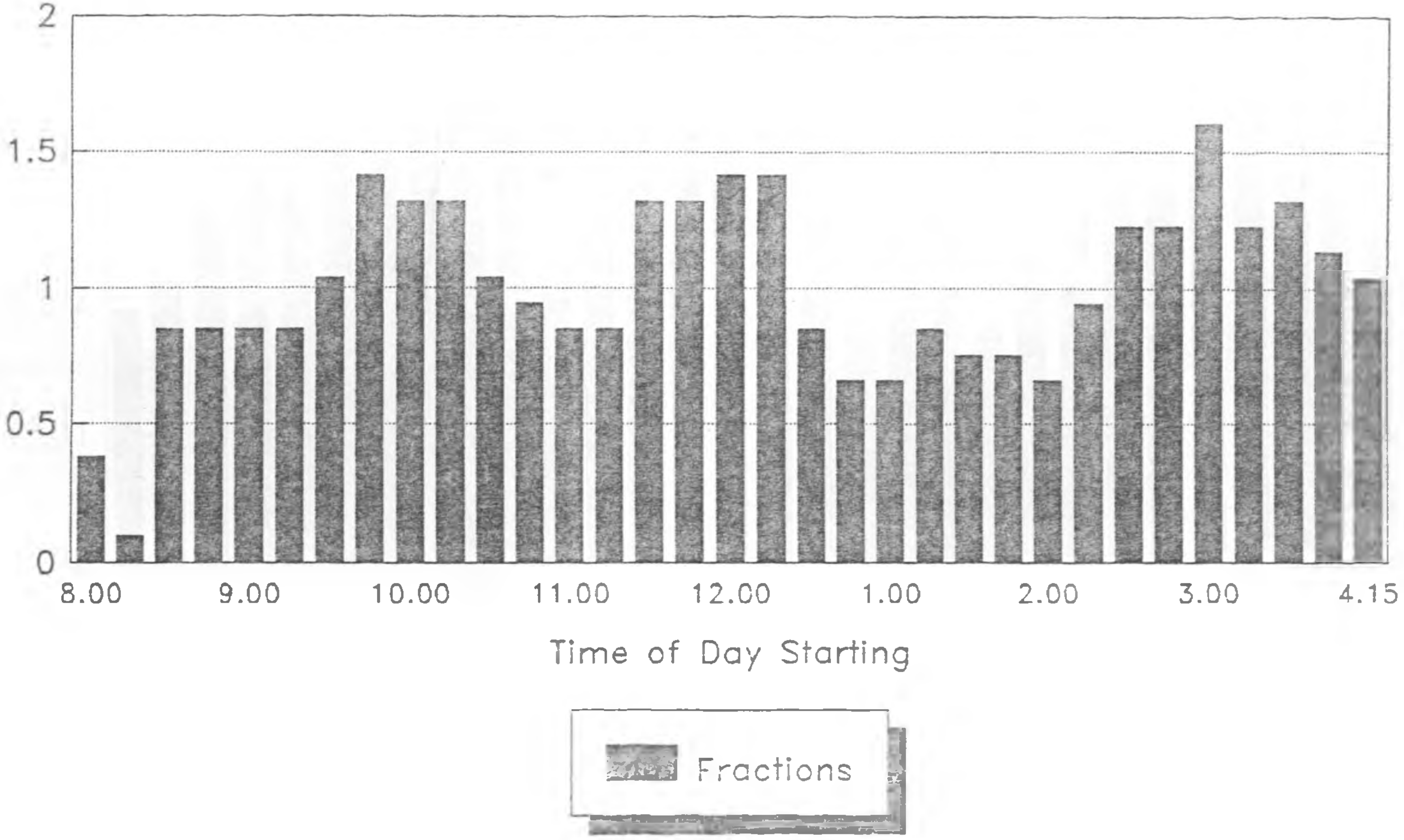
Appendix DP-P2

Fractions of Parked Vehicles
Link L2



Fractions are for vehicles parked during 15 minute period, in relation to total vehicles parked during the study period.

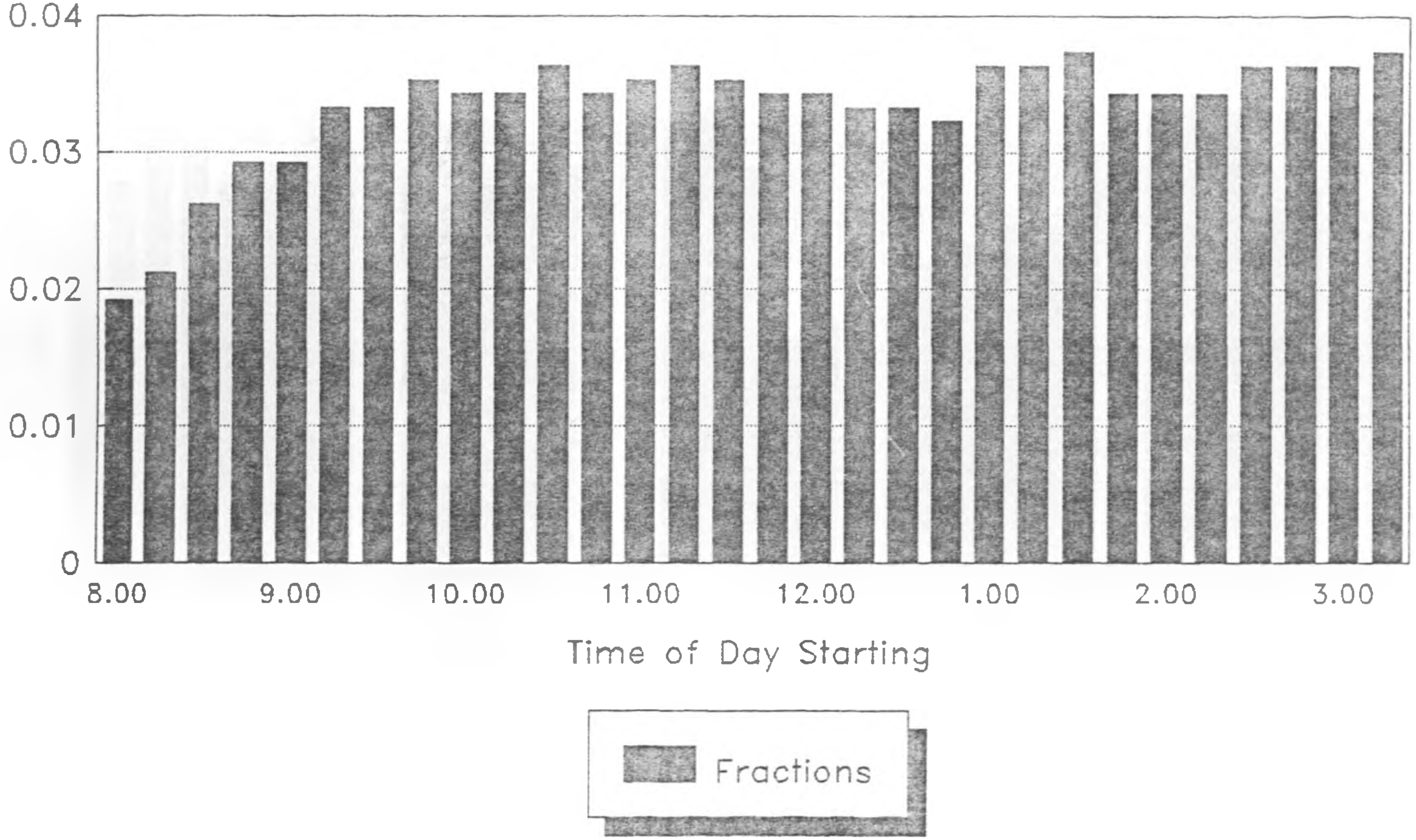
Fractions of Parked Vehicles
Link L3



Fractions are for vehicles parked during
15 minute period in relation to total
vehicles parked during the study period.

Fractions of Parked Vehicles

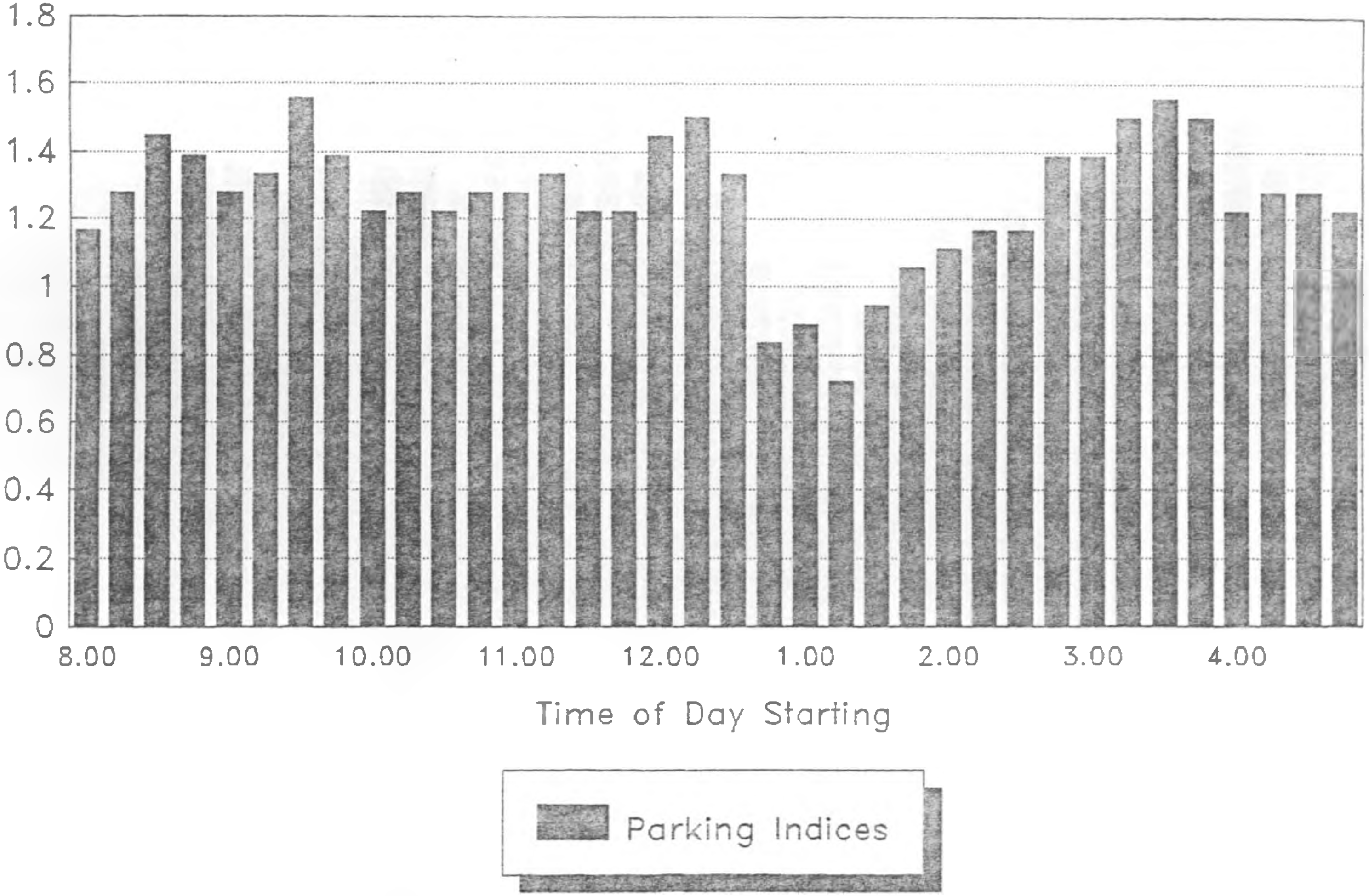
Link L4



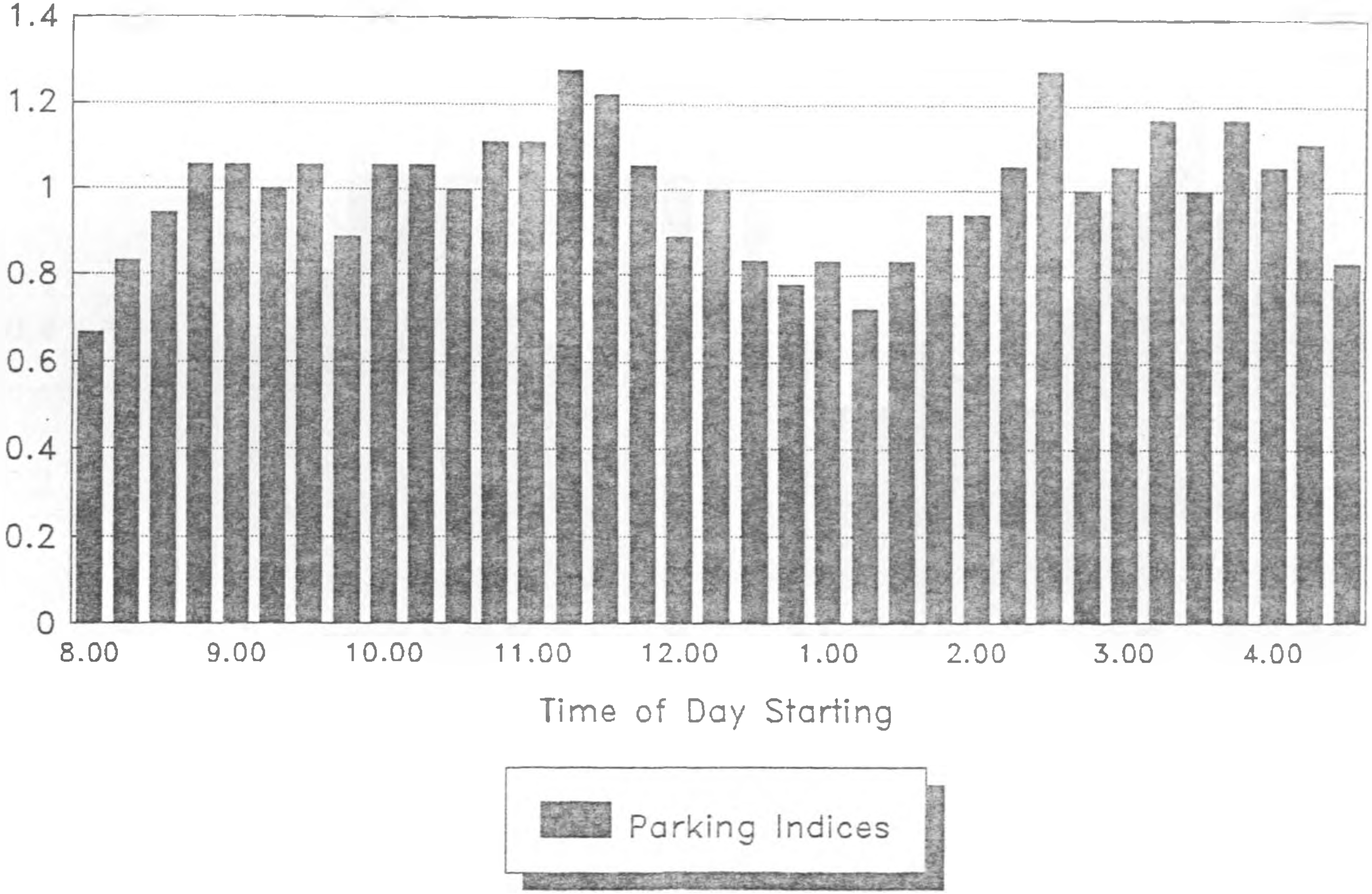
Fractions are for vehicles parked during 15 minute period, in relation to total vehicles parked during the study period.

Appendix DP-P3

Variation of Parking Indices with Time
Link L1

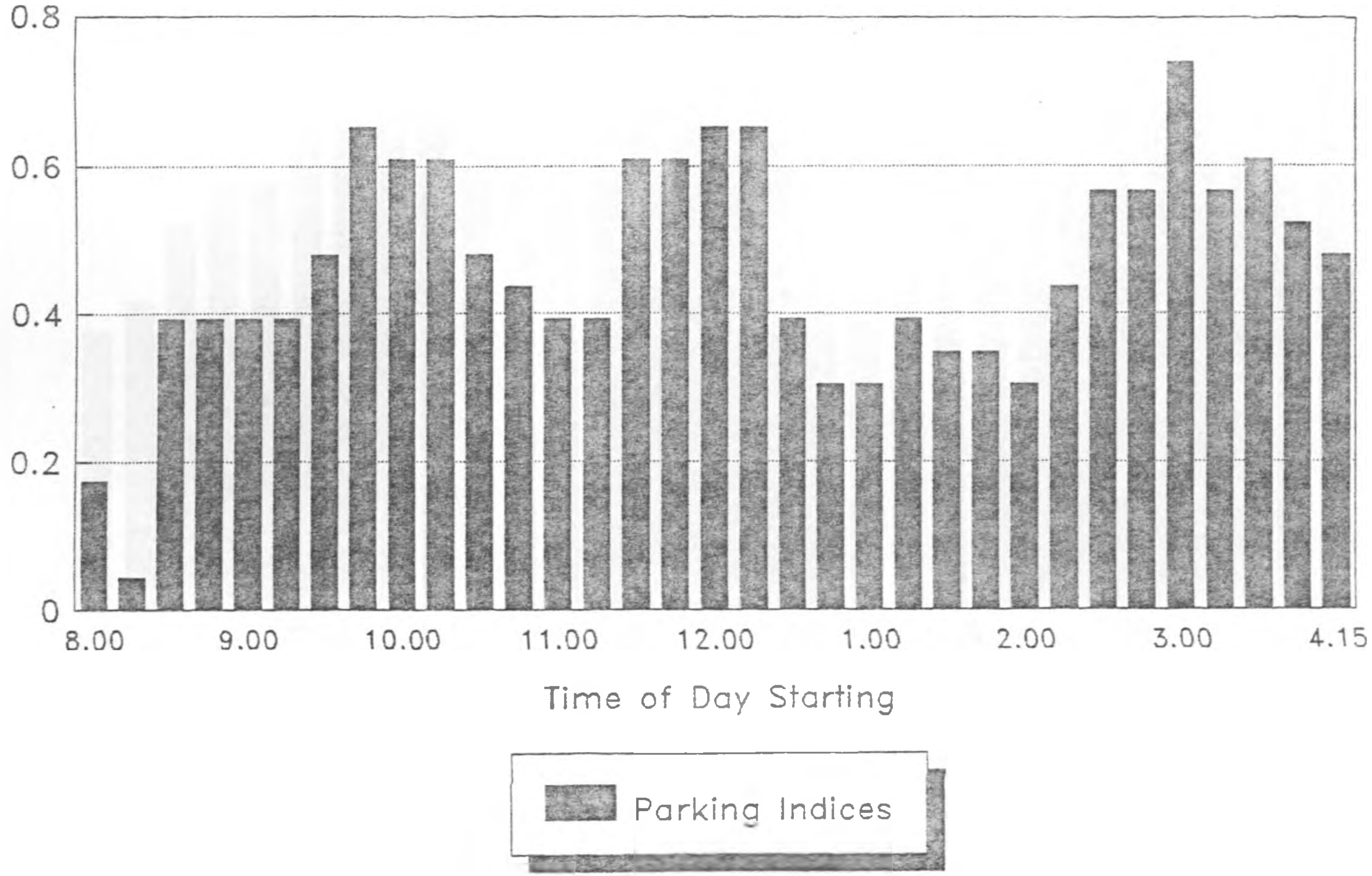


Appendix DP-P3 Variation of Parking Indices with Time
Link L2



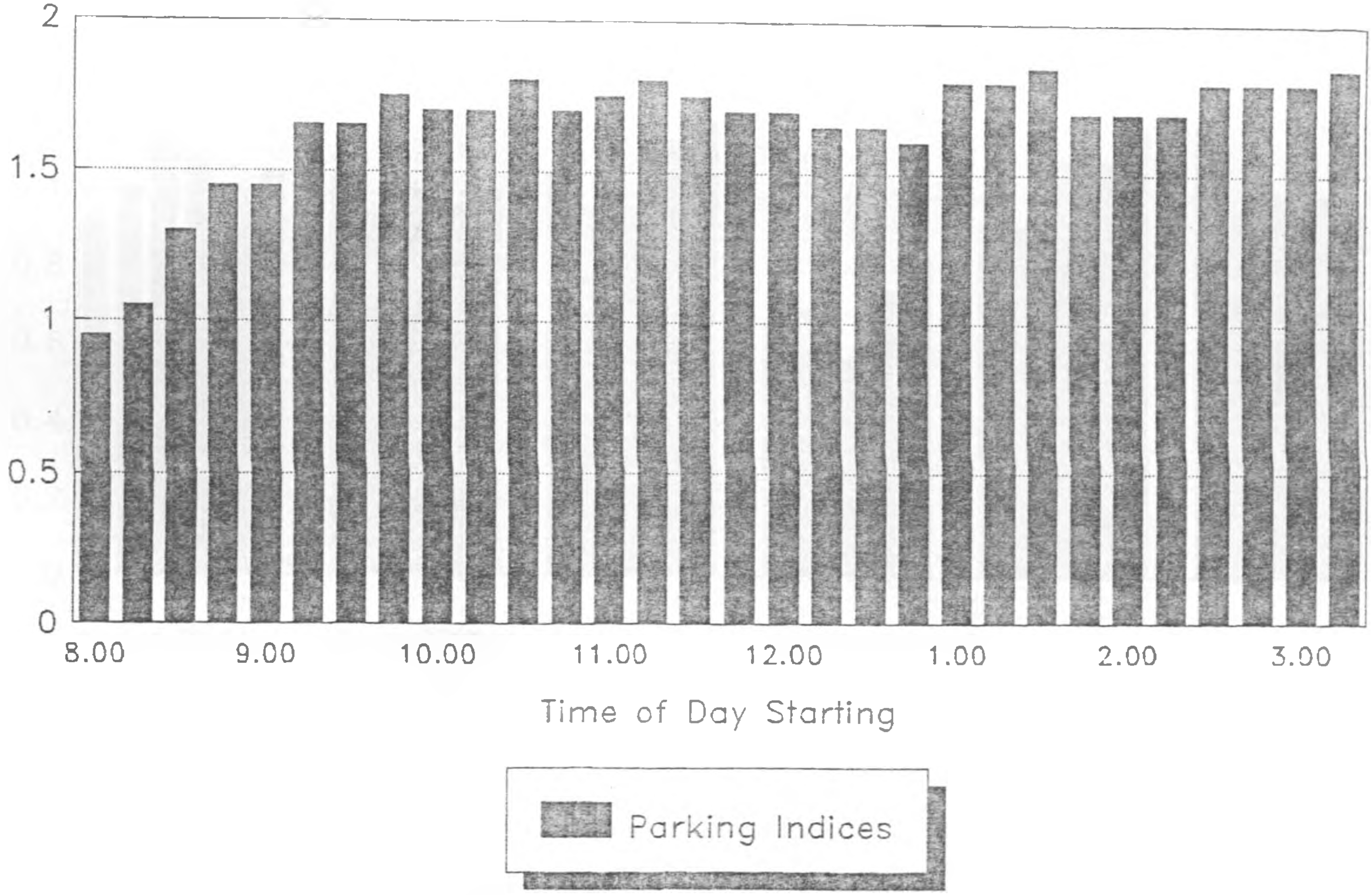
Appendix DP-P3

Variation Parking Indices with Time
Link L3



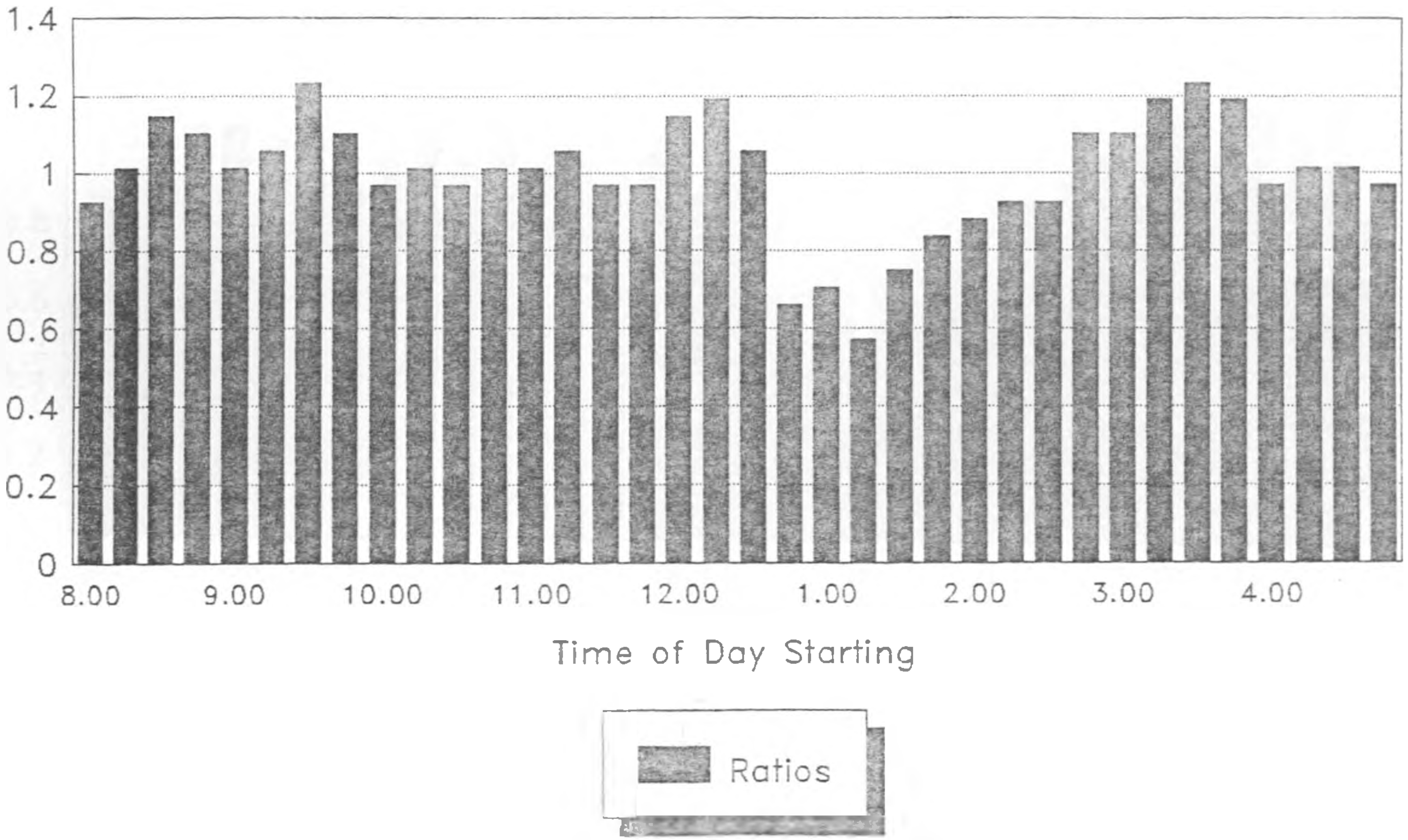
Appendix DP-P3

Variation of Parking Indices with Time
Link L4



Appendix DP-P5

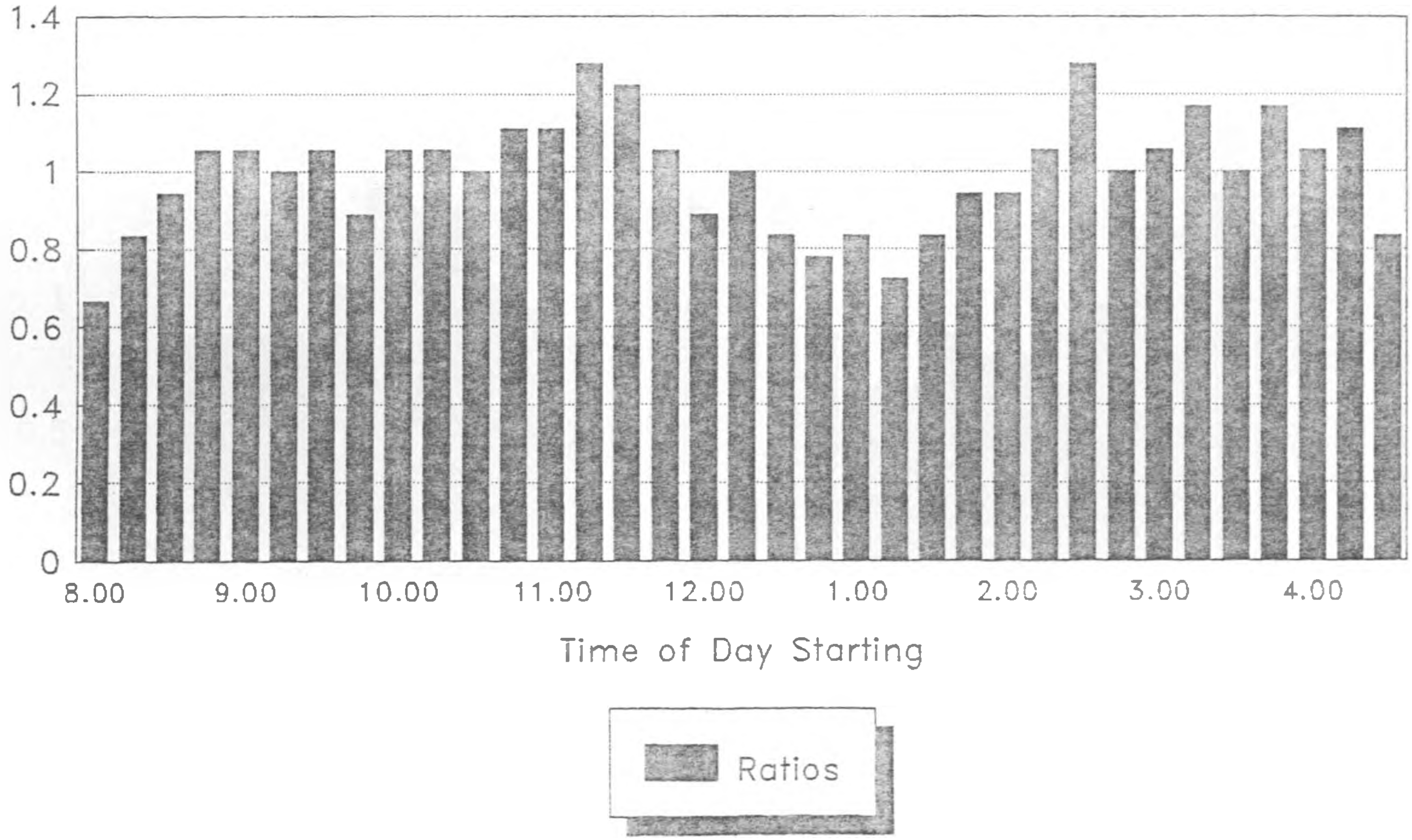
Parking Usage-to-Average Accumulation
Link LI



Ratios are for parking
usage-to-average
accumulation

Appendix DP-P5

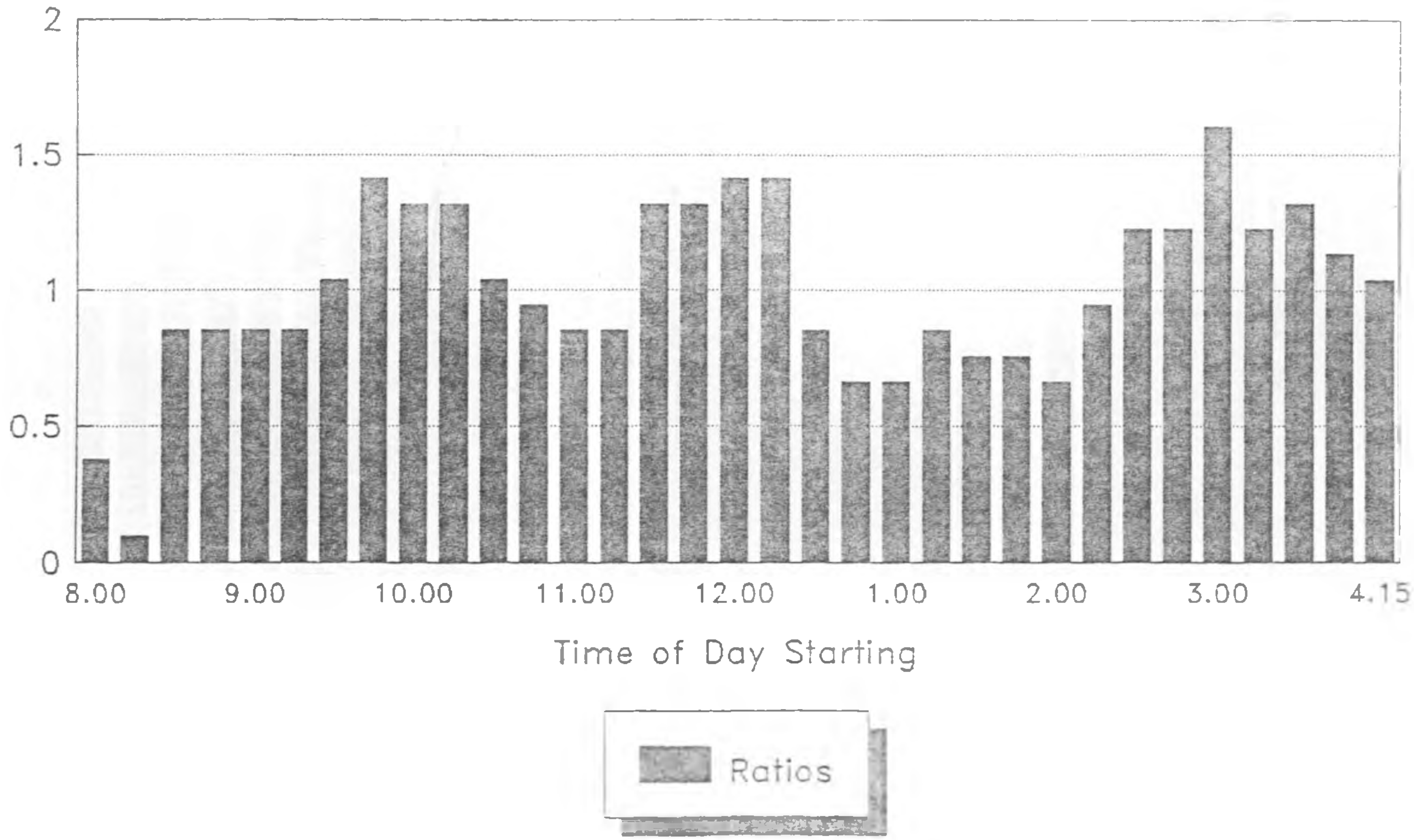
Parking Usage-to-Average Accumulation
Link L2



Ratios are for parking
usage-to-average
accumulation

Appendix DP-P5

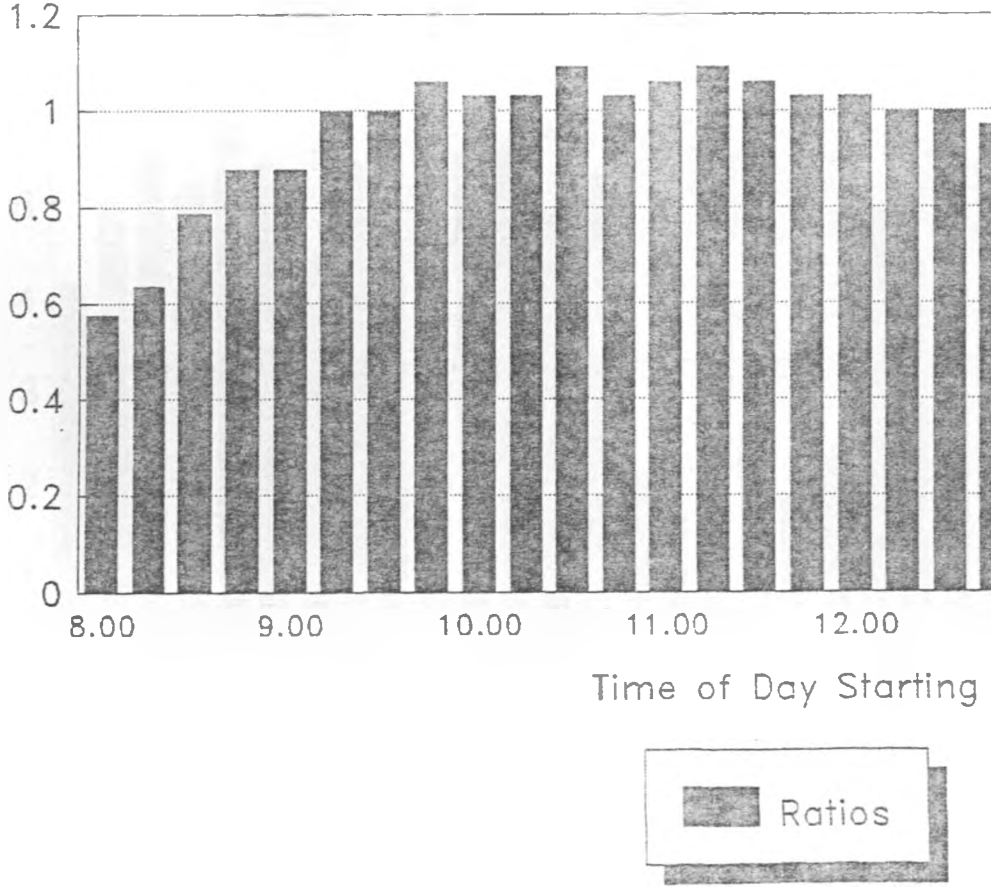
Parking Usage-to-Average Accumulation
Link L3



Ratios are for parking
usage-to-average
accumulation

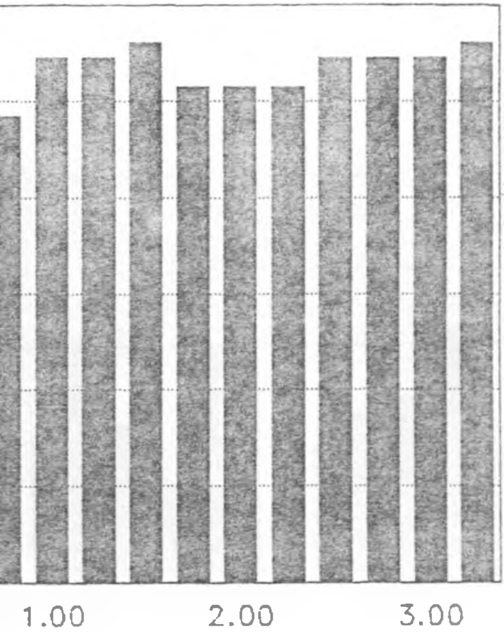
Appendix DP-P5

Parking Usage-to-Average
Link L4



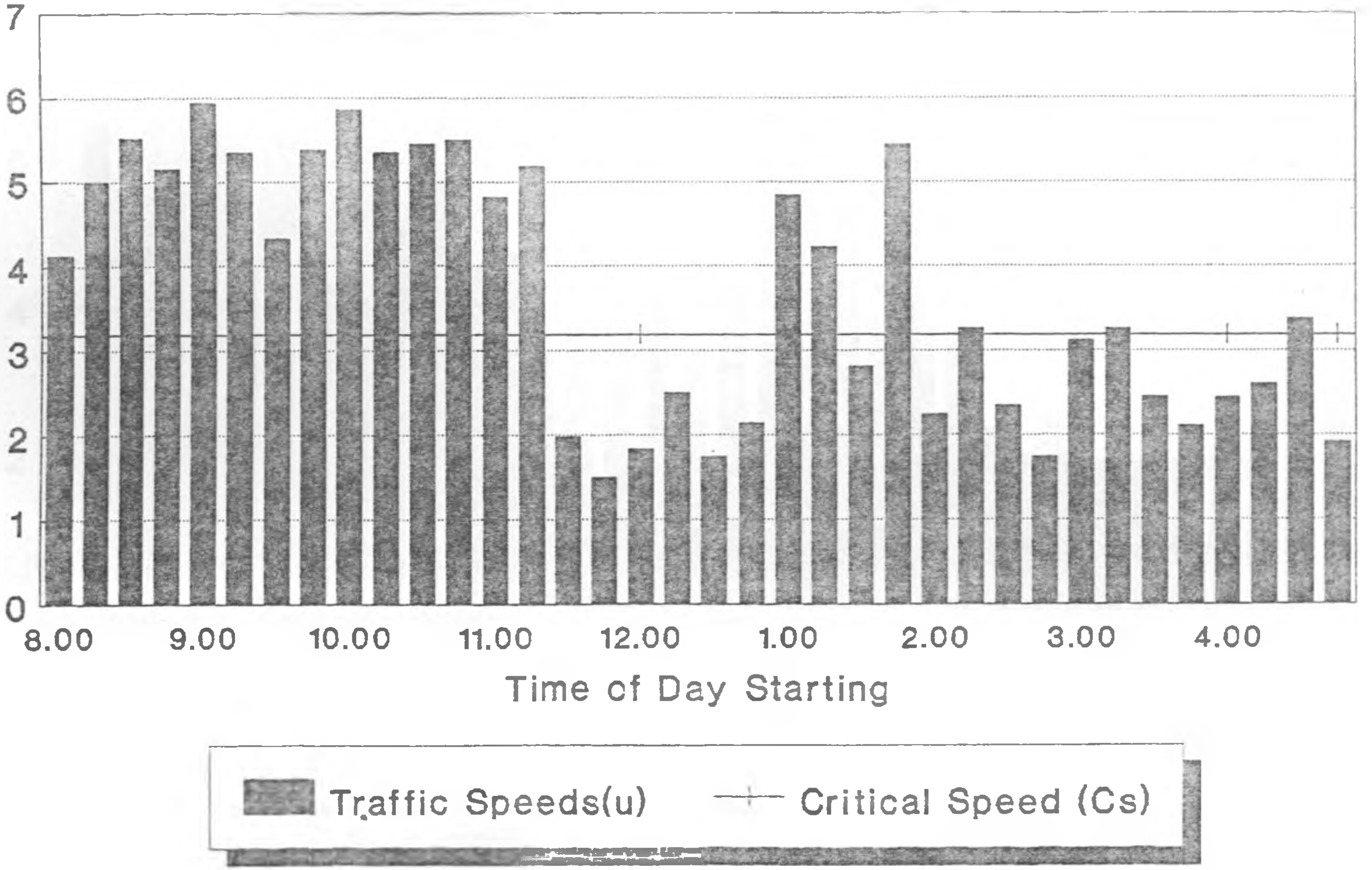
Ratios are for parking
usage-to-average
accumulation

Accumulation



Appendix DP-S1

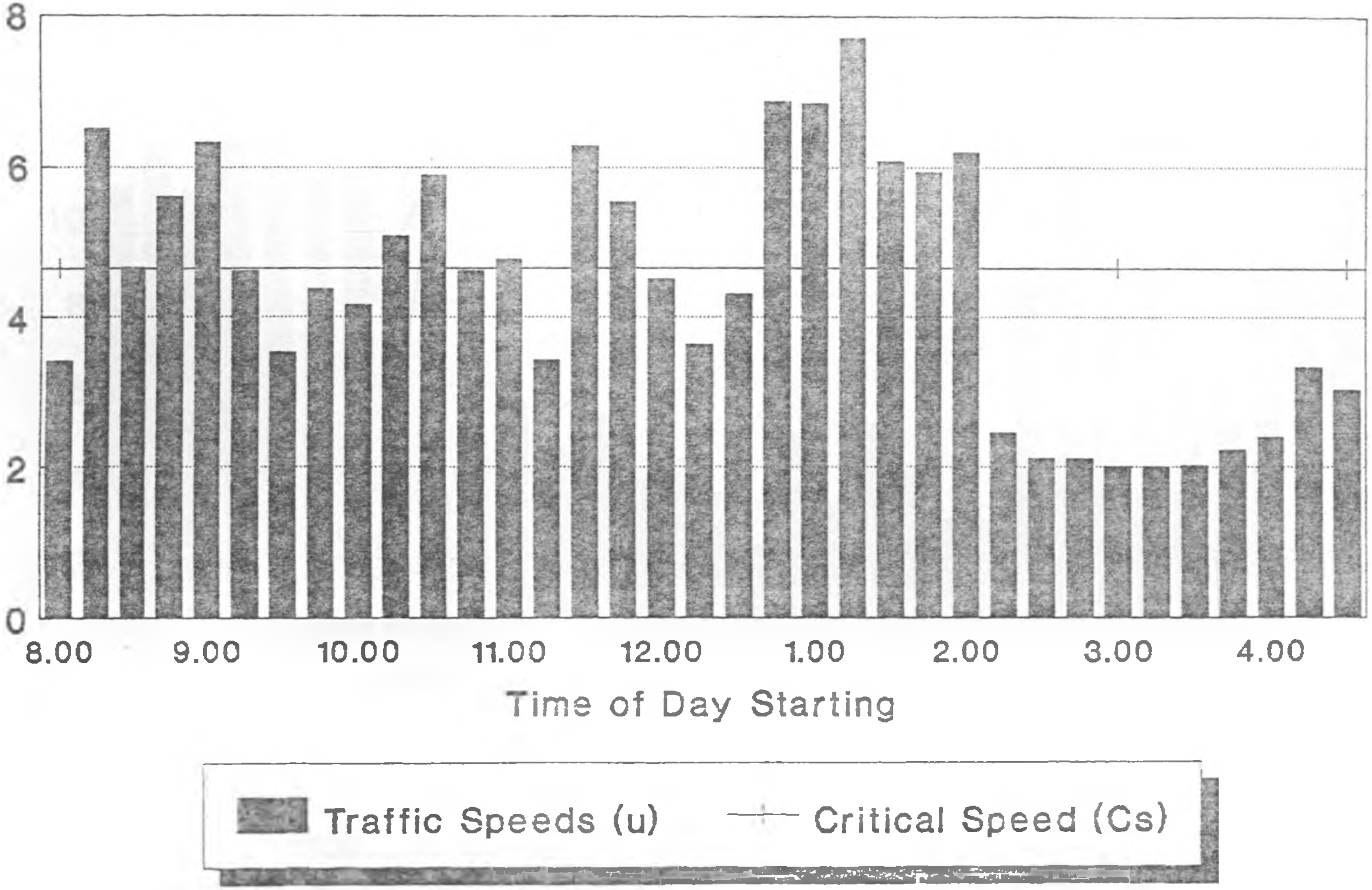
Variation of Traffic Speeds with Time
Link L1



All expressed in meters per second

Appendix DP-S1

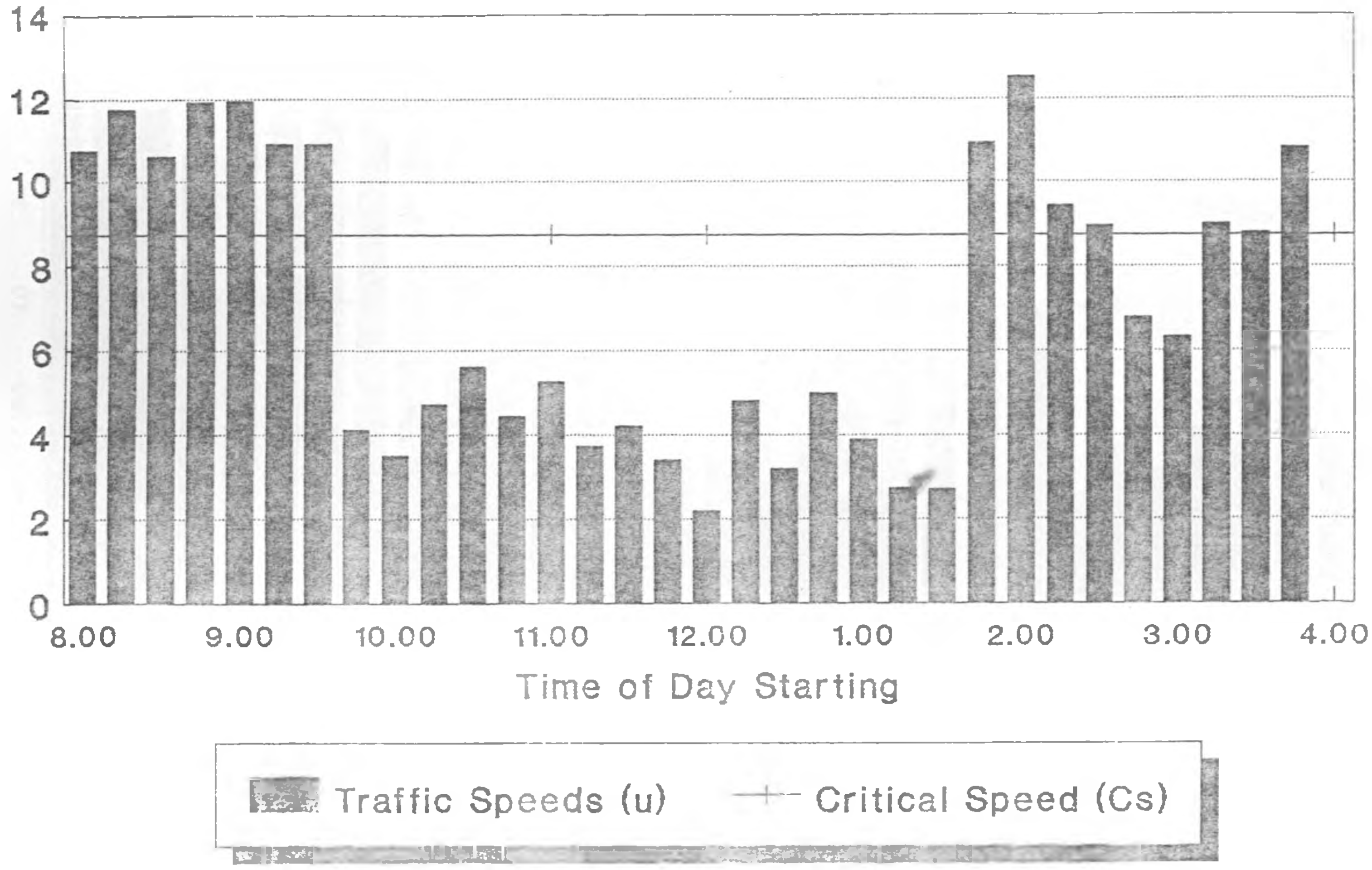
Variation of Traffic Speeds with Time
Link L2



All expressed in meters per second

Appendix DP-S1

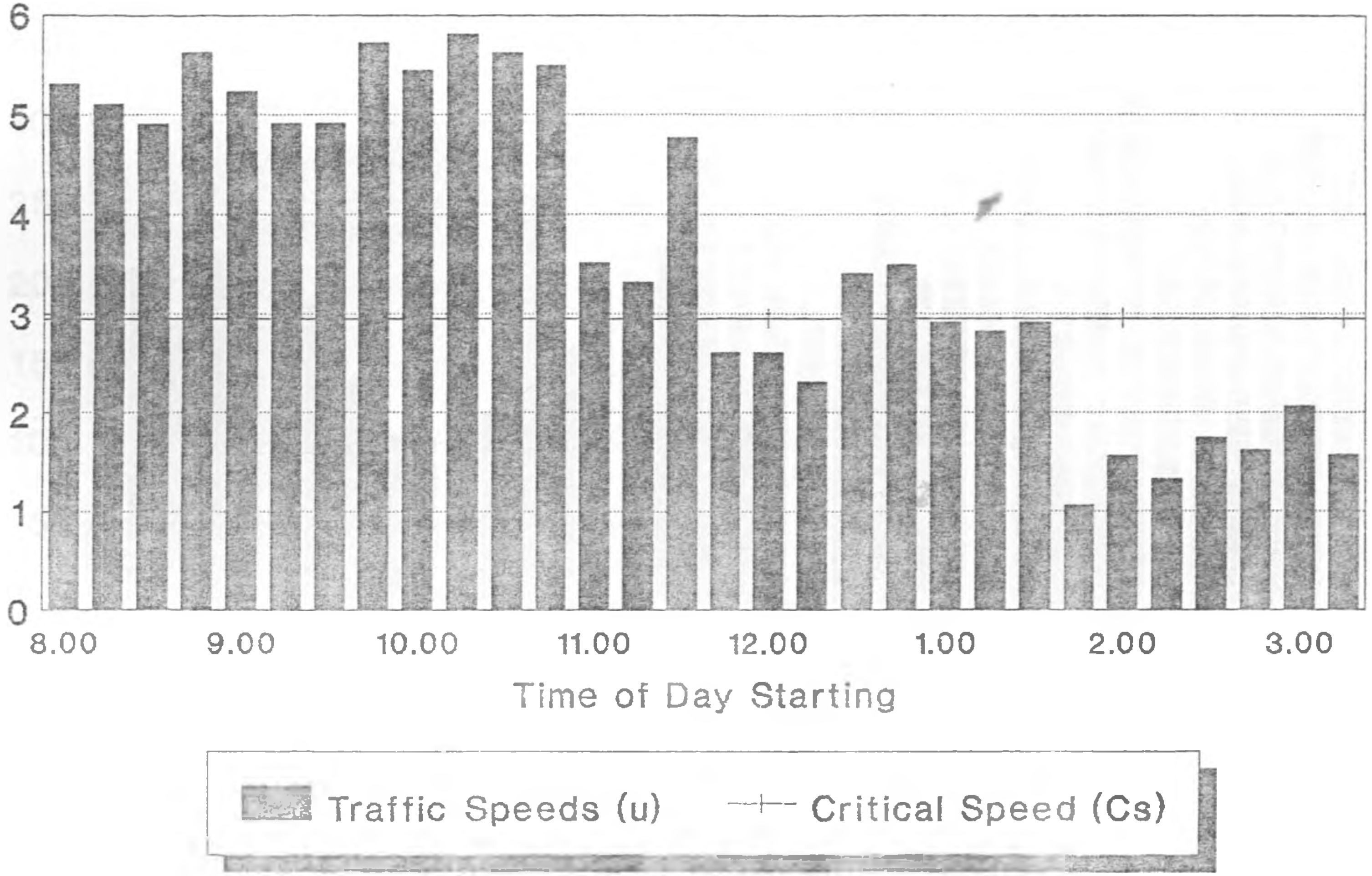
Variation of Traffic Speeds with Time
Link L3



All expressed in meters per second

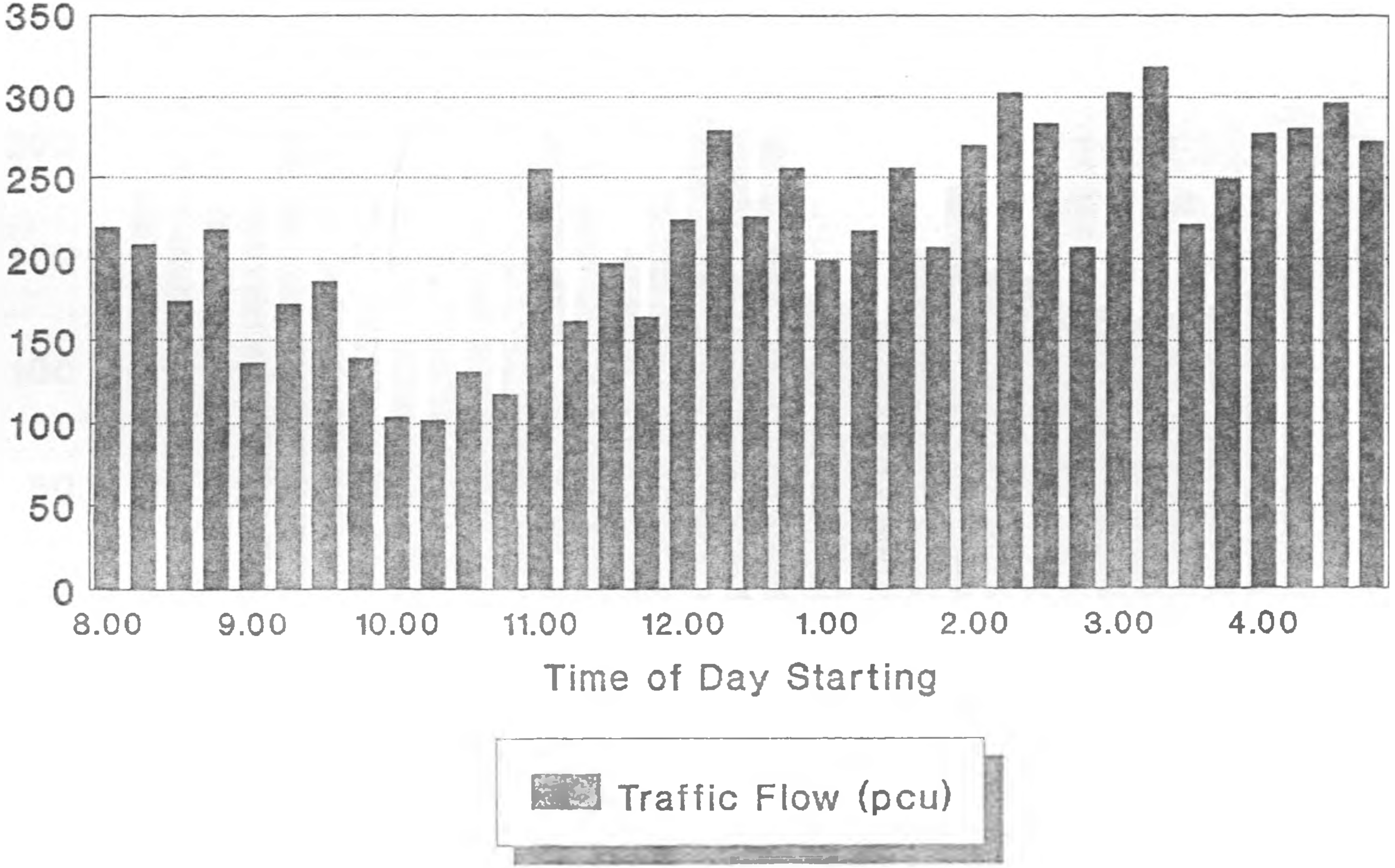
Appendix DP-S1

Variation of Traffic Speeds with Time
Link L4



All expressed in meters per second

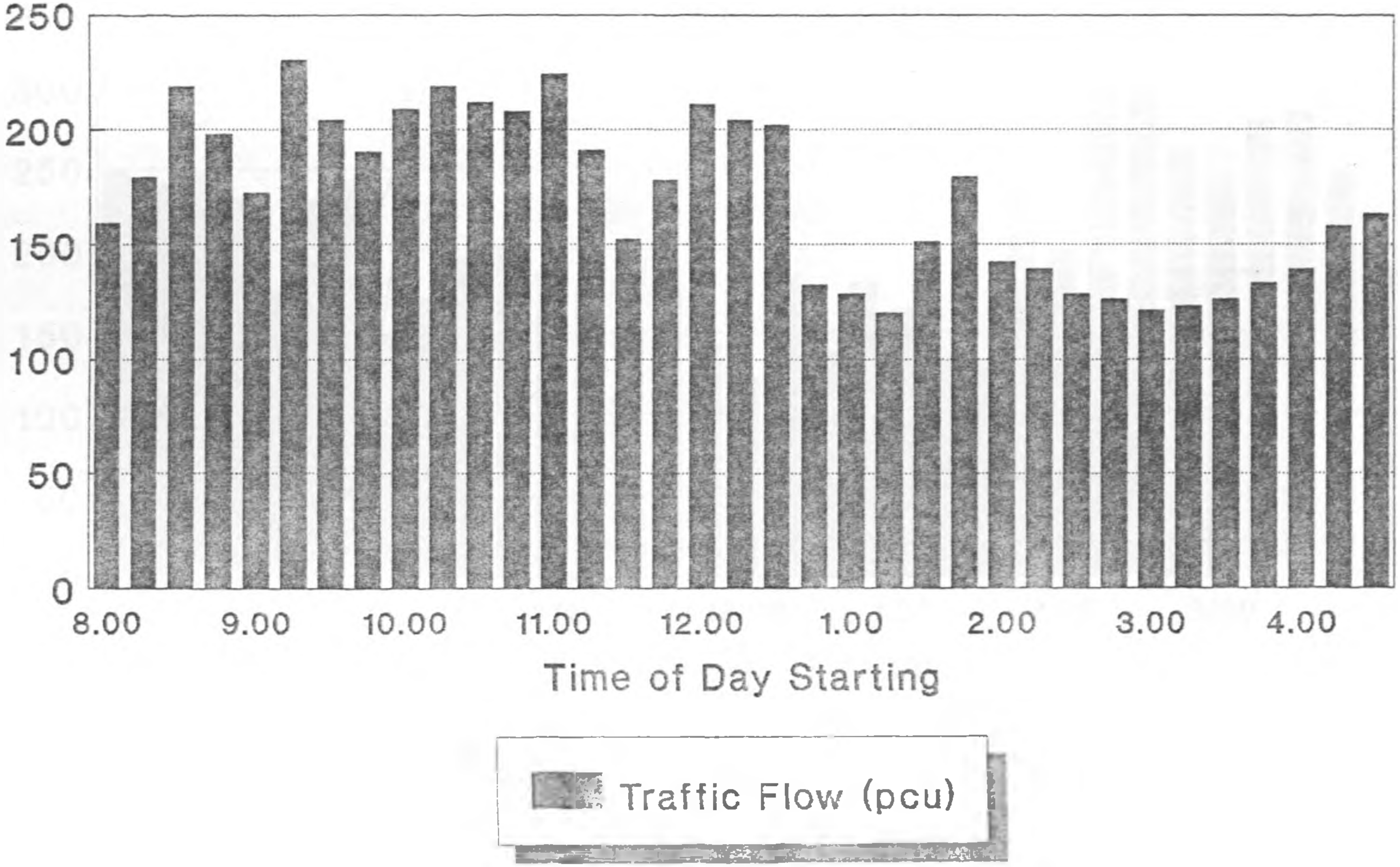
Appendix DP-F1 Variation of Traffic Flow with Time
Link L1



Flows are totals
for 15 minute period

Appendix DP-F1

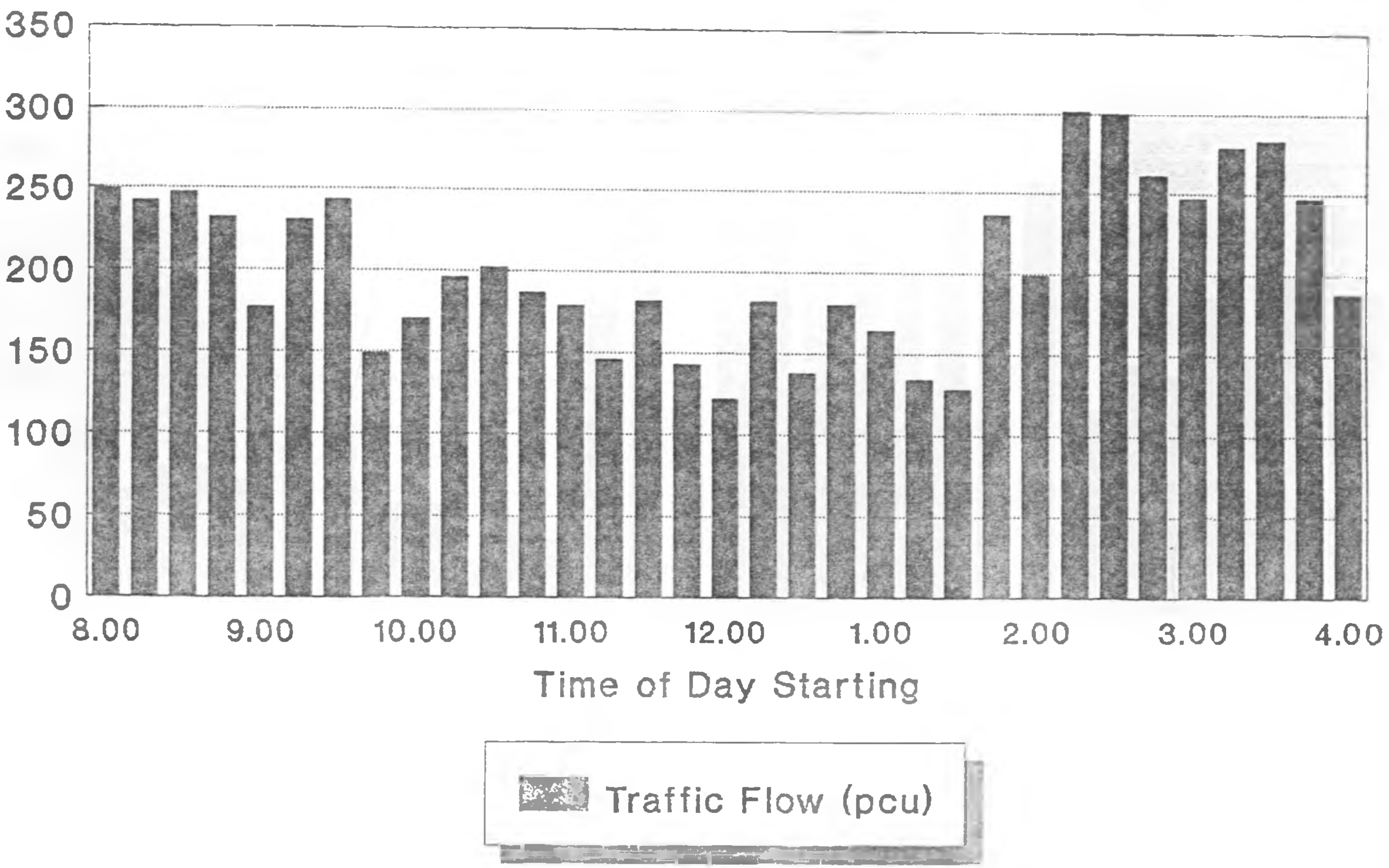
Variation of Traffic Flow with Time
Link L2



Flows are totals
for 15 minute period

Appendix DP-F1

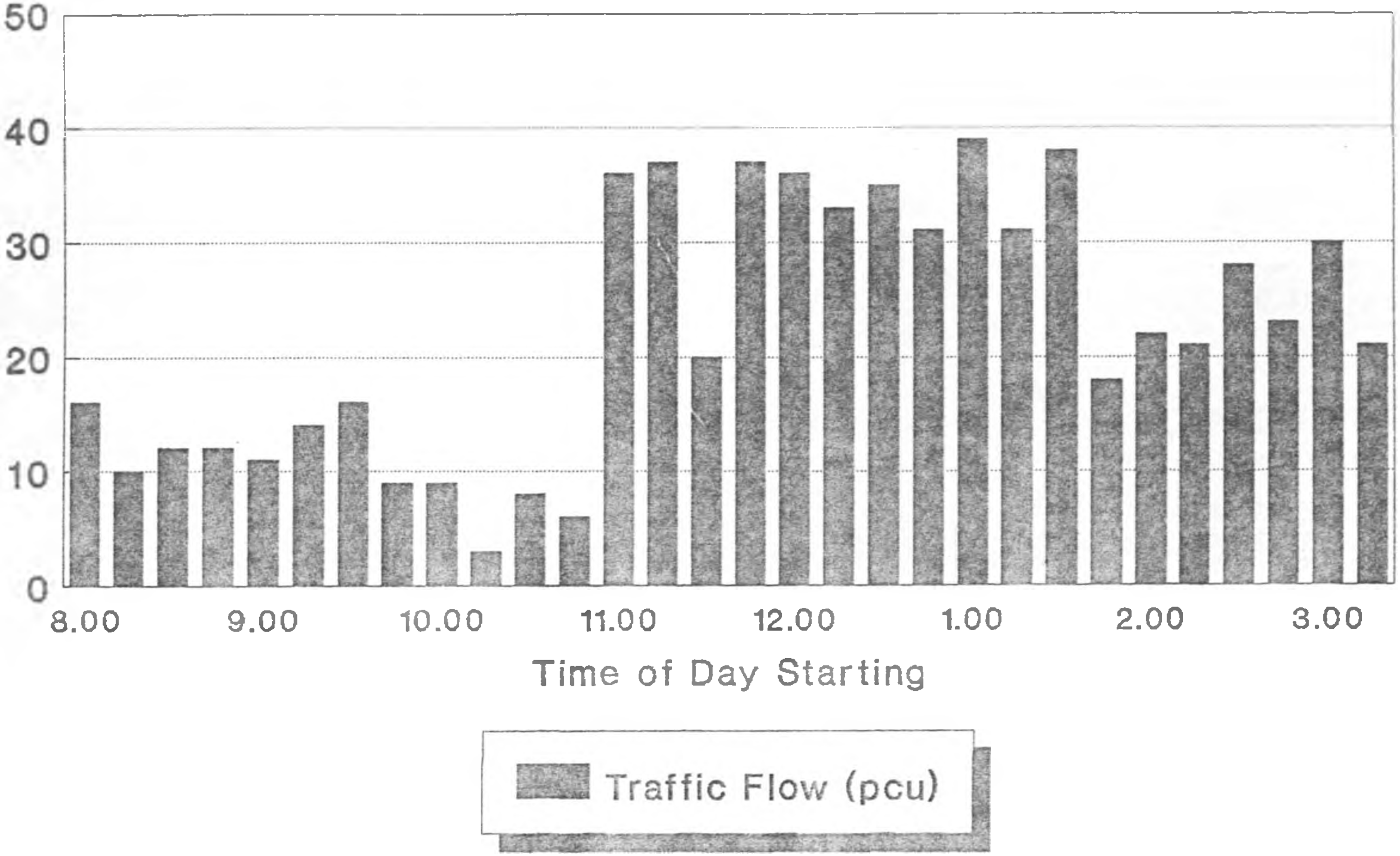
Variation of Traffic Flow with Time
Link L3



Flows are totals
for 15 minute period

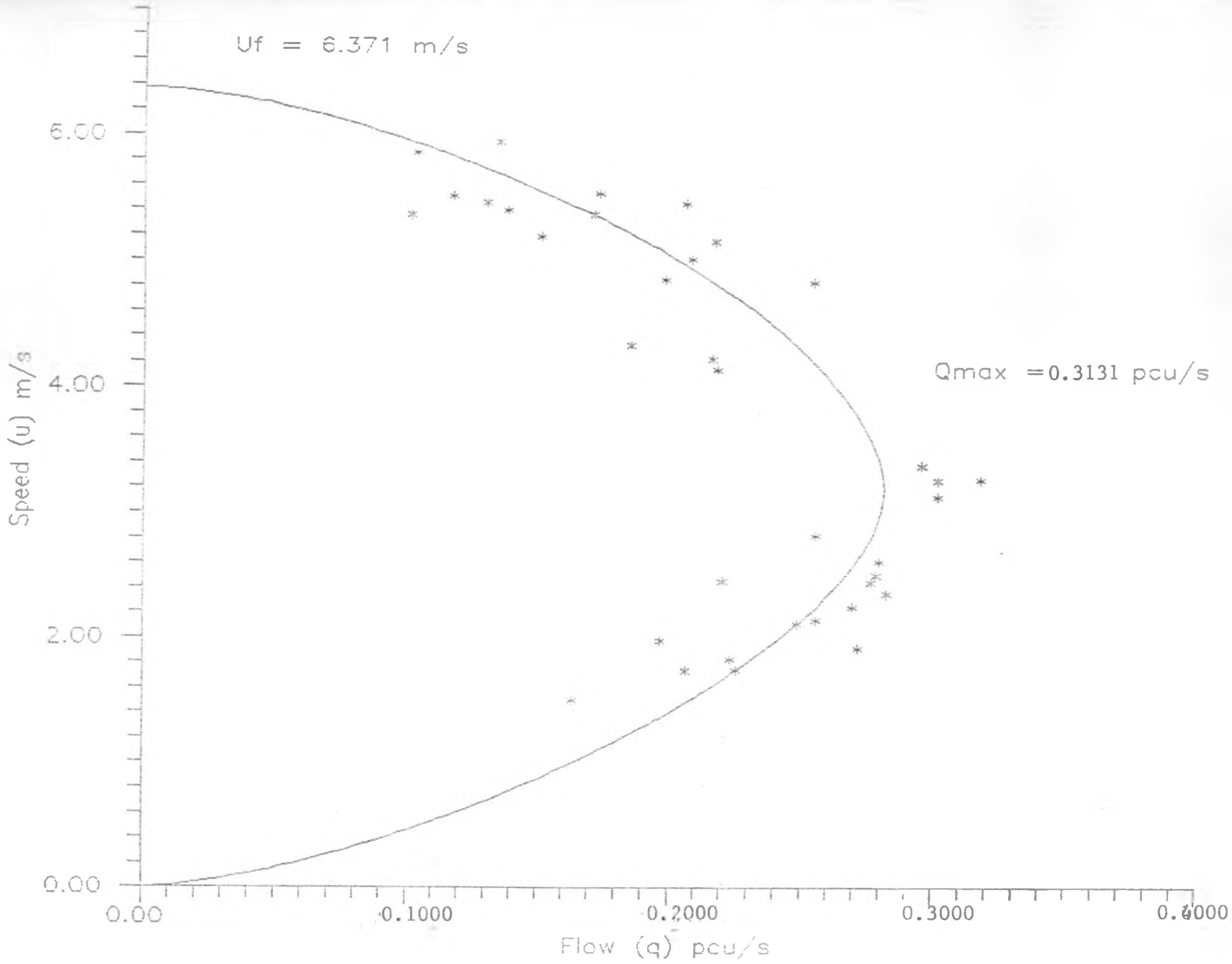
Appendix DP-F1

Variation of Traffic Flow with Time
Link L4

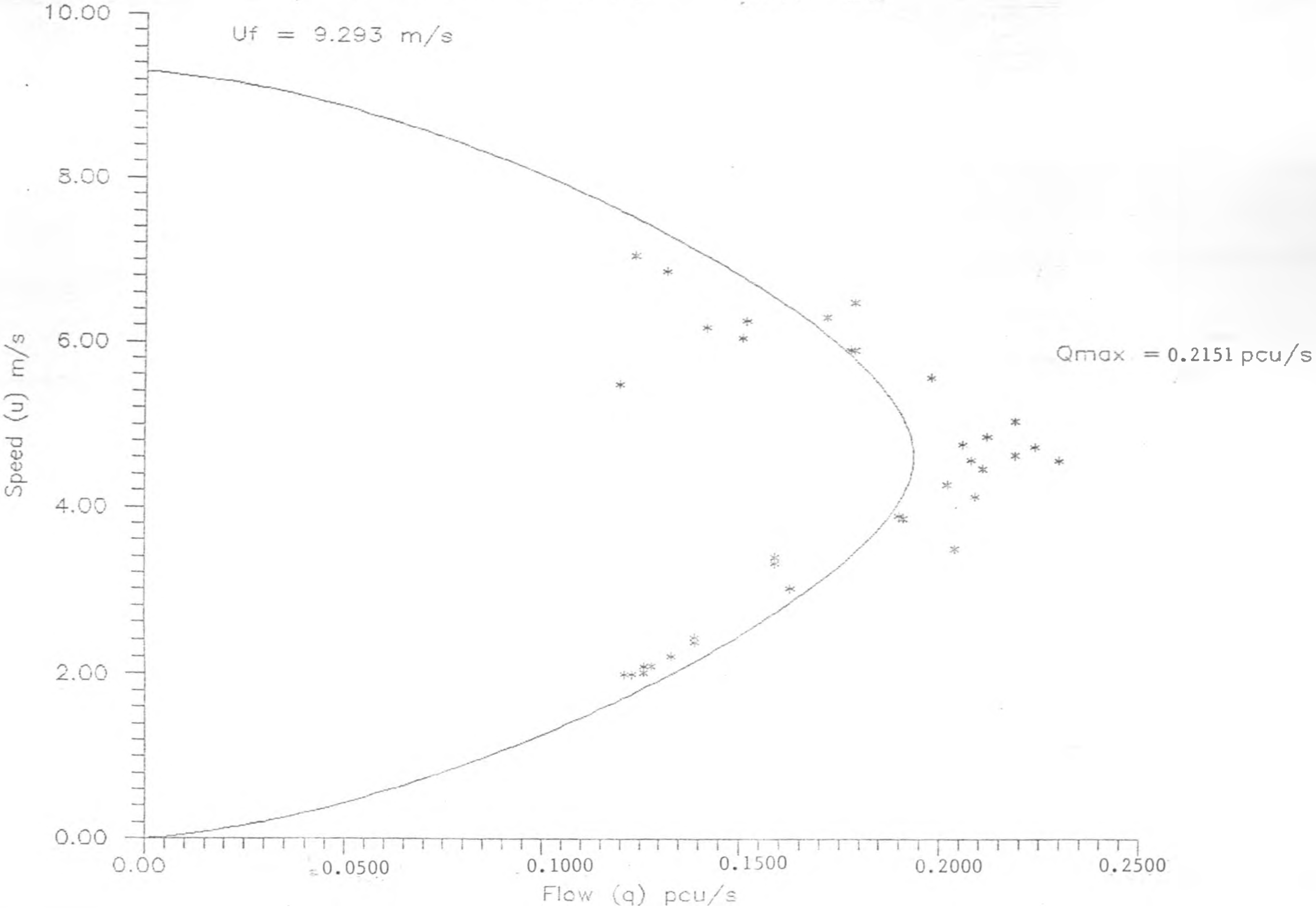


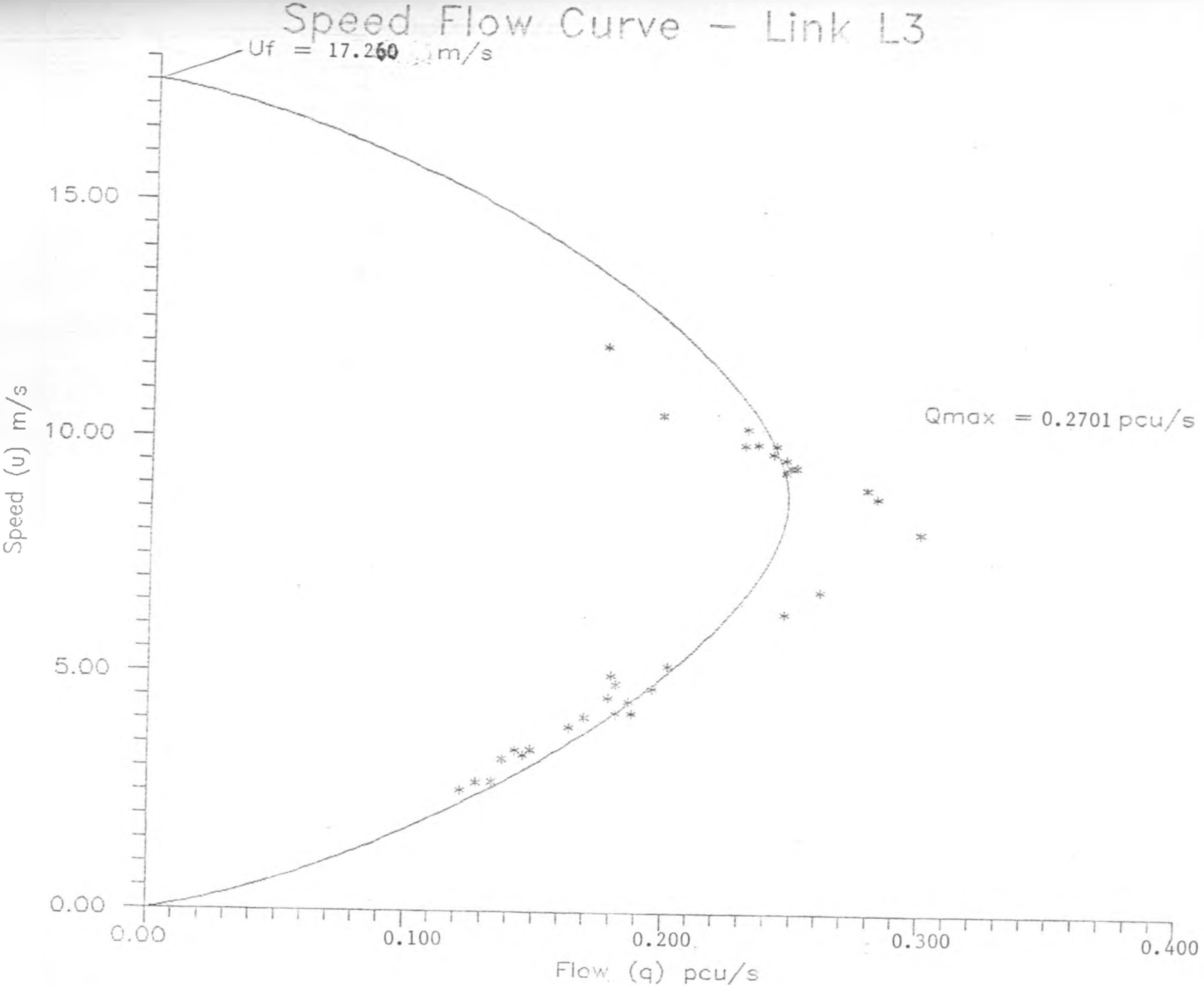
Flows are totals
for 15 minute period

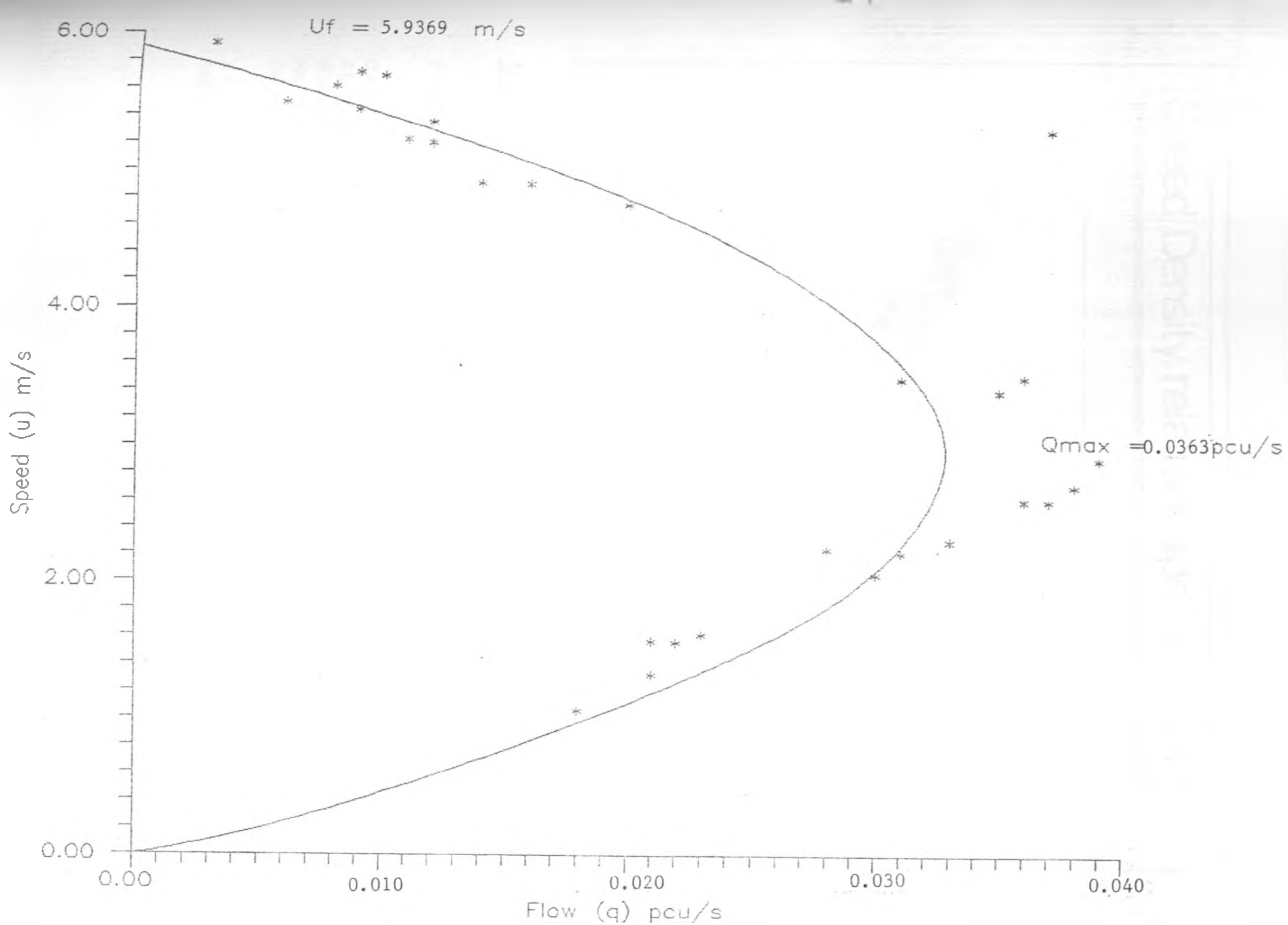
Speed Flow Curve – Link L1

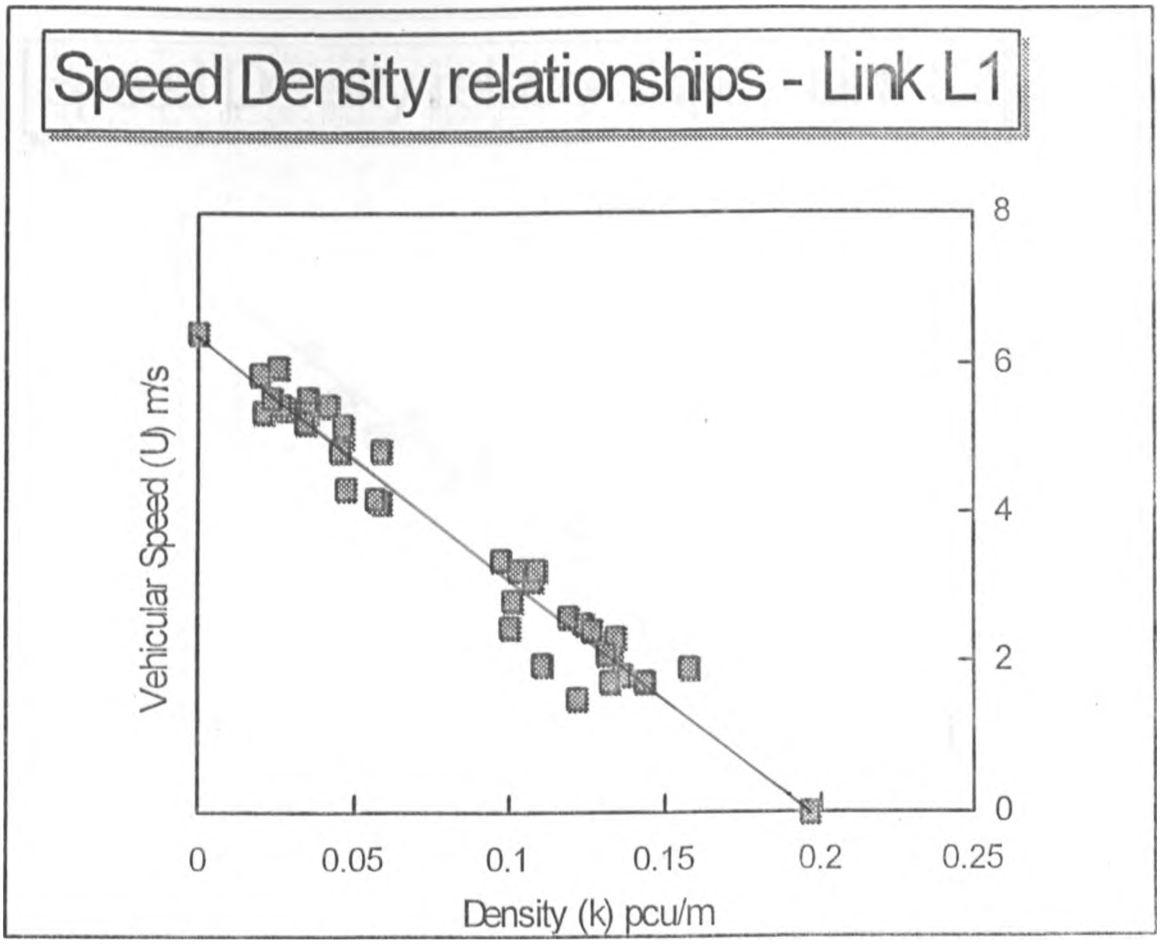


Speed Flow Curve – Link L2




Speed Flow Curve - Link L3
Uf = 17.260 m/s
Qmax = 0.2701 pcu/s
Speed (u) m/s
15.00
10.00
5.00
0.00
0.00
0.100
0.200
0.300
0.400
Flow (q) pcu/s

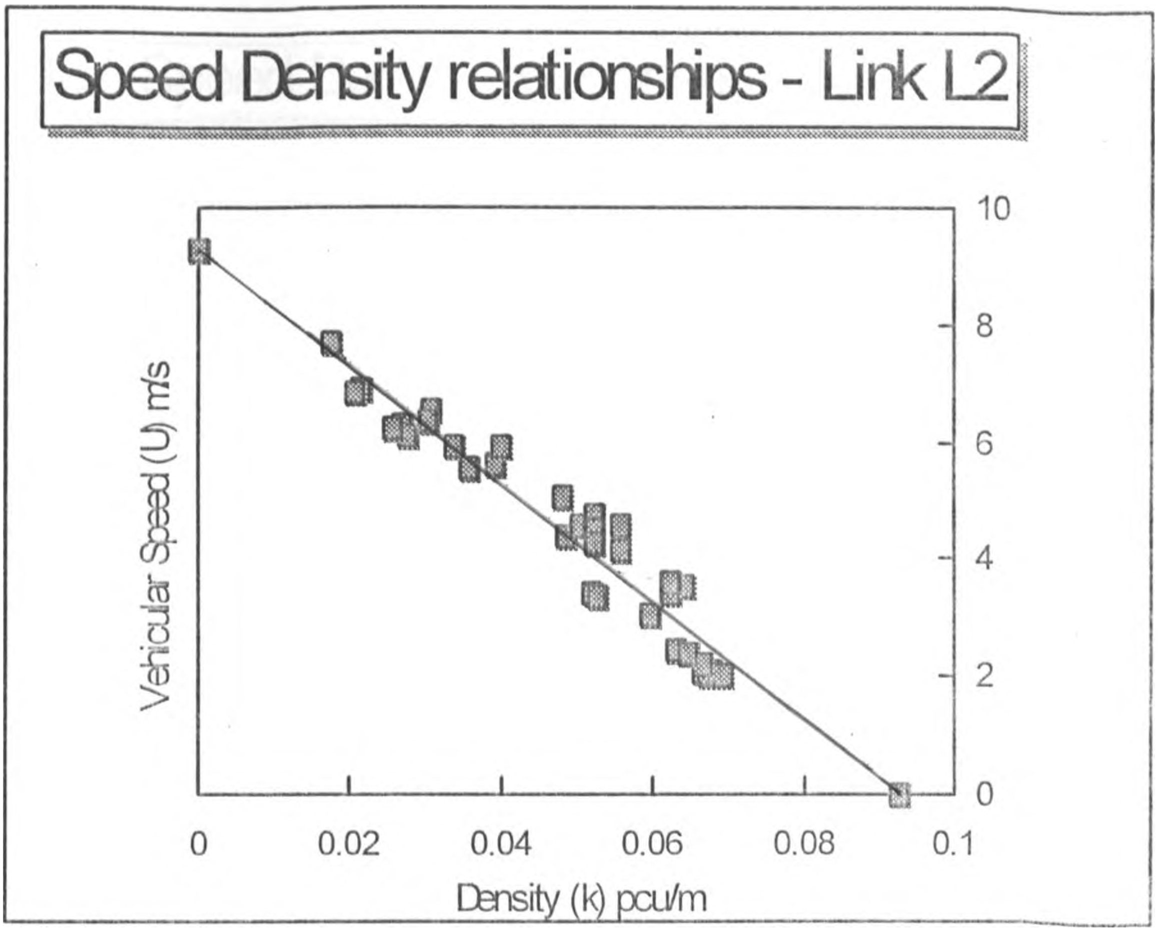

Uf = 5.9369 m/s
Qmax =0.0363pcu/s
6.00
4.00
2.00
0.00
Speed (u) m/s
0.00
0.010
0.020
0.030
0.040
Flow (q) pcu/s



Speed Density model - Link L1

Regression Output

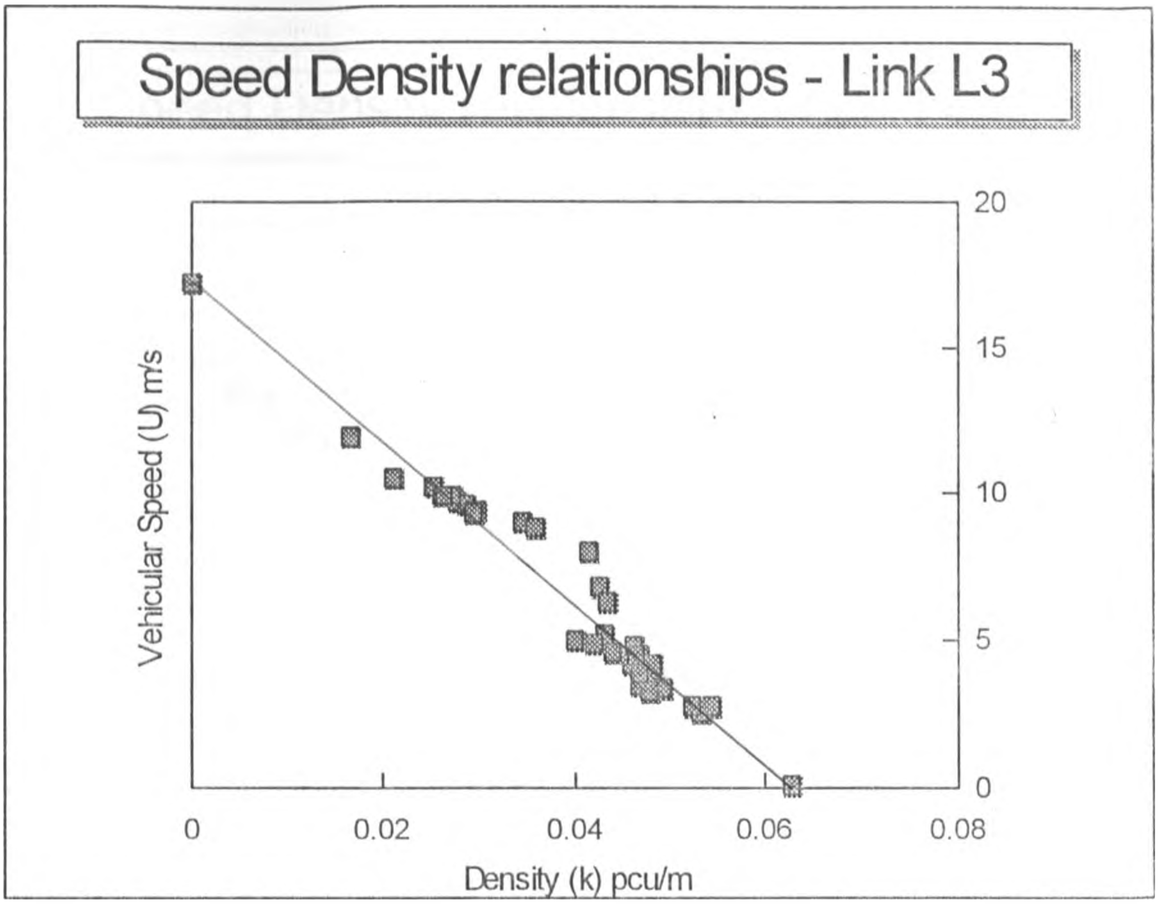
Constant		6.37139160423568323
Std Err of Y Est		0.359102624188469848
R Squared	0.94267721216259	0.944315006100797893
No. of Observations		36
Degrees of Freedom		34
X Coefficient(s)	-32.4117204191232619	
Std Err of Coef.	1.34981194852495587	



Speed Density model - Link L2

Regression Output

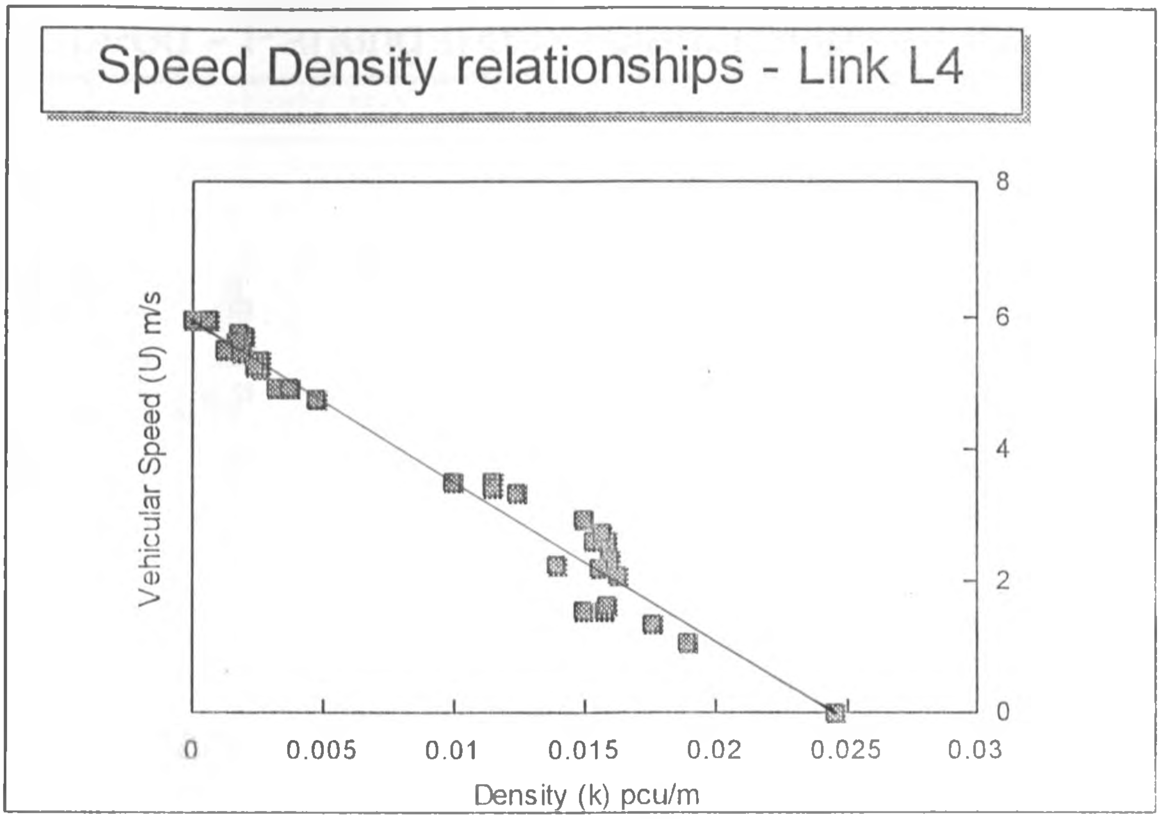
Constant		9.29285634565172038
Std Err of Y Est		0.477270242005711082
R Squared	0.919038038981525	0.921419273129131096
No. of Observations		35
Degrees of Freedom		33
X Coefficient(s)	-100.351158684057578	
Std Err of Coef.	5.1014636471744737	



Speed Density model - Link L3

Regression Output:

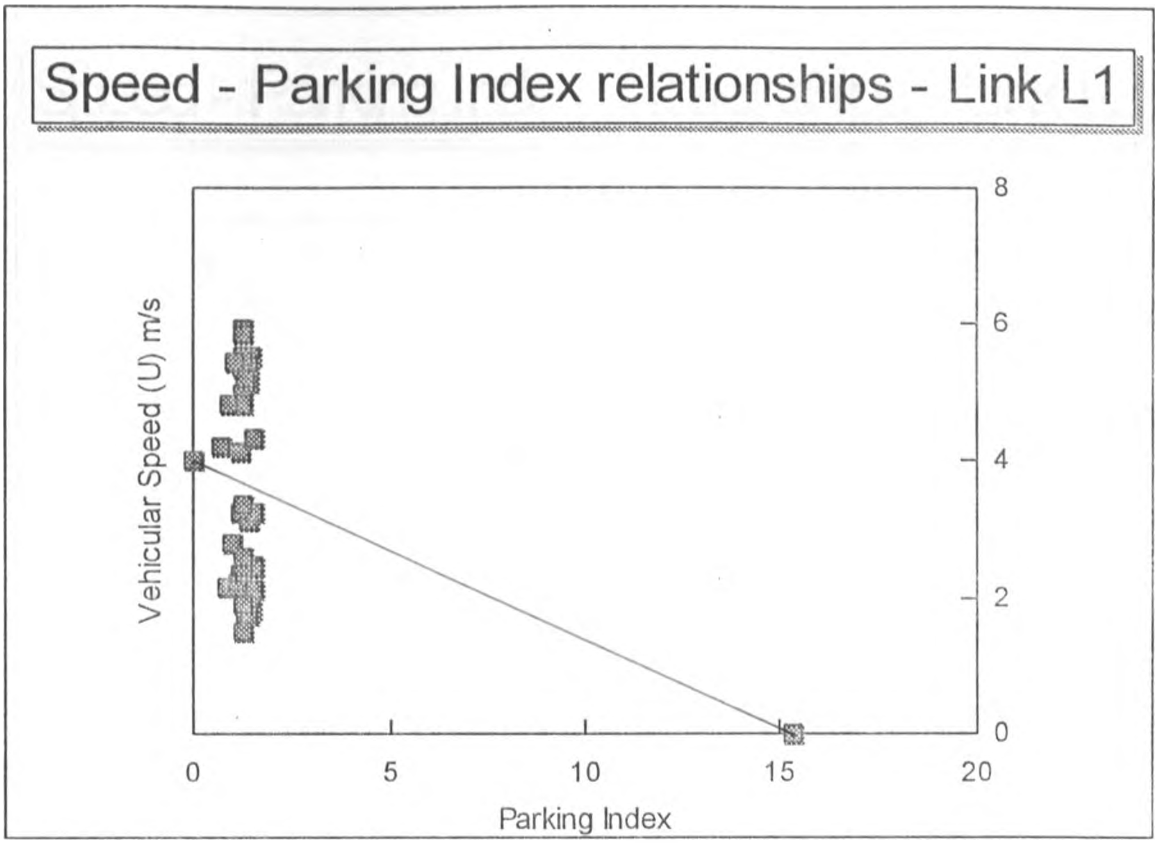
Constant		17.2604367965805412
Std Err of Y Est		0.770146640495419649
R Squared	0.931854323504336	0.93398387589480633
No. of Observations		33
Degrees of Freedom		31
X Coefficient(s)	-275.213134942928465	
Std Err of Coef.	13.1414604535651105	



Speed Density model - Link L4

Regression Output

Constant		5.93686628767148404
Std Err of Y Est		0.335909133458233452
R Squared	0.956464665932474	0.95796588434860147
No. of Observations		30
Degrees of Freedom		28
X Coefficient(s)	-242.220552850990158	
Std Err of Coef.	9.58865981946946964	



Speed - Parking Index model - Link L1

Regression Output

```
Constant                                          4.02050763884335455
Std Err of Y Est                                  1.52089873777166722
R Squared                   0.94267721216259    0.00114690935422759327
No. of Observations                                                36
Degrees of Freedom                                                 34

X Coefficient(s)        -0.262801652350665542
Std Err of Coef.         1.33007121414481446
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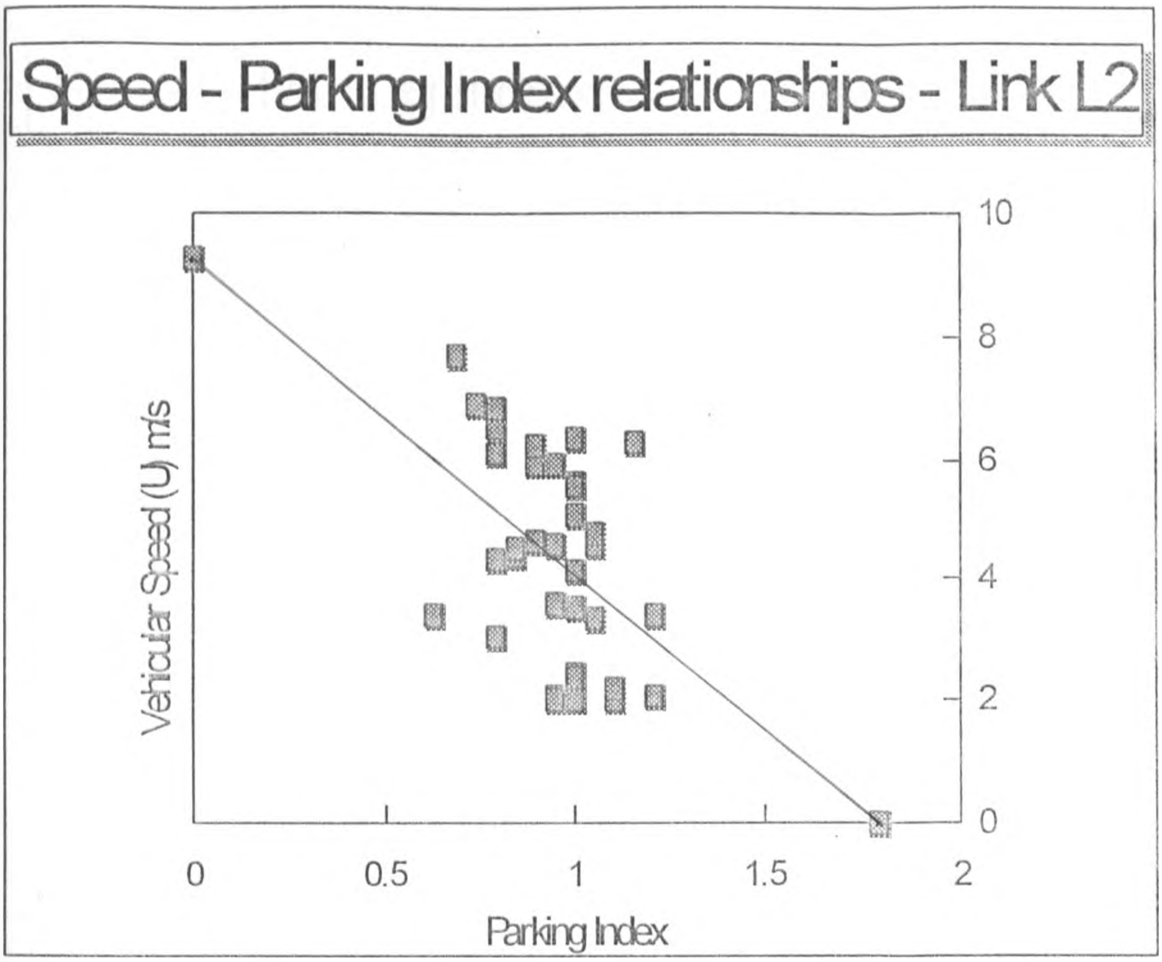
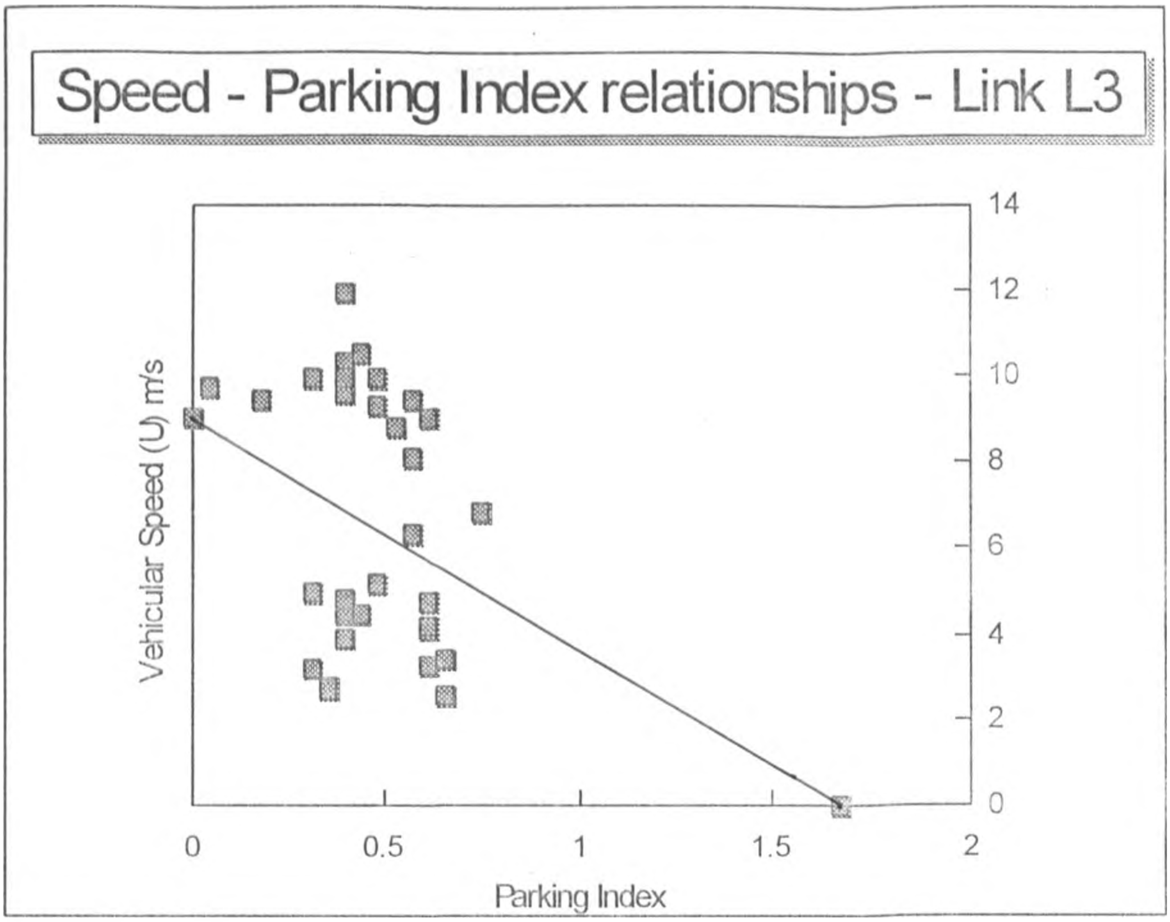


Speed - Parking Index model - Link L2

Regression Output

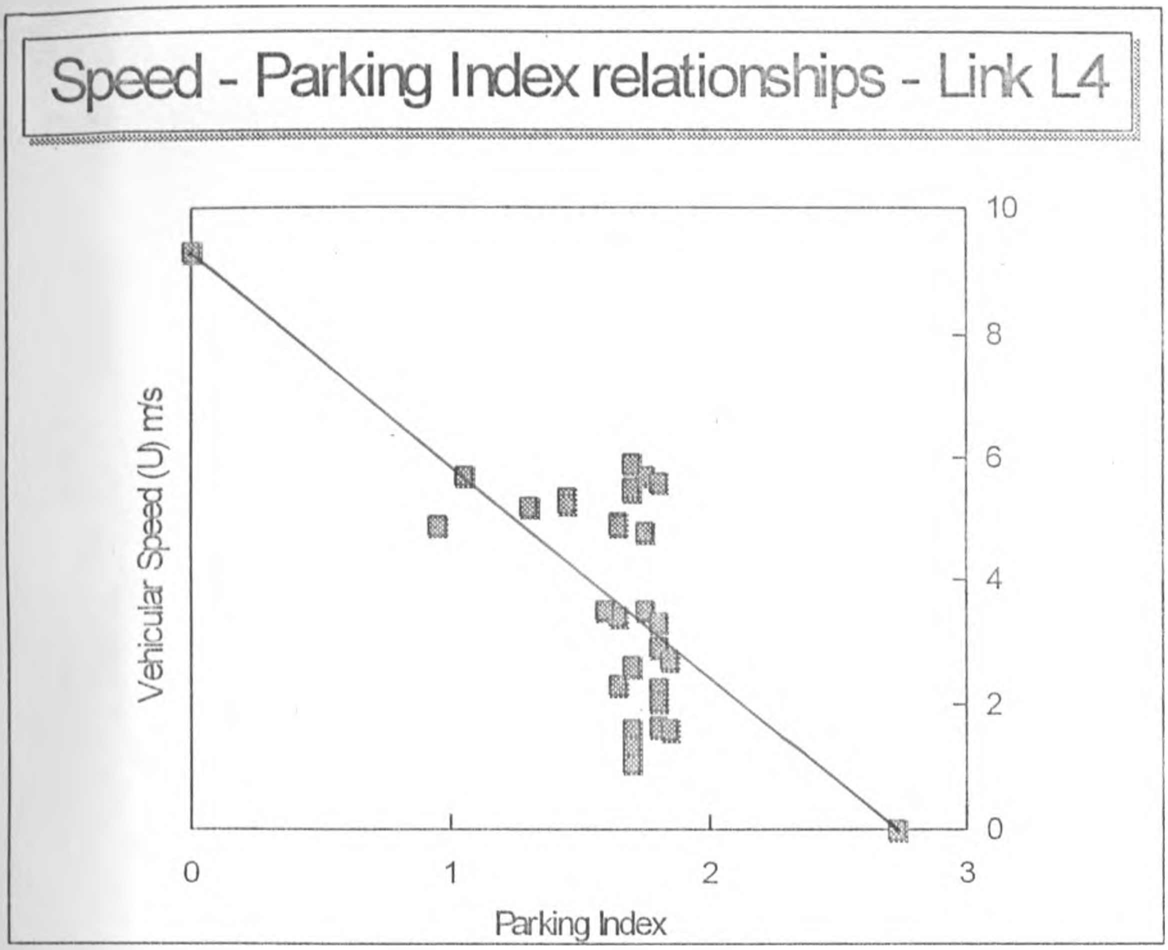
Constant		9.29074465529666106
Std Err of Y Est		1.53808297471812441
R Squared	0.919038038981525	0.183893460306677057
No. of Observations		35
Degrees of Freedom		33
X Coefficient(s)	-5.16673120345904395	
Std Err of Coef.	1.89473808528787401	



Speed - Parking Index model - Link L3

Regression Output

Constant		9.02276425318046175
Std Err of Y Est		2.88107989062324601
R Squared	0.931854323504336	0.0761238104039170474
No. of Observations		33
Degrees of Freedom		31
X Coefficient(s)	-5.39128019475420135	
Std Err of Coef.	3.37332111201107313	



Speed - Parking Index model - Link L4

Regression Output

Constant		9.31189608293500526
Std Err of Y Est		1.45676028772238219
R Squared	0.956464665932474	0.209440654121657217
No. of Observations		30
Degrees of Freedom		28
X Coefficient(s)	-3.4244174064187721	
Std Err of Coef.	1.25731595321500229	

APPENDIX MAP

MAP ON NAIROBI CENTRAL BUSINESS AREA

ROAD NETWORK

KEY:

BOUNDARY OF NAIROBI CENTRAL BUSINESS AREA ··· —— ··· —

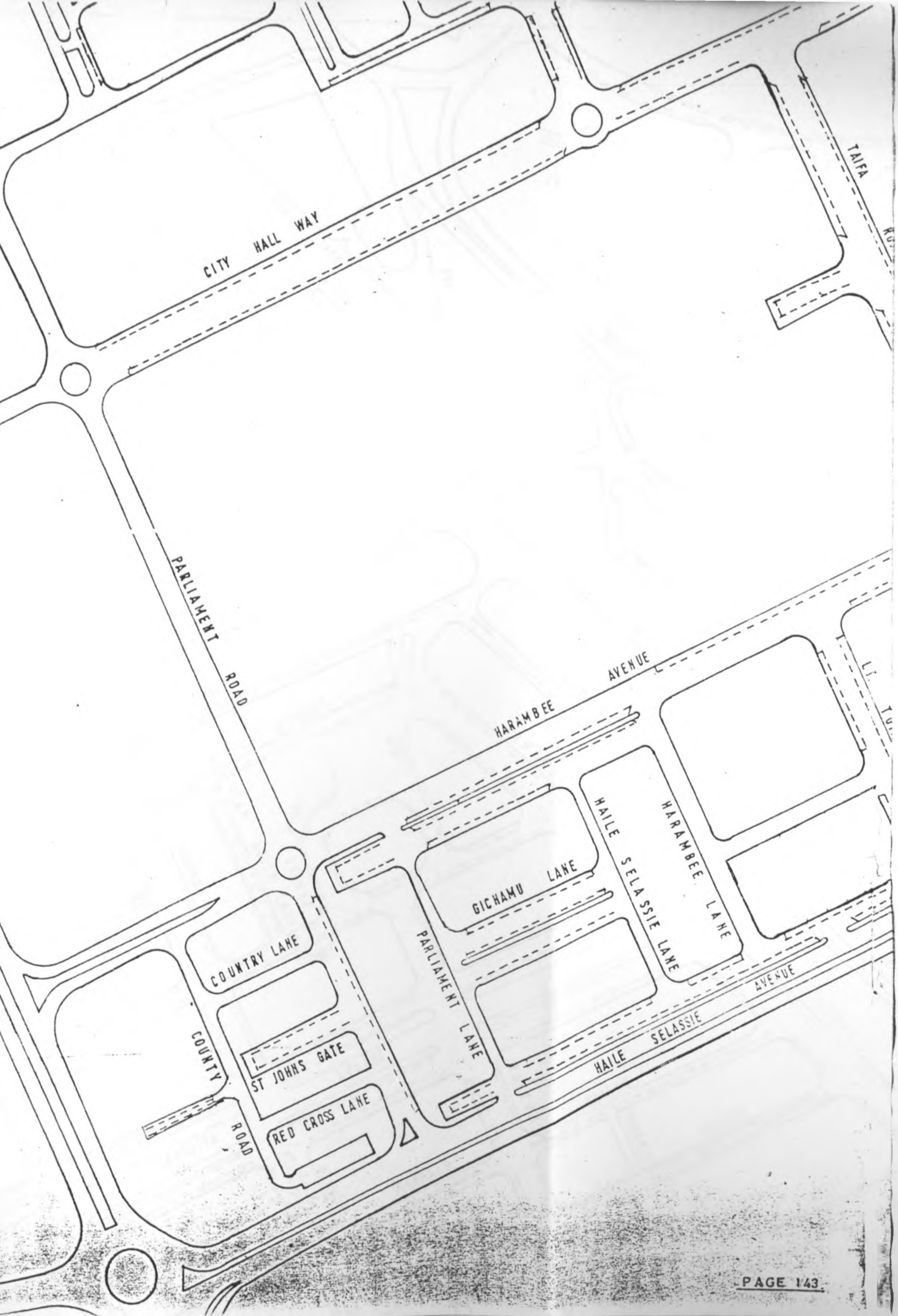
FIGURE 1 SHEET No1

NAIROBI CENTRAL BUSINESS AREA

ROAD NETWORK

SHEET ARRANGEMENTS

2	3
1	4


CITY HALL WAY
TAIFA
RO
PARLIAMENT ROAD
HARAMBEE AVENUE
HAILE SELASSIE LANE
HARAMBEE LANE
GICHAMU LANE
PARLIAMENT LANE
COUNTRY LANE
COUNTY ROAD
ST JOHNS GATE
RED CROSS LANE
HAILE SELASSIE AVENUE

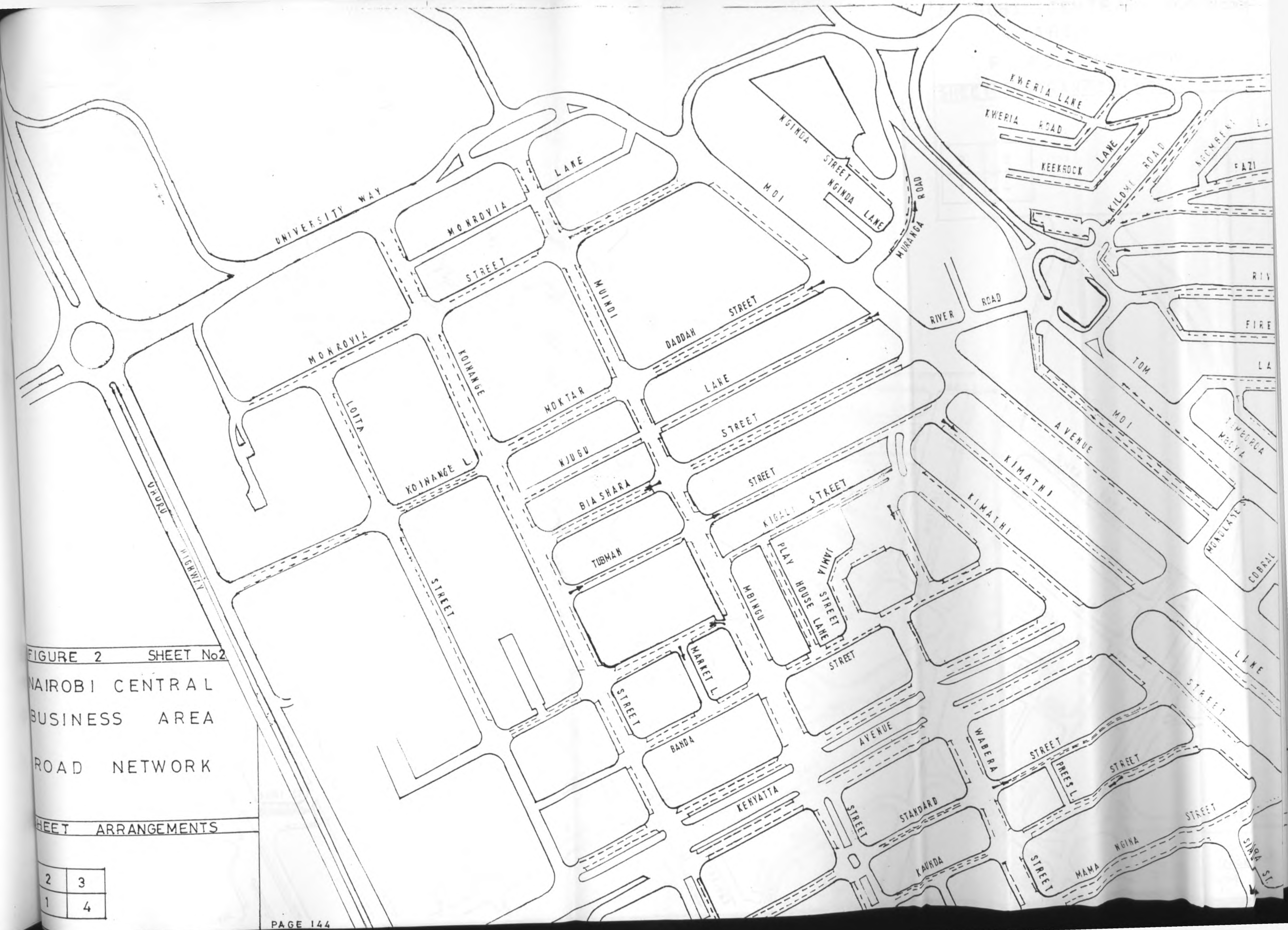


FIGURE 2 SHEET No2

NAIROBI CENTRAL
BUSINESS AREA
ROAD NETWORK

SHEET ARRANGEMENTS

2	3
1	4

FIGURE 3 SHEET No 3

NAIROBI CENTRAL BUSINESS AREA

ROAD NETWORK

SHEET ARRANGEMENTS

2	3
1	4

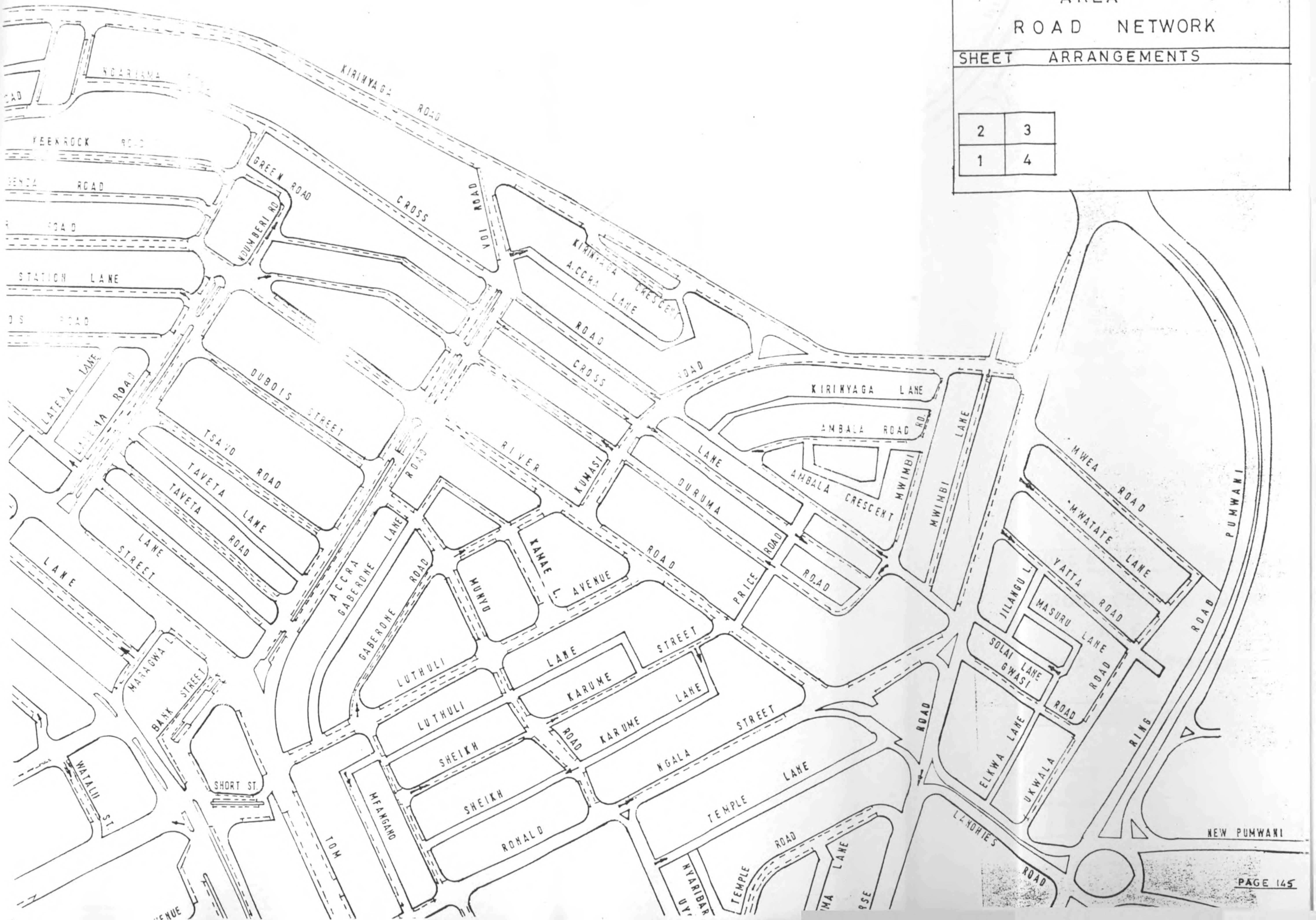


FIGURE 4 SHEET No4

NAIROBI CENTRAL BUSINESS
AREA
ROAD NETWORK

SHEET ARRANGEMENTS

2	3
1	4

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