# COMPARING FIXED STOP AND HAIL STOP MODE OF SERVICE OF FIXED ROUTE INTRA URBAN BUS OPERATIONS

BY

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A THESIS PRESENTED TO THE POSTGRADUATE SCHOOL AHMADU BELLO UNIVERSITY ZARIA, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (HIGHWAY AND TRANSPORTATION ENGINEERING)

DEPARTMENT OF CIVIL ENGINEERING
AHMADU BELLO UNIVERSITY
ZARIA

AUGUST, 1996

## DECLARATION

I hereby declare that this thesis has been written by me and that it is a record of my own research work. It has not been accepted in any previous publication for a higher degree.

All sources of information are specifically acknowledged by means of references.

Adekunle Taiwo Olowosulu

August, 1996.

## CERTIFICATION

This thesis entitled "COMPARING FIXED STOP AND HAIL STOP MODE OF SERVICE OF FIXED ROUTE INTRA URBAN BUS OPERATIONS" by Adekunle Taiwo *OLOWOSULU* meets the regulations governing the award of the degree of Masters of Science in Highways and Transportation Engineering of Ahmadu Bello University, and is approved for its contribution to knowledge and literary *presentation*.

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## DEDICATION

This work is dedicated to a loving mother, late Mrs Emilia Olowosulu .

**ACKNOWLEDGEMENTS**

I wish to express my profound gratitude to my supervisor, Prof. Olusegun Adebisi for his constructive criticisms and steady counsel in course of this project. I also thank him for scrutinising the work which had greatly improved the work. My sincere appreciation also goes to DR. K. J. Osinubi for his assistance throughout the course of the work.

I am sincerely grateful to the following organisations, the Transport Research Laboratory, UK and Transport and Operations Research Group, Newcastle Upon Tyne, for sending me relevant research publications

I also acknowledge the support of the staff of the Department of Civil Engineering, A.B.U, Zaria during the course of this work, particularly with the use of the departmental computer facilities.

I wish to thank the following individuals who had in their own ways contributed to the work, notable among them are Nike Amuda, Solomon Oranusi, Vivian Eghaboh, Clement Meseda, Ronald Kangkolo, Mrs R. Obi, e.t.c.

Finally, I record my profound gratitude to my family for their patience and love while the course lasted. I also acknowledge their finacial supports, particularly those of 'Niji.

'Kunle T. Olowosulu

August, 1996

## ABSTRACT

Fixed stops and Hail stops are among the possible mode of service used in intra-urban transit. Under the fixed stop service, vehicles stop to load or unload passengers at designated points only. For the hail stop service vehicles stop to load and/or unload at any point along the route on demand by patrons.

The relative performance of fixed stop and hail stop services have been evaluated and compared. The objective that guided the comparison is that of minimisation of the total system cost. Models for total system costs per passenger are set up and the optimum headways that best satisfy the chosen objectives are determined for each service.

Numerical values are specified for models' variables. Sensitivity analyses have been used to isolate the parameters affecting the total system costs and optimum headways. The most significant elements affecting both functions are demand on the route, length of the route, value of out-of-vehicle time and the normal operating cost. Results from the sensitivity analyses were then used to generate guidelines for comparing the two modes of service under consideration and isolate the conditions under which one service is more appropriate for adoption than the other. On the latter, two hypotheses were advanced, which are then used to derive a general methodology for comparing the modes of service. Highlight from the proposed methodology is that the demand, value of time, the route length and the operating cost are

needed to be compared for both services. In the situations where demand is low, value of time high, the route short and operating cost low the hail stop may well be better. It was found out that for a 24 seater vehicle capacity that hail stop was better at nearly all demands considered.

The effect of vehicle size on the modes of service were examined; larger vehicles are more appropriate to be used for the fixed stop service and smaller capacity vehicles for the hail stops service. Also examined is the effect of changing 0-D pattern on the services. Hail stop was found to be more sensitive to changes in the 0-D pattern. On this basis it is recommended that where demand is low enough, hail stop operation should provide collective and distributive service i.e moving patron to high activity areas(e.g CBD) and from CBD to residential locations. While the fixed stop is more suitable to serve as line haul service between important major activity centres in urban areas.

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## NOTATION

| | |
|---|---|
| a | Fraction of the headway for which a passenger remain waiting |
| F | Fare |
| g | Average ridership rate |
| $\gamma_n$ | Normal Operating cost per unit distance |
| $\gamma_s$ | Excess operating cost (Service cost) |
| $\gamma_a$ | Excess operating cost (acceleration/deceleration cost) |
| h | time interval between buses measured from head to head as they pass a given point on the roadway |
| $h^t$ | optimum headway |
| IVTT | The time passenger spent inside a bus |
| j | Ratio of the number of stops made in a trip to number of passengers carried by a bus |
| K | Time required to service a typical passenger (boarding and alighting) under fixed stop |
| K' | Time required to service a typical passenger under hail stop |
| L | Length of the route |
| $L_p$ | Penalty Length: the portion of the route where deceleration and acceleration manoevres takes place |
| L' | Effective route length i.e. total route length less the penalty length |
| $\psi$ | Average bus dwell time per stop |
| n | Number of patron stops made in a bus trip |
| OPC | Operators cost per passenger |

| | |
|---|---|
| Q | Average number of passengers carried during a bus trip |
| σ | Fraction of bus trip time for which a typical passenger remains on bus |
| S | The number of designated stops under the fixed stop |
| $t_a$ | Average alighting time per passenger |
| $t_b$ | average dead time per stop |
| $t_{ps}$ | time penalty for stopping |
| $V_i$ | Unit value of passenger travel time spent inside a bus |
| $V_o$ | Unit value of passenger travel time spent outside a bus |
| WKT | Average time a typical passenger takes to walk to a stop |
| WTT | Average time a patron wait for a bus |

# CHAPTER 1

## INTRODUCTION

### 1.1 PREAMBLE

Quite a large percentage of commuting needs in major urban centres of developing countries, are met by road transport. Within the road transport, public transport caters for a major share of the demand. In Nigeria, bus transit is the most important mode of intra-urban public transport, as people rely heavily on public transportation due to low level of household incomes.

The bus transit systems in operation in Nigeria are mostly privately run and they offer unscheduled services. They mostly operate the fixed route strategy where vehicles ply a designated route and stop at fixed stations or at any point along the route, on demand.

Overcrowding, long travel time, rickety and ill-maintained vehicles, and delays are some travellers' impression on travel by passenger bus. Another very common feature is that drivers of these buses are faced with the decision on whether to wait at a particular terminal for full load or gamble on finding passengers by the roadside.

Thus, planners of transit properties are faced with dilemma on which operating policies to enforce. A rational basis to guide the adoption of good operational practices that ensure improved quality of transit service is needed. The aim of the present research is to develop an analytical

tool that will aid the operation planning activities. This study, however, focusses on only an aspect of urban bus operation which is the mode of service employed.

Fixed stops and Hail stops are among the possible mode of service used in intra-urban transit. Under the fixed stop service vehicle stop to load and/or unload passengers at designated points only. For the hail stop service vehicles stop to load and/or unload at any point along the route on demand by patrons.

Conceptually, hail stop service will provide enhanced accessibility but at a slower journey speeds over the fixed stop service. This will therefore:

(i) permit passengers to board anywhere along the route making it unnecessary for operators to provide bus stops
(ii) offer the old and handicapped reduced walking distance.

The enhanced accessibility, however, raises the question of speed-access trade-offs. For example, when does increased accessibility of hail stop begin to be outweighed by unnecessary stopping and starting and associated longer travel times. It seem possible also that on the lowly traffic route, that cost savings that will accrue to the operators by limiting the number of stops will be outweighed by the increased access cost. In this research, capabilities of fixed stop service and hail stop service are evaluated hence an understanding of this access-speed trade-offs will be achieved.

## 1.2 STUDY OBJECTIVES

The main objective of this study is to develop a mathematical model of a bus route that is simple, but comprehensive enough to capture the major influencing factors. The model is then to be used to evaluate the impact of changes in service specifications on level of service and thereby provide the basis for ascertaining when the hail stop mode of service is superior to the fixed stop mode and vice-versa. Thus, the study objectives involve:

- Developing the methodology for comparing the modes of services.
- Modelling performance indicators (walk time, travel time, in-vehicle time, etc.)
- Determining the influence of mode of service on the performance indicators.
- Assessing the influence of demand distribution in terms of concentration in time and/or space through appropriate sensitivity analysis.
- Using numerical examples to illustrate a few applications of the developed models and its data needs.

## 1.3 SCOPE

The groups principally affected by the public transit systems are the operators, users and environment. Policy decisions on public transit system have to consider the interests of these groups. Operator would naturally wish to

adopt policies that minimise their operating cost or maximise their profit margins. On the other hand, users will tend to favour policies that minimise their total travel cost (fare and time costs), and this may lead to operating the system at a deficit or by subsidy. It is clear that the desires of the operators may not always agree with those of the users. Hence the need for system regulation. The regulatory body thus has to look at the system as a whole. In this case a socially more responsive objective will be that of minimisation of the total system cost. This objective has, infact been adopted for similar studies (Adebisi 1982; Hendrickson 1981;Ukponu 1983; among others) in the past.

It is also desirable to compare alternative actions under different viewpoints. In this study the minimisation of total system cost is used as the criteria for comparisons of the mode of services. The scope of the work is confined to the fixed-stop and hail-stop modes of service. Except for the sensitivity analyses, wherein values of parameters have been carefully selected to reflect real-life situations, the analysis is largely theoretical.

## 1.4 STUDY METHODOLOGY

To achieve the objectives set out for this research, a basic bus route model is developed. Mathematical sub-models for users costs, operators costs and total system cost are set up for each mode of service. The sensitiveness of the model variables is explored by varying numerical values of variables. The model is then used to evaluate the relative

performances of the services and to determine conditions for which one mode of service is more desirable than the other, when they are both operated optimally.

Numerical examples are used to establish confidence bands for the comparison of results.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

The review of previous studies on urban public transport systems in both developed and developing countries, as relevant to the topic of this research, is presented in this chapter, with a bias towards findings in developing countries. The review is undertaken in five headings, namely

(i) Unconventional Transport System

(ii) Bus Passenger Trip Time

(iii) Transit Stops

(iv) Generalised Users' Costs

(v) Operators Costs

## 2.2 UNCONVENTIONAL TRANSPORT SYSTEM

In major cities of the developing countries public transport provision largely depend on unconventional transit systems popularly known as Paratransit, Intermediate Public Transport(IPT), etc. In contrast with conventional systems which provide fixed route stage bus services, the bus services provided by IPT operators are usually fixed route, unscheduled, variable but frequent headways, hail and ride services as with commuter omnibus (Maunder and Mbara 1995). Apart from bus like services IPT systems are operated to provide other flexible services (taxi, carpool, subscription buses, etc.). For example, the Jeepneys of Manilla in the

Philippines, Autorickshaws in India, Danfo in Nigeria, to mention a few.

The organisation and operating procedure of these modes vary from city to city. Mostly the ownership of IPT are left to private enterprise in these cities (Bolade 1989; Fouracre and Maunder 1986). This has led to multiplicity of the types of vehicles in a particular city. The types range in complexity from non-motorised human powered vehicles like Becak in Indonesia carrying one or two passengers in taxi-like fashion to converted pick up automobiles operating shared taxi services on a flexible route e.g Silor of Chieng Mai Thailland and the converted van operating a fixed route like bus service, e.g Turkish minibuses in Ankara (Fouracre 1977). A common operational practice with quite a number of IPT divers is to wait at terminals for a good load before leaving, thus having little available capacity for picking passengers along the route, this practice tends to increase the waiting times of passengers along the route. (Fouracre and Maunder 1986).

The use of intermediate transport has become a source of contention (Jacobs and Fouracre 1976). There is, for instance, a growing debate of government involvement,both in respect of ownership and regulation (see, Khezwana and Maunder 1994). A study in Zimbabwe has shown that government participation has greatly assisted in improving the level of service offered the travelling public in Harare (Maunder and Mbara 1993).

The impact of bus regulatory policy in five African

cities has also been studied (Maunder 1990), the main conclusions of his study are:

- The lack of regulation encourages the use of small capacity vehicles, though city size is also likely to be significant explanatory factor, smaller cities requiring smaller vehicles.
- Absence of government control is often compensated by self regulation by transport industry as in Jos (Jos is a local administrative city in central Nigeria).

Recent findings on the initial effect of introducing IPT to a regulated urban transport environment is used to further highlight the issues and problems associated with the mode of transport (Maunder and Mbara 1995). Commuter omnibuses were introduced in Harare to compete with conventional stage bus service the predominant form of public transport in the city. The main point are summarized as follows:

- The introduction of commuter omnibuses increased both the supply and capacity of the public transport system in Harare.
- The level of service improved by the reduction in the average passenger waiting times.
- Generally, passengers perceived the introduction of commuter omnibuses positively and acknowledge

the improvement in public transport services which has ensued.

. The additional routes which were opened have considerably expanded the network.

. Along certain corridors conventional services have diminished thereby constraining modal choice and leaving passengers increasingly dependent on commuter omnibus services. Similar experience has been observed in (Jamieson Mackay & Partners 1981), where minibuses have attracted a significant number of passenger from stage bus companies reducing their service to compensate for loss in passengers. This, however, constitute a disbenefit to stage carriage users.

. Congestion at major boarding locations in city centre appears to have increased, thus adversely affecting other road users and the environment in general.

In general, the quality of the service provided by IPT have been found to be what obtains in conventional stage carriage services in the developing World (Fouracre and Maunder 1986; Maunder 1990). If, however, standard economic comparisons are made, the IPT would be found less cost efficient. For example, the cost of operating minibuses is more than twice as expensive as that of stage buses in terms cost per seat and carrying only half as many passengers per bus employee in Kuala Lumpur (Jamieson MacKay & Partners

1981).

It is evident from these reviews that IPT has a role to play in transport service provision either in competition with and/or supplementary to conventional transport modes. What is however debatable is the optimum nature of this role. It is on this background that the present study aims at developing models/methodology that help in rationalising the operation planning processes, particularly with IPT operations. Associated with this is the understanding of the underlying processes (laws) governing the operation of the mode. This will in a long way assist in the assessment of performance of IPT in its proper context rather than evaluating the system on basis of performance measures developed for use in conventional modes.

## 2.3 BUS PASSENGER TRIP TIMES

Bus passenger trip times have been broadly classified into in-vehicle and out of vehicle time. The latter is the portion of the time a passenger commits to a trip even though the time is not spent in the vehicle, while the in-vehicle time is the time he spends in the vehicle.

### 2.3.1 IN-VEHICLE TIME

The in-vehicle time is made up of three major elements: non-stop running time, delay at patron stop and what may be termed as "general delay".

Delay at stops comprises time spent in actual loading and unloading patron and a "penalty" time. The time for

loading and unloading depend on several factors including fare collection mechanisms, the amount of baggage carried by patrons, number of passengers on the bus and number to board or alight, physical design, number of doorways (Chapman et al. 1977; Hendrickson 1981). It has been observed that bus passengers alight more quickly than board particularly when one man operation is used (Cundill & Watts 1973; Fouracre et al. 1981). Penalty time is subdivided into dead time and penalty for stopping. Penalty for stopping is due to deceleration to and acceleration from the stop. Dead time is the period which the bus is stationary before any embarking or disembarking. It depends on whether passengers are to board or alight or both (Chapman et al. 1977; Fouracre et al. 1981). A number of researchers have assumed dead time to be constant (e.g Cundill & Watts 1973; Adebisi 1986). However, in situation where passengers lack knowledge of bus schedule and often inquire about bus destination, bus passenger tend to waste more time because of patron inadequacies, bus dead times seems passenger/driver dependent (Chiejina 1982). Chiejina fitted the exponential distribution to his observed dead time data.

General delay comprises stop delays and traffic and roadway delays. The latter is due to traffic conditions, weather conditions, etc. that induce the bus drivers to maintain speed of travel less than the desired speed. Stop delay occurs during the period which the vehicle is stationary(e.g at traffic signals). The general delay depends on the speed of other traffic on the link, road design,

probability of delay, amount of time spent in each delay (Chapman et al. 1977; Fouracre et al. 1981)

Passengers already on board suffers all the different types of delay mentioned above. Generally stop represent disutility to current riders as additional patron imposes burden on them; incremental vehicle travel time for a new boarding might range from 13 to 20 seconds (Hendrickson 1981).

### 2.3.2 OUT OF VEHICLE TIME

Passengers' out of vehicle time is made up of two components: the waiting time and walking time (access/egress time).

The waiting time experienced by a transit patron is one of the most important elements of the level of service provided by a public transport system. It consist of (i) the waiting time at the point of boarding and (ii) schedule delay. The latter represents the extra time a user commits to a trip because his actual arrival time at his destination differs from his preferred arrival time. Several previous studies have investigated passengers' waiting time at a stop. Several mathematical models have been proposed for its computation. For example, when random arrival of patrons, unlimited vehicle capacity, frequent and regular spacing of vehicles on a route are assumed, the commonly used model asserts that the average time patron have to wait before a bus is one-half the headway. Some other researchers have proposed modifications that have general application. Among

them, Osuna and Newell (1972) proposed that waiting time at particular loading point is as given in equation 2.1, i.e:

$$E(w) = \frac{h}{2}[1 + (\frac{\sigma}{h})^2] \qquad 2.1$$

where h= the mean headway

σ = standard deviation of the headway distribution

Equation 2.1 still assumes infinite capacity for buses and that passengers always board the first bus to arrive at the loading point. Vehicle capacity may be exceeded for one (or more) trips due to fluctuation in demand or in headways. Thus, some patrons have to wait for subsequent vehicle. The inability of passengers to always board the first arriving bus clearly affects their waiting times. The simplistic random arrival waiting model no longer suffice. A simple modification proposed by Fouracre et al. (1981) is:

$$E(w) = \frac{h}{2}(1 + (\frac{\sigma}{h})^2) + h(P_1+P_2) \qquad 2.2$$

where $P_1$ and $P_2$ are the probabilities of being unable to board the first and second buses respectively.

h and σ is as defined above (equation 2.1)

This modification offer a better explanation for the observed waiting time data from their studies on bus operation in Delhi, India.

If buses tend to adhere to a fixed schedule and there are passengers who make the same trip frequently, a

proportion of the passengers are then likely to coordinate their arrival time with bus schedule so as to minimise their wait times at the points of boarding. The proportion of the passenger aware of schedule are termed as "aware" passengers. The manner in which "aware" passengers select their arrival times have been investigated (Turnquist 1978; Bowman & Turnquist 1981).

The influence of passenger volume on patron waiting time was studied by Hendrickson (1981). He found that effect of volume depends on behaviour of patrons and vehicle capacity. For example, in the case of 'aware' passengers volume which is higher than normal results in waiting time increase of the same amount as the external delay impose on current rider by a new patron.

Traditionally planners and system operators have tended to reduce the magnitude of wait time through increases in frequencies of bus service. Hibbert(1994) has taken a new direction in undertaking preliminary studies on appraisal of impact of environmental improvement through infrastructural provision at station on the disutility of waiting for a bus at stations. It is believed that an improved waiting environment would reduced the disutility associated with waiting.

Another important element of the level of service provided by a bus service is the walking time to and from a bus stop. It has been shown that the magnitude depends on the network of street, density of the bus route, spacing of bus route and spacing of bus stops (Chapman et al. 1977). UK

Department of the Environment (DOE) has recommended walking distance of not more than 400 metres from the furthest house to a bus stop for a new residential development (DOE 1973). A study in the US has also shown that the average time taken to final destination after alighting from a mass transit system is 4.5 minutes (Fort 1973).

## 2.4 TRANSIT STOPS

A transit stop/station represents an interface between the passenger and the transit system. Hence, its number and location is important operating policy variable. The complexity of transit stop depends on the mode of service employed on the route. With the hail and ride service, gathering points of passenger are formed along the route which more or less, constitute surrogate stops. With fixed stop operation, complexity of stop ranges from a simple signpost to a grandiose building.

In order to minimise the access to a transit system, the UK Department of Environment has issued guidelines on stop spacing (DOE 1973). Other researches have also been carried out studies on stop spacing notably among which are those of Lesley(1976), Chapman et al.(1976) and Vaughan and Cousins(1977)

Lesley in his paper developed a theoretical model of an individual urban route which was used to determine the optimum distance between stops. Optimisation was under two criteria: Bus passenger generalised costs and total community costs. The optimum bus spacing, he derived was considerably

less than the recommendations of DOE. Chapman et al. from a simpler model gives optimum number of stops per kilometre which minimises the time of a passenger journey of L Km. Vaughan and Cousins derived stop spacing from a more sophisticated model which allows for 'many - to - many' trips by the use of a continuous function to describe the joint distribution of origins and destinations.

*Fixed and flexible stops are the possible options of the* mode of operation employed on a route. Fixed stop service serves to reduce the number of stop and hence reduce the accessibility to transit vehicle. Flexible stops e.g hail stops offered increased accessibility to patron, particularly the choice of alighting points. Robson and Hall(1988) studied the perceived influence of introduction of Hail stop service on residents of low status housing estate in UK. They found that most residents found the service helpful but a fewer used it mostly for alighting. Similarly, in Israel, current *riders of Sherut taxi (Hail and ride shared taxi) in a survey* stated that the main loss that will result in the discontinuing Sherut operation is the choice of alighting points (Salomon and Silman 1985). It is necessary to know when the increased accessibility is outweighed by stop and start manoeuver of frequent stoppings. Such knowledge will guide on when and where hail - stop service should be introduced.

## 2.5 GENERALISED USERS' COSTS

Costs associated with bus trips consist of a number of quantifiable and non-quantifiable components. The latter includes discomfort, inconveniences and overcrowding while the former includes walking time, in-vehicle time and fare paid. The generalised users' costs of passenger should consist of weighted sum of the quantifiable components. Mc Intosh and Quarmby (1970) recommends a certain procedure. The main relevant points are :

(i) Generalised cost should be considered a linear sum of its component variables, each with a coefficient reflecting its relative importance.

(ii) The variables to be included are time and money costs

(iii) Time spent in different activities (namely, in - *vehicle, walking and waiting) should be seperately* identified and given seperate coefficients.

(iv) All coefficients should be divided by the coefficients for in-vehicle time in order that all the terms in the equation should be expressed in common units.

Weights to attach to components of the generalised costs with respect to in-vehicle time have been subject of a series of research. Quarmby (1967) while combining all travel time not spent in a vehicle into "excess time" found a coefficient 2.3 times that of in-vehicle with one group, and 2.6 for

another. Costinett (1973) gave walking time a weight of 1.7 and waiting time 2.2. Morhring (1972) in review of previous studies stated that "excess time" between the ranges of 2 to 3 is adopted by most public transit researchers.

Goodwin (1976) proposes a three component approach to generalised cost, i.e :

$$G = \sum T_i + \sum E_i + M \qquad 2.3$$

where G is the generalised cost

$T_i$ is the time spent in activity i (walking,waiting etc.) $E_i$ is effort spent in activity i

M is money spent

'Effort' is related to such variables as comfort, *irritation, physical and mental stress, overcrowding,* protection from weather, etc. Goodwin's proposal seeks to focus attension on the importance of factors (e.g comfort, convenience, etc.) which, although experienced over time are nevertheless logically distinct from time and capable of independent manipulation from time. It also provides framework whereby the effects of changes in these factors may be quantitatively estimated and evaluated.

The quantification in monetary terms of time spent travelling has resulted in numerous controversies, many of which have not been resolved. There is considerable amount of empirical knowledge about the subject and many doubts still exist on how to quantify time savings or losses. This situation had arisen because research in the field had been less aware of the theoretical issue involved (Brezelius

1979). It has also been argued that it is only through careful consideration of the theoretical implications of a model which has a sound theoretical basis that meaningful interpretations of results can be made. Otherwise, some modellers, because they have not derived the theoretical implications, are unsure of the meaning of their results (Watson 1974).

The benefit of travel time savings accrues to different classes of transport users, the vehicle occupants and commercial vehicle owners. Time savings for passengers in bus, car and taxi may occur during working or non-working time. Working time savings should be valued at the average wage rate, plus overheads (TRRL 1988). Some other researchers have valued time as a percentage of wage rate (e.g Quarmby 1967; IAURP 1969; Watson 1974). Non-working time is usually based on perceived cost studies. Some studies show that the value of travel time savings in period of leisure is between 25 to 45 percent of individual earnings (TRRL 1988).

Valuing time savings in developing countries should be done cautiously. Thomas (1983) valued non-working time between 25 - 55 percent of wage rate for different categories of road users. CRRI (1982) report the result of user cost study in India. Bus passenger time was valued at mean hourly wage rate plus 20 percent as overhead. Leisure time was not evaluated, however, Kadiyali (1991) suggest 25 percent of work time value for India environment. Ukponu (1983) in studies on operating strategies for intra urban transit used 18.75 kobo/hr as the unit value of time being 25 percent of

the low income earnings in Nigeria at the time he undertook the study. This value he adopted in cognisance of the fact that in the case of Nigeria, most users of public transport are captive to it and are mostly from low income group. However, TRRL (1988) is of the opinion that to use a percentage of the average wage rate lead to an underestimation of time costs in developing countries because only the comparatively wealthy can afford to travel even by bus and certainly by car.

Fares paid by patron are generally viewed from two distinct but interrelated viewpoints; the fare level and fare structure. Fare level is the money values at which fares are charged, which could range from being entirely free to being set at a level which enables the service to run at profit (Mbara and Maunder 1994). Fare structure relates to the principle under which the fares are set. It generally of two types. The fixed and graduated fares.

Flat fares are paid regardless the distance travelled at a fixed amount. Graduated fare structure will give larger amount of information to transit operators/planners (e.g passenger lead) than flat fare (TRRL 1987). The flat fare is easier to collect and it permits innovative fare collection mechanisms to be developed.

The effect of fare increases on patronage is to decrease patronage particularly short trips and discretionary journeys which are made largely during weekends and during off-peak periods. It may also lead to a reduction in evening peak patronage than morning peak as patrons may resort to walking

back home after work but use public transport for the journey to work to enable them to arrive at their place of work in time (Mbara and Maunder 1994).

## 2.6 OPERATOR COSTS

Different aspect of vehicle operating costs have received attention of researchers for a number of years in the developed World. Among the earlier research works are those of Moyer and Winfrey (1939), Sawhill and Firey (1960).

An earlier research on operating cost focussed on developing countries is that of de Weille (1966). De Weille based on American experience prepared cost tables for developing countries, which relied heavily on Winfrey (1963) as its source of primary data. It became clear after publication of de Weille's work that results based on American vehicles and environment are not appropriate for predicting consumption in developing countries which are faced with different physical and economic environments. These environmental incompatibilities and the need for economic appraisal of highway investment in developing nations led the World Bank to initiate a program of research to develop cost model relevant to developing countries. The result of this initiative was a series of studies undertaken in 1971 and 1982. The report of these studies are contained in Hide et al. (1975), GEIPOT (1981), Morosiuk and Abaynayaka (1982) and CRRI (1982). The components of vehicle operating costs estimated in the studies are fuel, engine oil, tire maintanance, depreciation, interest and crew costs. The

highway characteristics measured include roughness, horizontal curvature, rut depth, altitude and width among others. Some important vehicle characteristics relevant to the studies are vehicle age, gross vehicle weight, power to weight ratio, projected frontal area of vehicle etc.

Chesher and Harrison (1987) explained the theory and estimation procedure of the vehicle operating cost used in the cost studies discussed above. They point out the limitation of the studies' results and their transferability to other environments. In their work, where necessary, a reanalyses of the original data were done. They were thus able to come up with new estimates that permit some level of comparisons to be made between the different estimates obtained from the original work.

The user cost studies referred to above are concerned mainly with the influence of highway conditions on transport costs without much consideration to the demand side of the market. Another limitation of the studies, in context of urban setting, is that the results are for non-urban highways. Extensions would need to be made to adapt result of the studies to urban environment.

Based on published findings, the structure of operating costs in cities of developed and developing countries revealed interesting differences. In UK, for example, the major cost component which constitute about two-thirds of the total, is wages of staff, with maintenance and spares making up most of the remainder. Operating costs in the developing countries cities were markedly different, with

staff costs being about one-third of the total, but fuel and depreciation constituted much greater fraction of total costs than UK. In Blantyre and Lilongwe, the main urban centres of Malawi, the cost of fuel actually exceeded staff costs and represented a remarkable 40 percent of total operating costs. Another major difference is proportion of total costs allocated to depreciation and interest charges. In many developing countries the operational lives of buses are often short; sometimes as low as six years; consequently vehicles have (in theory) to be replaced at very short interval of time and depreciation are correspondingly high (Jacobs et al. 1986, 1987)

Fuel consumption, at present, account for the largest percentage of total vehicle operating cost in developing countries. Hence, a more detailed understanding of fuel consumption as related to physical phenomena that influence it becomes necessary, particularly at urban centres. Chang et al. (1976) had calibrated a simple linear equation which can be used to predict fuel consumption as a function of distance (i.e the reciprocal of the average speed) in an urban traffic. They explained that the simple linear equation which they formulate for fuel consumption was due to the fact that the most relevant traffic variables are correlated with average trip time.

# CHAPTER 3

# MODEL FORMULATION

## 3.1 INTRODUCTION

A simple bus route model is to be constructed to bring together independent variables that influence the operation of urban bus services.

An idealised fixed bus route along a straight road centrally located within a rectangular service area is used. The overall organisation of the model system is illustrated in Figure 3.1. The mode of service used are Hail stops and/or fixed stops.

Under the fixed stop service which is assumed, the vehicles ply the route with patron stops made only at designated points. For the Hail stop service which is also considered, patron stops are made at any point along the route on request.

The model specification include basic component models of users, operators and total system costs.

The service specification determines the vehicle operating and the level of service provided. The cost of travel is derived from the level of service (performance) measure. Ridership is also affected by the level of service provided and vice-versa as shown in Figure 3.1. The objective function is the linear combination of all the other cost components.

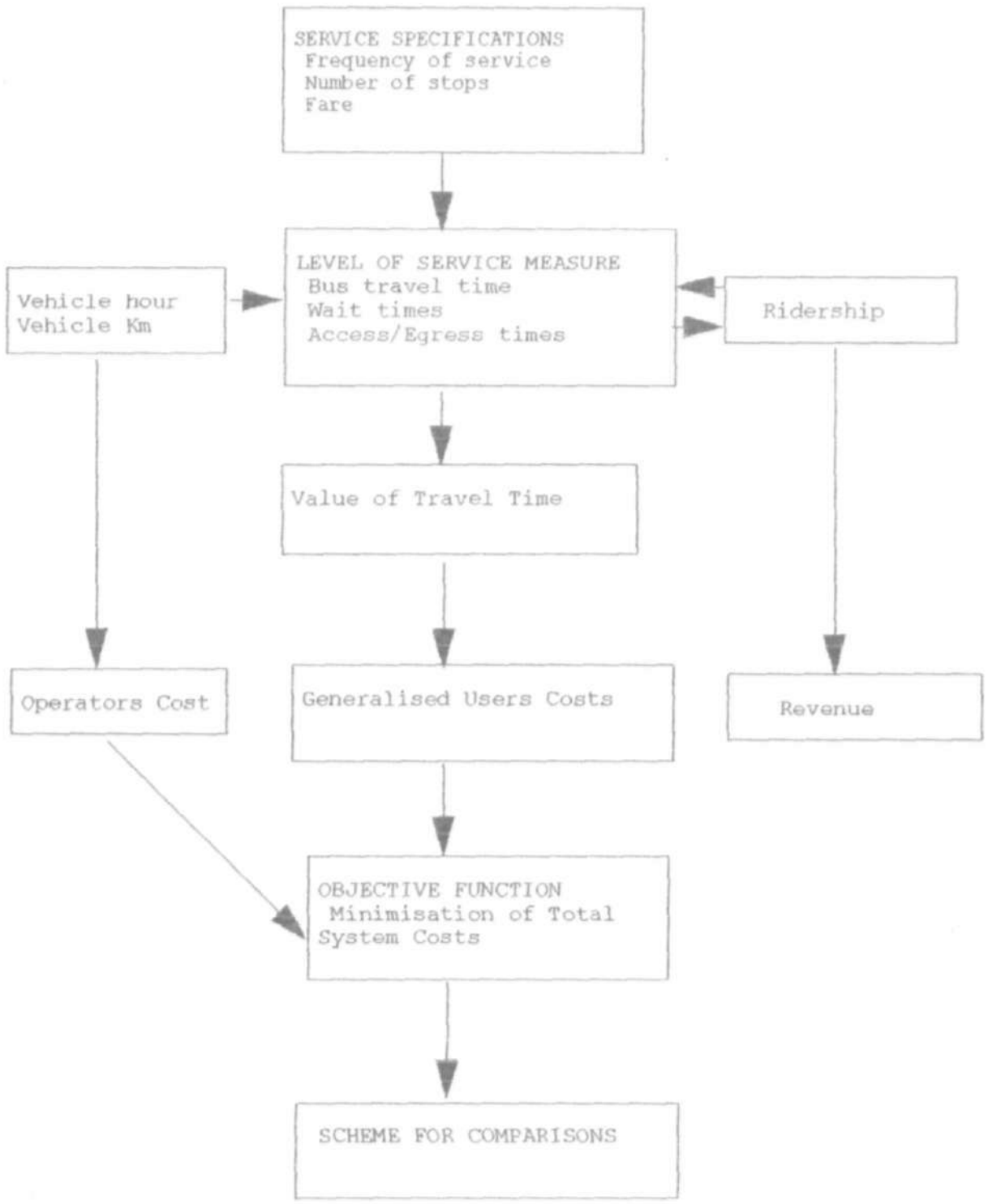



Figure 3.1 OVERVIEW OF THE MODEL SYSTEM

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### 3.1.1 BASIC ASSUMPTIONS

(i) All buses used are identical in performance but they are of various sizes.

(ii) All passengers are captive to the public transport mode and will always travel regardless of the service on the route

(iii) The effect on ridership due to small changes in service specification is negligible.

The assumption (ii) and (iii) above are justified in the case of Nigeria where users are largely captive to the mode used. Also, wide range of measures designed to revamp the country's ailing economy have been applied. This, among other things, resulted in the considerable devaluation of the local currency. Associated with this, prices of imported and locally assembled cars increased. Thus, purchase of cars for private transport and commercial operations decline drastically. In Lagos, for example, new registration of commercial vehicles went down from over 500 in 1983 to as low as 800 in 1987 (Bolade 1989). The gap that had existed between supply and demand for public transport was further amplified. The resultant effect became dependence on public transport by majority of populace for urban travel.

## 3.2 USERS COSTS MODEL

Users' costs consist of fares and costs attributable to their time commitment for the trip.

The total time commitment comprises of time spent inside the vehicle and time spent outside the vehicle (e.g waiting, walking). Total trip time is defined as consisting of the time a patron leaves his origin to when he reaches his destination. If it is supposed that $V_0$ is the value of time spent outside the vehicle and $V_i$, value of time spent inside the vehicle. Then, the average users cost, USC is given as

$$USC = (IVTT)V_i + (WKT + WTT)V_o + F \qquad 3.1$$

where IVTT is the average in-vehicle travel time

WKT is the average walking time

WTT is the average waiting time and

F is the fare paid.

Since fare paid constitutes a transfer of benefit from one sub system to another, it is therefore internal to the system. It is ignored in subsequent evaluations as suggested by previous researches (Adebisi 1982). In equation 3.1 a constant time value is assumed. This erroneously implies that all users attach the same value to travel time and that marginal utility of travel time is constant regardless the time length of trip (Adebisi 1982). However, as the passenger are captive to the mode and passenger trip lengths for intra urban travel are seldom long the assumption made is reasonable. Also, the time costs reflect society's values rather than the individuals. For demand forecasting

individual's values would be more relevant.

The value of out-of-vehicle time ($V_0$) is greater than in-vehicle time because trip makers are willing to pay more to save out-of-vehicle time than in-vehicle time.

For analytical convenience the in-vehicle travel time IVTT, is taken to be a fraction σ, of the vehicle travel time, VTT.

$$IVTT = \sigma . VTT \qquad 3.2$$

where $0 \leq \sigma \leq 1$

The vehicle travel time consist of non-stop travel time and dwell time for patron stops.

$$VTT = t_{ns} + n\Psi \qquad 3.3a$$

where, $t_{ss}$ is the non-stop travel time, $\Psi$ is the average dwell time per stop, and n is the number of patron stop.

The non-stop travel time depends on the speed of traffic on the roadway, frequency of delays and durations of individual delays encountered (Chapman et al. 1977)

The dwell time per stop is dependent on the marginal boarding and alighting times, number of passengers boarding and alighting, arrival rate of passengers, time since the previous bus time penalty for stopping at each stop (Cundill & Watts 1973; Chapman et al. 1977). Where boarding and alighting are assumed not to be undertaken simultaneously, the dwell time $\Psi$ is approximately given by equation 3.3b, i.e:

$$\Psi = t_d + t_{ps} + (t_a + t_b)Q_i/n \qquad 3.3b$$

where $t_a$, $t_b$ are marginal alighting and boarding times

respectively, $t_d$ is the dead time, $t_{ps}$ is the extra time required for acceleration and deceleration for patron stop (compared to not making the stop). n is the number of patron stop. $Q_i$ is the number of passenger per unit time at the time period of interest i. i, is an index indicating I distinct periods during which variables such as ridership, frequency may be different (e.g peak, offpeak).

For the case where alighting and boarding are done simultaneously, some slight modification of equation 3.3b is necessary.

Substituting equation 3.3b into equation 3.2, we have:

$$VTT = t_{ns} + n(t_d + t_{ps}) + (t_a+t_b)Q_i \qquad 3.3c$$

For fixed stop operation involving n stoppings per trip,

$$VTT = t_{ns} + nt_p + KQ_i \qquad 3.3d$$

where $K = t_a + t_b$ ; $t_p = t_d + t_{ps}$ 3.3e

n = number of actual stoppings per trip.

$t_p$= penalty time and

K = patron service time.

For Hail stop operation

The average number of stops, n, that are made during a bus trip is given by

$$n = jQ_i \qquad 3.3f$$

where j is dependent on passenger trip ends, $0 \leq j \leq 2$. For the case where no common origin and destination is recorded, j = 2. If all passengers board at point of origin and are all bound to the end of route j = 0. Other likely situations lie within the two extreme situations described. Thus,

$$VTT = t_{ns} + Q_i(t_a + t_b) + jQ_i t_p \qquad 3.3g$$

$$VTT = t_{ns} + K'Q_i \qquad 3.3h$$

In order to simplify equation 3.3g we introduce:

where $K' = (t_a + t_b + jt_p)$

Combining equation 3.3d and 3.3h gives

$$VTT = \begin{cases} t_{ns} + nt_p + KQ_i & \textit{Fixed stops} \\ t_{ns} + K'Q_i & \textit{Hail stops} \end{cases} \qquad 3.3j$$

The wait time experienced by bus passengers has been found out to be generally a function of headway, vehicle capacity and service reliability. Headway, h, by definition is time interval between successive vehicles measured from head to head (bumper to bumper) as they pass a given point on the roadway. If random patron arrival obtains and unlimited vehicle capacity is assumed, the average wait time can easily be shown to be as equation 3.4a, i.e.

$$WTT = \frac{h}{2}\left[1 + \frac{Var(h)}{h^2}\right] \qquad 3.4a$$

When there is vehicle capacity limitation equation 3.4a is modified (Fouracre et al. 1981) to :

$$WTT = \frac{h}{2}\left[1 + \frac{Var(h)}{h^2}\right] + h[P_1 + P_1] \qquad 3.4b$$

where h is mean headway

Var(h) is variance of headway distribution

$P_1$ and $P_2$ are probabilities of being unable to board the first and second buses respectively.

Equations 3.4a and 3.4b can conveniently be reduced to give

$$WTT \simeq ah \qquad 3.4c$$

where a, is constant whose actual value depends as shown already, on the circumstances along the route.

For the case where passenger arrive randomly, vehicle capacity is unlimited and vehicle are dispatched randomly, $Var(h) = h^2$

Therefore $a = 1$ and $WTT = h$ 3.4d

The expression derived for waiting time is relevant for both services.

The distance from a house to a bus stop depends on the characteristics of the network, spacing of bus stops, etc. If grid network of street is assumed, to simplify the analysis and the width of catchment area surrounding each stop is W, measured at right angles to the route. For a route length L, with passenger trip ends uniformly distributed over the catchment area, the average walking time to and from a stop is given as :

$$WKT = \begin{cases} \frac{W}{2u} + \frac{L}{2us} & \textit{Fixed stops} \\ \frac{W}{2u} & \textit{Hail stops} \end{cases} \qquad 3.5$$

where u is the walking speed, s is the number designated stops on the route.

Substituting equation 3.2, 3.3, 3.4c and 3.5 in the average users' cost per passenger equation (3.1), we have

$$USC = \begin{cases} \sigma V_i(t_{ns} + KQ_i + nt_p) + V_o[\frac{W}{2u} + \frac{L}{2us} + ah] & \textit{Fixed stops} \\ \sigma V_i(t_{ns} + K'Q_i) + V_o[\frac{W}{2u} + ah] & \textit{Hail stops} \end{cases} \quad 3.6$$

## 3.3 OPERATORS COST MODEL

Operating costs, in developing countries, are more sensitive to distance than duration of operation. This is because the major components of operating costs such as fuel, depreciation, etc. are more intensely affected by distance covered. Staff cost which is sensitive to time is about one-third the total operating cost in cities of developing countries (Jacob et al. 1986).

For the discussion of operating cost in urban centre, it is convenient to classify cost under two principal headings, "Normal" and "Excess". "Normal" operating costs is defined as the cost of operating a vehicle on the highway with no stops made to load or unload passenger. This could be referred to as non-stop operating costs. However, stops are made along the trip due to traffic and roadway conditions. "Excess" operating costs is thus defined as the cost over and above the normal operating cost incurred due

to stops made to service patrons. This can be described as "penalty" cost. The excess operating cost is further divided into acceleration/deceleration cost which is due to vehicle decelerating and accelerating to make a patron stop. Similarly, the idle time cost which results from time taken to service the passenger at stops i.e period which the vehicle is stationary may be referred to "passenger service" cost.

The normal operating cost, denoted as $\gamma_1$, is sensitive to distance. It is identical to the cost estimate from users cost studies on vehicle operating cost in developing countries for non-urban highways reported in Chesher and Harrison (1987). The acceleration /deceleration cost on a trip will depend on the number of stops made during the trip, average speed, vehicle accelerating and decelerating characteristics. It needs to be monitored over a distance on the route to be able to properly quantify this penalty cost. For this work it is denoted as $\gamma_2$. Indications from fuel consumption experiments and surveys on vehicle operating costs is that the frequent stop-and-go motion, among other aspects of driver behaviour, is responsible for the higher fuel consumptions recorded in the users survey than the controlled experiments . A scaling factor of 1.31 - 1.61 was used to correct the differences in the fuel consumptions recorded in the two studies (CRRI 1982) (i.e the scaling factor is used to multiply the controlled experiments' measurement). Consequently, other cost component would be affected for example it should expected that wear and tear

will increase in tire and engine etc. due to frequent decelerating and accelerating. There has been no study which indicates exactly how frequent acceleration/deceleration affect vehicle operating cost. As such the decelerating/accelerating cost is assumed to be related to the normal operating cost in this study.

Studies in India (CRRI 1982) measured fuel consumption at idle periods during forced stops. This yield an estimate for idle time cost, $\gamma_s$, which depends on the duration of loading and/or unloading patrons, and number of stops. Hence, the idle cost is sensitive to time, it is therefore measured in cost per unit time period.

From the foregoing discussions, the average operator costs per patron, OPC, can be expressed as:

$$OPC = \begin{cases} \dfrac{(\gamma_a L' + \gamma_a n L_p)}{Q_i} + \gamma_s\left(K + \dfrac{nt_d}{Q_i}\right) & \textit{Fixed stops} \\ \dfrac{(\gamma_a L' + \gamma_a Q_i j L_p)}{Q_i} + \gamma_s(K + jt_d) & \textit{Hail stops} \end{cases} \qquad 3.7$$

where L' is the effective route length i.e total route length less the penalty length, $L_p$, defined as that part of route where acceleration and deceleration manoeuvres took place.

To simplify the expression above it is assumed that for reasons discussed earlier that $\gamma_a$ is related to $\gamma_d$ as follows

$$\gamma_a = 1.1\gamma_d \qquad 3.8$$

where $\gamma_d$ is the acceleration/deceleration cost and $\gamma_a$ is the

normal acceleration cost.

The operators costs per passenger will thus become

$$OPC = \begin{cases} \frac{\gamma_p}{Q_i}(L + 0.1nL_p) + \gamma_s(K + \frac{nt_d}{Q_i}) & \textit{Fixed stops} \\ \frac{\gamma_p}{Q_i}(L + 0.1jQ_iL_p) + \gamma_s(K + jt_d) & \textit{Hail stops} \end{cases} \quad 3.9$$

## 3.4 TOTAL SYSTEM COST MODEL

The objective function which is to be minimised is the total system cost per passenger, Z. The total system cost is the sum of users costs and operator costs, i.e

$$Z = USC + OPC \quad 3.10$$

By substituting equations 3.6 and 3.9 in the above expression, we have:

$$Z = \begin{cases} \sigma V_i(t_{ns} + KQ_i + nt_p) + V_o[\frac{W}{2u} + \frac{L}{2us} + ah] \\ + \frac{\gamma_p}{Q_i}(L+0.1nl_p) + \gamma_s(K+\frac{nt_d}{Q_i}); \quad \textit{Fixed stops} \\ \sigma V_i(t_{ns} + K'Q_i) + V_o[\frac{W}{2u} + ah] + \frac{\gamma_p}{Q_i}(L + 0.1\,Q_iL_p) \\ + \gamma_s(K + jt_d); \quad \textit{Hail stops} \end{cases} \quad 3.11a$$

An average passenger flow rate of $g_i$ passenger is assumed. The ridership rate is normally dependent on the time of the day, with peak flow rate higher than the offpeak passenger traffic. It is also assumed that $g_i$ is constant but

vary with time of day. i is an index indicating the time period at which ridership is considered (e.g peak or offpeak).

The average number of passenger per bus trip $Q_i$, is by definition

$$Q_i = g_i h \qquad 3.11\ b$$

where h = headway between buses

Then substituting above expression into equation 3.11a, we have:

$$Z = \begin{cases} \sigma V_i(t_{ns} + Kgh + nt_p) + V_o[\frac{W}{2u} + \frac{L}{2us} + ah] \\ +\frac{\gamma_n}{gh}(L + 0.1nL_p) + \gamma_s(K + \frac{nt_d}{gh}) \ ; \quad \textit{Fixed stops} \\ \\ \sigma V_i(t_{ns} + K'gh) + V_o[\frac{W}{2u} + ah] + \frac{\gamma_n}{gh}(L + 0.1jghL_p) \\ + \gamma_s(K + jt_d) \ ; \qquad \textit{Hail stops} \end{cases} \qquad 3.12$$

The expression defined for Z in equation 3.12 constitute the basis on which subsequent analytical manipulations are based. The focus of work done is to determine the conditions for which each type of service can be optimally operated. The two optimal states are then compared to determine when one is better suited for service than the other.

# CHAPTER 4

## ANALYSES OF OBJECTIVE FUNCTION

### 4.1 MINIMISATION OF THE TOTAL SYSTEM COST

The route configuration has been assumed for this study, the dispatch headway is the only design variable to be optimised for each mode of service.

Considering the fixed stops mode of operation, we have the objective function from equation 3.12 as :

$$Z = \sigma V_1 K g h + V_o a h + \frac{\gamma_n}{gh}(L + 0.1nL_p) + \gamma_s \frac{nt_d}{gh} + T_1 \qquad 4.1$$

$T_1$ are terms that do not contain h

Partially differentiating the objective function with respect to h gives $h_1^*$

$$\frac{\partial Z}{\partial h} = \sigma V_1 K g + V_o a - \frac{\gamma_n}{gh^2}(L + 0.1nL_p) - \gamma_s \frac{nt_d}{gh^2}$$

For Z to be minimum

$\frac{\partial Z}{\partial h} = 0$ *and* $\frac{\partial^2 Z}{\partial h^2} > 0$ *and* $h = h_1^*$ *is the corresponding headwa*

$$\frac{\partial^2 Z}{\partial h^2} = \frac{\gamma_n}{gh^3}(L + 0.1nL_p) + \frac{nt_d}{gh^3}\gamma_s$$

which is greater than zero for the range of values applicable to the bus routes. This implies that the function is minimum at $h_1^*$.

So

$$\frac{\partial Z}{\partial h} = 0$$

$$\sigma V_1 K g + V_o a - \frac{\gamma_n}{gh^2}(L + 0.1nL_p) - \gamma_s \frac{nt_d}{gh^2} = 0$$

Rearranging the above expression

$$h_1^* = \sqrt{\frac{\gamma_n(L + 0.1nL_p) + \gamma_s nt_d}{\sigma V_1 K g^2 + V_o a g}} \qquad 4.4$$

For the Hail stop mode of operation, the objective function from equation 3.12 is :

$$Z = \sigma V_1 K' g h + V_o a h + \frac{\gamma_n L}{gh} + T_2 \qquad 4.5$$

where $T_2$ are terms that do not contain h.

Partially differentiating with respect to h gives $h_2^t$

$$\frac{\partial Z}{\partial h} = \sigma V_1 K' g + V_o a - \frac{\gamma_n L}{gh^2} \qquad 4.6$$

For Z to be minimum,

$$\frac{\partial Z}{\partial h} = 0 \text{ and } \frac{\partial^2 Z}{\partial h^2} > 0 \text{ and } h = h_2^* \text{ is the corresponding headway}$$

$$\frac{\partial^2 Z}{\partial h^2} = \frac{\gamma_n L}{gh^3};$$

this is greater than zero for the range of values applicable to the bus route. The objective function is minimum at $h_2^t$

$$\sigma V_1 K' g + V_o a - \frac{\gamma_n L}{gh^2} = 0 \qquad 4.7$$

Re-arranging the above expression

$h_2^t$ is the optimum headway for the hail stop service. The

$$h_2^* = \sqrt{\frac{\gamma_s L}{\sigma V_i K' g^2 + V_o a g}}$$

optimum headway derived for the two services are subject to vehicle capacity contraint. If we let M correspond to vehicle capacity at the maximum load point on the route. Then the optimum headway constrained by vehicle capacity is given as

$$h^* = \frac{M}{g} \qquad 4.9$$

Combining equations 4.4, 4.8 and 4.9 the optimum headway is given as follows:

$$h^* = \begin{cases} \sqrt{\dfrac{\gamma_n(L + 0.1nL_p) + \gamma_s n t_d}{\sigma V_i K g^2 + V_o a g}} & ; \ \text{if } h^* g < M \text{ for fixed stops} \\ \sqrt{\dfrac{\gamma_n L}{\sigma V_i K' g^2 + V_o a g}} & ; \ \text{if } h^* g < M \text{ for Hail stops} \\ \dfrac{M}{g} & ; \ \text{otherwise for both services} \end{cases} \qquad 4.10$$

For subsequent analyses we specifically focus on many-to-one and one-to-many O-D patterns. These characterise the collection and distribution phases of transit patronage. The collection phase is normally in the morning peak where patrons from densely populated residential area are carried to major activity centres while the distribution phase is at evening peak when patrons from high activity centres(e.g CBD) are dropped at their residential area. If the passenger trip ends are uniformly distributed, $\sigma = 0.5$. For the O-D pattern considered $j = 1$ and with random vehicle arrival $a = 1$.

## 4.2 SENSITIVITY ANALYSES

Sensitivity analysis can be used to isolate the most important variables affecting a function. It is undertaken when one variable is altered by a given amount while the other variables are held constant. The resulting change in function is noted. The variables producing the greatest changes to the value of the function are thus the most influential. This operation is termed as first level sensitivity analysis of the function. As a subsequent step, these most influential variables are altered over a range to determine their effects on the function. This is called the second level sensitivity analysis.

Sensitivity analysis will be performed on the optimum headways and the total system costs. This approach has become necessary because there is a limited scope for direct analytical manipulation of the derived functions.

### 4.2.1 MODEL SPECIFICATION

It is necessary to specify numerical values for some of the variables contained in the model to facilitate exploration of its sensitiveness to the design parameters. A service area of length 8 km and width 1 km is used. Two operating periods are considered, namely the peak and off-peak periods. The numerical values assumed for variables in the functions have been carefully chosen to reflect practical values. Hence, the values are derived from studies in developing countries in as much as possible. Liberal extractions are made from Fouracre et al. (1981) as well as

Chesher and Harrison (1987).

*Chesher and Harrison (1987) reported four users cost* studies on vehicle operating cost that were conducted between 1971 and 1982 in Kenya, the Eastern Carribeans, Brazil and India. In their report they discussed the transferability and use of costs equations developed from these studies. They cautioned that it is important to consider vehicle design and the local economic environment before the choice of cost equations are made. In the absence of users cost study in Nigeria, findings from the Brazilian study and modifications by Chesher and Harrison are used. The vehicles assumed in making estimates of the operating cost is of the light goods *vehicle category, gross vehicle weight 2100 Kg, a 24 seater* minibus(e.g Nissan Civilian).

In CRRI (1982), fuel consumption characteristics while idling were reported. Values of between 12.3 cc - 35 cc per min. were observed. For light goods vehicle, 14.00 cc/min is estimated as being adequate. The total operating cost estimate arrived at following suggestions given by Chesher and Harrison with other simplifying assumptions is ₦12.60 per *kilometer for the light goods vehicle.*

Relevant extractions are now made from Fouracre et al. (1981), of journey time components. Penalty for stopping was found to be 13 seconds per stop on the average although average value of 9 seconds was monitored elsewhere (Chapman et al. 1977). The dead time per stop for single decker two doors vehicle was found to vary from 3.0 to 3.4 seconds depending on whether it is during off-peak or peak period or

boarding/alighting occurred. Higher values were reported in Chiejina (1982) for the same type of vehicle. The total delay to a vehicle caused by its interaction with other traffic increased journey time by 38 percent on one route at peak period and 30 percent at the off-peak. The operating speed was set at 50 km/h for single deck buses. It is to be expected that a higher operating speed is attainable by smaller vehicles. Hence, a value of 60 km/h is adopted for light goods vehicles at peak period in this study. This would appear to be an under estimation of speed given in Chesher and Harrison (1987) for vehicle capacity considered (72.1 km/h). However, this speed (72.1 km/h) was measured for non-urban highway, thus it is reasonable to step down the value to the one assumed above for intra-urban operation. Moreover, in Nigeria, a speed limit of 56 km/h is imposed on commercial vehicle operation within urban areas.

The penalty length, $L_p$, being the length through which stopping and starting maneouvres are achieved is derived by multiplying penalty for stopping with average operating speed.

The average stop spacing is taken to be 400 m (i.e about 2.5 stops per kilometer) for the fixed stops service. The value of in-vehicle time is taken as the hourly wage plus 20 percent employers overhead for peak period. 40 percent of the peak time value is assumed for the off-peak period. Wages are deregulated in Nigeria, for the purpose of this study a value of ₦1500 per month is taken to be representative wage rate for low income earners. This group constitute the majority

users of public transport (Sanni 1982). If it is assumed that there are approximately 160 working hours per month, the mean hourly wage rate is ₦9.38 per hour. By adding the employer overheads of 20 percent, the average value of time equals ₦11.25 per hour.

The details of other values specified for the model variables and which are reasonably reflective of the Nigerian environment are shown in Table 4.1

**Table 4.1 Values Specified for Model Variable**

| VARIABLES | TIME OF THE DAY | |
|---|---|---|
| | PEAK | OFF-PEAK |
| Normal operating cost, $\gamma_n$ | ₦12.60/km | ₦12.6/km |
| Idle time cost, $\gamma_s$ | ₦6.00/hr | ₦6.00/hr |
| Alighting time per passenger, $t_a$ | 3.0 sec | 3.0 sec |
| Boarding time per passenger, $t_b$ | 3.0 sec | 3.0 sec |
| Dead time, $t_d$ | 5.0 sec | 5.2 sec |
| Penalty for stopping, $t_{ps}$ | 11.0 sec | 11.0 sec |
| Value of in-vehicle time, $V_i$ | ₦ 11.25/hr | ₦4.5/hr |
| Value of out-of-vehicle time, $V_o$ | ₦ 22.5/hr | ₦9.0/hr |
| Average ridership, rate, g | 100pass/hr | 50pass/hr |
| Length of route, L | 8km | 8km |
| Width of route, W | 1km | 1km |
| Walking speed, u | 1m/sec | 0.9m/sec |
| Number of stops, n | 20 | 20 |
| Passenger service time, K | 3.0sec | 3.0sec |
| Passenger service time, K' | 19sec | 19sec |
| Penalty time, tp | 16sec | 16sec |
| Penalty length, $L_p$ | 0.09167km | 0.1102km |
| Average operating speed, V | 60km/h | 72.1km/h |

### 4.2.2 OPTIMUM HEADWAYS

#### 4.2.2.1 FIXED STOP OPERATIONS

Using the data in Table 4.1, the optimum headways for the two demand periods i.e peak and off-peak periods were found to be 12.72 min and 28.66min respectively.

Sensitivity analysis was used to isolate the most important variables affecting the optimum headway. With the values specified in Table 4.1 as the base values, a series of first levels sensitivity analyses were undertaken by increasing the listed variables by 10 percent. In each case all other variables were kept fixed in values while only the variable indicated was varied in value. The result from these first level sensitivity analysis are shown in Table 4.2.

Table 4.2. **Sensitivity Analyses on Optimum Headways for Fixed Stop Operations. (Variable increased by 10% in each case).**

| Variable | Peak Demand Period | | Off-peak demand period | |
|---|---|---|---|---|
| | Value of $h^t$ (min) | % change in $h^t$ | Value of $h^t$ (min) | % change in $h^t$ |
| Base values | 12.723 | - | 28.660 | - |
| $\gamma_a$ | 13.343 | 4.9 | 30.056 | 4.9 |
| L | 13.329 | 4.8 | 28.700 | 4.7 |
| n | 12.738 | 0.1 | 28.700 | .1 |
| $L_p$ | 12.737 | 0.1 | 28.700 | .1 |
| $\gamma_s$ | 12.724 | 0.0 | 28.662 | 0 |
| $t_d$ | 12.724 | 0.0 | 28.662 | 0 |
| $\sigma$ | 12.710 | - .1 | 28.645 | - .1 |
| $v_i$ | 12.710 | - .1 | 28.645 | - .1 |
| k | 12.710 | - .1 | 28.645 | - .1 |
| g | 12.118 | - 4.8 | 27.312 | - 4.7 |
| $V_0$ | 12.142 | - 4.6 | 27.339 | - 4.6 |

Results shown in Table 4.2 clearly indicate that $\gamma_a$, L, g and $V_0$ are the most influential variables for both peak and

off-peak periods. When the variables were in turn increased by 10 percent, $\gamma_{\beta}$ increases the optimum value of h by 4.9 percent, and $V_0$ decreases $h^*$ by 4.6 percent, for both demand periods. g and L produces - 4.8 percent and + 4.8 percent changes in optimum headway respectively for peak period, while in the off peak they record -4.7 and +4.7 percent changes in the optimum headway respectively.

The most influential variables are selected for further examinations. When varied through a range of - 50 percent to + 50 percent of their base values. The resulting effects on the optimum headways are shown in Figs. 4.1 and 4.2 for the peak and off-peak periods respectively. The results show that a 50 percent reduction in $\gamma_{\beta}$ or L result in almost 30 percent reduction in optimum headway for both peak and off-peak periods while increases of same magnitude result in 22 percent increase in optimum headway. A reduction of 50 percent in g or $V_0$ produces about 40 percent increase in optimum headway while increases of similar amount only lead to reduction of 20 percent.

The headway that minimises, as already mentioned earlier, the total system cost were found to be 12.72min and 28.66min for the peak and off-peak periods respectively. These imply average vehicle loads of 21 and 24 passengers respectively for the peak and off-peak periods. It is interesting to note that the minimum cost vehicle loads are somewhat low suggesting the use of low capacity vehicles to ensure reasonable load factor (i.e ratio of passenger-km to seat-km provided) is achieved on the bus route. It is

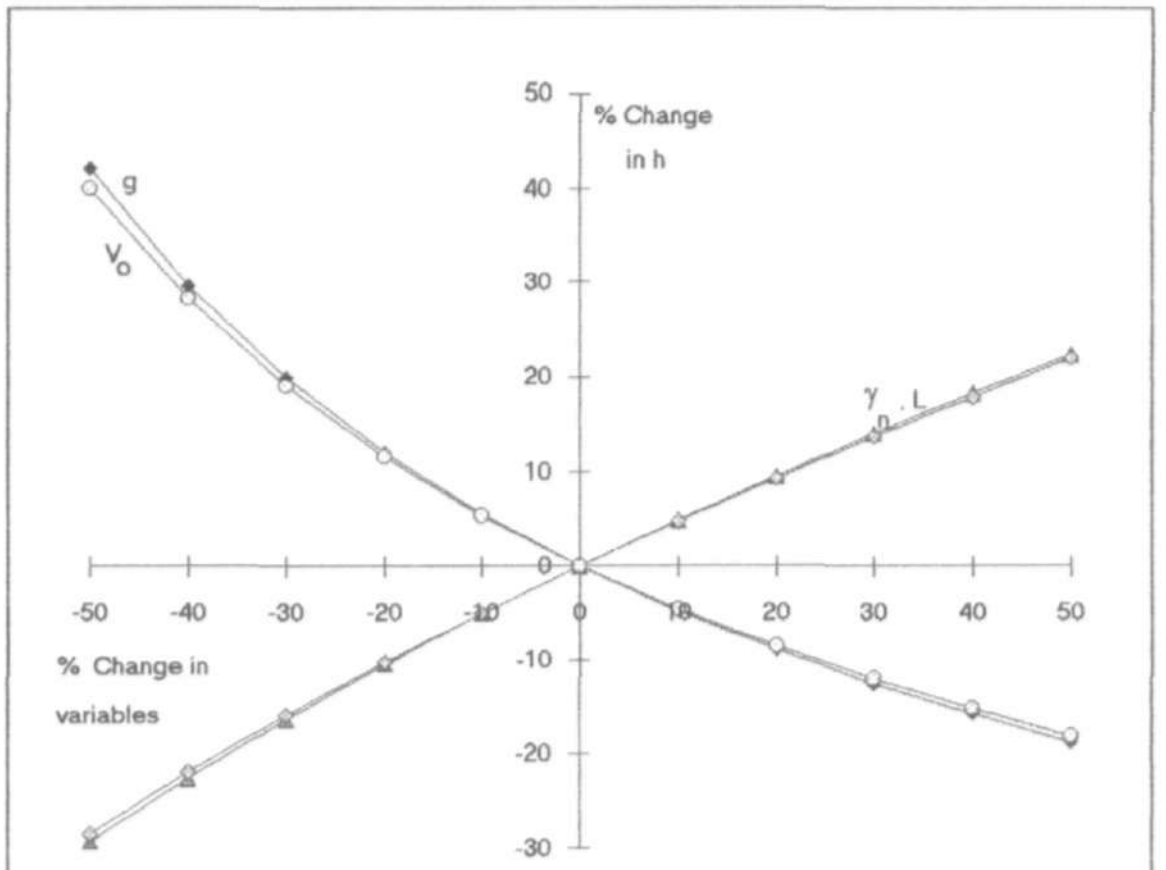



Fig 4.1 Fixed Stops: Headway - Sensitivity Analysis (peak)

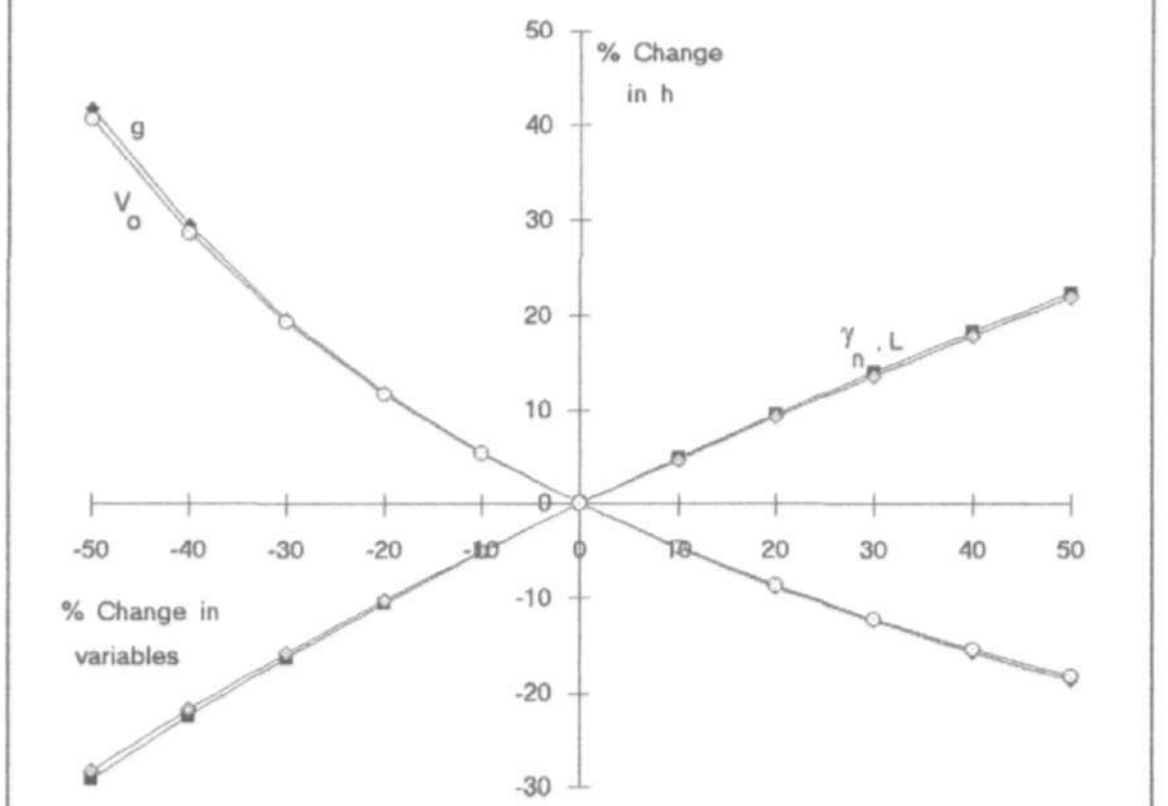



Fig 4.2 Fixed Stops: Headway - Sensitivity Analysis (offpeak)

observed that the vehicle loads for both demand periods are sufficiently close to make it possible for the use of same vehicle capacity for the two periods. The number at the peak period need only be increased for the more frequent service required at this period. In addition it is possible to charge lower fares at off-peak period than peak because of the lower cost of operating vehicle per unit output at the off-peak.

Perhaps not surprisingly, headways are most sensitive to demand, particularly as demand is reduced. Since at low demand the cost of operating a vehicle is now spread over a lower output and to maintain the current level of service passenger have to be prepared to pay more. If the constraint of minimising the total system cost is to remain in force then the headway for optimum conditions has to increase i.e. a cut down in service to reflect the decrease in patronage become necessary. Reducing demand by 50 percent pushes headways to 18.08 min and 17.395 min for peak and off-peak periods respectively. The corresponding average vehicle load are 15 and 17 passengers respectively. Hence, a lower load factor is recorded resulting in lower vehicle productivity. Furthermore, the total system cost per passenger increases. Similarly, reducing the value of out-out-vehicle cost by half increases the optimum headway to 17.99 min and 40.53 min respectively for peak and off peak periods, with corresponding average vehicle loads of 30 and 34 passengers respectively. There is an obvious improvement in vehicle utilisation, as more number of passengers are carried, but at the expense of reduced service frequency. Consequently,

the total system cost will reduce as both operating cost and out vehicle cost which are most dominant in the system cost will reduce per unit output. Changes in cost of operating a vehicle per unit distance as an important part of the system cost affects the headway also. A reduction in this cost leads to the situation where system operating cost reduces and more frequent service to minimise the out of vehicle cost becomes optimal. If $\gamma_{\parallel}$ is reduced by half brings down the optimum headways to 9 min and 20.33 respectively for peak and off peak periods with corresponding load of 15 and 17 passengers respectively. Thus, more vehicles are required to cater for the increased frequency of service. However, a lower vehicle productivity is achieved.

The operating cost also depend on the length route. For a given passenger throughput an increased length indicate higher operating costs, therefore cost minimising headway will be adjusted to allow higher number of passengers to be served hence increased headway. For the same reasons as the operating cost per unit distance reducing the length leads to increase in frequency of service.

It is apparent that optimum headways are higher for off-peak periods than the peak period. The explanation is that at off-peak periods, the worth of passenger time is less and demands are low hence headways need to increase to compensate for the relatively higher system operating cost.

4.2.2.2. HAIL STOPS OPERATIONS

The optimum headways for hail stop service were found to be 11.94 min and 27.50 min for the peak and off-peak periods respectively. The results of the first level sensitivity analysis of the optimum headway are summarized in Table 4.3. The computations were undertaken in the same manner for the fixed stop operations.

**Table 4.3: Sensitivity Analyses on Optimum Headways for Hail Stop Operations (variables increased by 10% in each case).**

| Variables | Peak Demand Period | | Off Peak Demand period | |
|---|---|---|---|---|
| | Value of $h^*$ (min) | % change in $h^*$ | Value of $h^*$ (min) | % change in $h^*$ |
| Base values | 11.936 | - | 27.503 | - |
| $\gamma_n$ | 12.519 | 4.9 | 28.846 | 4.9 |
| L | 12.519 | 4.9 | 28.846 | 4.9 |
| $\sigma$ | 11.867 | -0.6 | 27.418 | -0.3 |
| $V_j$ | 11.867 | -0.6 | 27.418 | -0.3 |
| K | 11.867 | -0.6 | 27.418 | -0.3 |
| g | 11.315 | -5.2 | 26.149 | -4.9 |
| $V_0$ | 11.442 | -4.1 | 26.297 | -4.4 |

The most influential variable for the peak period is g, with $\gamma_n$ and L then $V_0$ marginally less. For the off peak $\gamma_n$, L, g are about equally the most important while $V_0$ is also slightly of lesser importance. These were again varied through a range of -50 percent to + 50 percent of their base values. The resulting effects on the headway are plotted in Figs. 4.3 and 4.4 for the peak and off-peak period respectively.

From Figs.4.3 and 4.4 it is evident that 50 percent reduction in $\gamma_n$ or L result in almost 30 percent reduction in

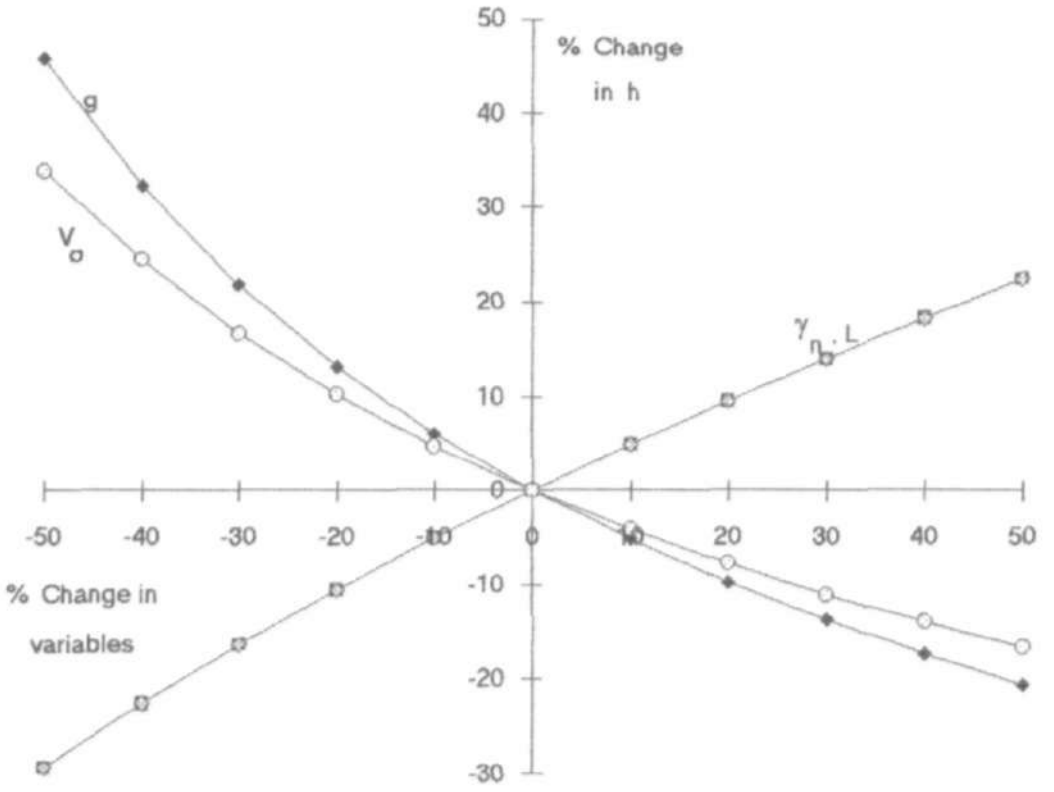



Fig 4.3 Hail Stops: Headway - Sensitivity Analysis (peak)

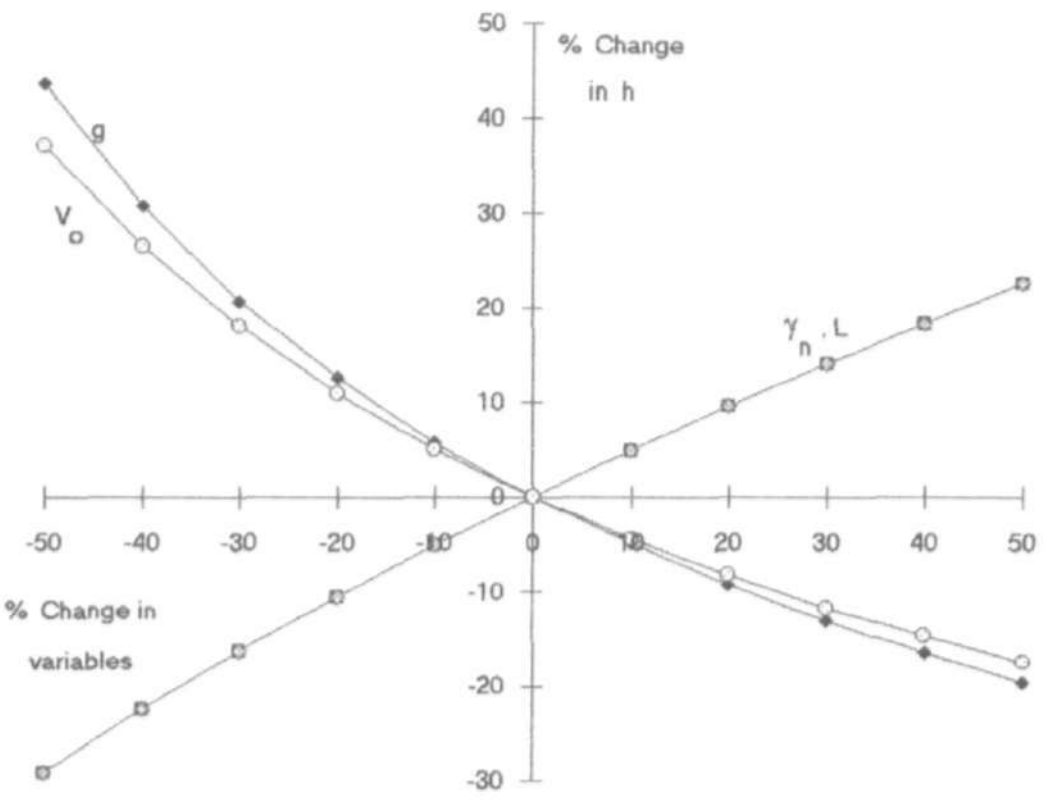



Fig 4.4 Hail Stops: Headway - Sensitivity Analysis (offpeak)

optimum headway, for both peak and off-peak periods, while increases of same magnitude result in 23 percent increases in optimums headway. A 50 percent reduction in g resulted in almost as much increases in optimum headway for the peak period, a slightly lower value of the function is recorded for the off peak, while similar increase in g leads only to about 20 percent reduction in optimum headway. A 34 percent increase in the optimum headway resulted when $V_0$ is reduced by 50 percent at the peak, a higher percentage is recorded for headway at off-peak.

The cost minimising headways were found to be lower for hail stop service than for the fixed stop service when operating under similar environment. This implies that a higher operating cost efficiency of service is achieved with fixed stop service. Higher average vehicle load is also possible with the fixed stop. Consequently a higher vehicle productivity obtains with fixed stop operation than hail stop. A lower break-even fare is also implied for the fixed stop operation.

The same variables have been found to affect the optimum headway for both hail stop and fixed stop services. The effect of these variables are not significantly different between the two services for $\gamma_{\ell}$ and L. A marked difference, however, existed with g and $V_0$ for both peak and off peak periods (as evident from Figs. 4.1 - 4.4). It is apparent from Figs. 4.1 and 4.4 that optimum headway for hail stop service is much more sensitive to demand than fixed stop. Thus, at lower demand levels optimum headways for both

services will approach the same. Hence, the most cost efficient service will now depend mainly on value of $V_0$, the number of stop and the value which j (coefficient which indicate the type O-D pattern in hail stop) assumes (see, equation 3.12).

We had already observed that effect of most important variables on optimum headways are either to increase or reduce its value, consequently affecting the average vehicle load. It should be mentioned, here, that the average vehicle loading could be taken as a proxy for comfort but it also determines average operating cost per passenger. As load factor increases overcrowding of vehicle results, as such convenience, comfort become reduced. Depending on the vehicle size a limit is reached, beyond which overcrowding of vehicles become intolerable. Moreover, the average passenger waiting time become unstable, when this limit is reached, the probability of passenger boarding the first arriving vehicle become small, hence capacity of the system becomes exceeded. Therefore for a meaningful load factor on route a decision on vehicle type had to be made. Since invariably an optimal frequencies of service are already established to minimise the total system cost, only the vehicle size is the decision option, to maintain a constant load factor. For the case where higher than normal average vehicle loading is encountered, then a bigger size vehicle is certainly more appropriate. From the foregoing discussions it could be summarized that smaller vehicles should be used when the situation favours reduced operating

cost and/or low demand and higher capacity vehicle employed when value of out vehicle cost is low etc. when it is operationally feasible.

Other factors such as the number of stops made, penalty length ($L_p$), idle operating costs ($\gamma_s$), a fraction of vehicle travel time ($\sigma$), passenger service time (K) have been found to have small impact on the optimum headways. These variables are not likely to change much in real life, to extent as to exert significant influence on the optimum headway e.g. the penalty length $L_p$ will always be much less than the route length as these are acted upon by the same cost element, hence its influence will always be negligible. The passenger service time(K) depends on the passenger O-D pattern, its influence will always be dampened by $\sigma$ and $V_i$. Furthermore, for the O-D pattern assumed the value of K will always be relatively small in comparison to other influential elements. These variables are thus, discarded in further considerations.

### 4.2.3 TOTAL SYSTEM COST

A series of sensitivity analyses were performed on the total system cost in a similar manner as ones performed on the optimum headways for both fixed stop operations and hail stop operations. The results are reported in section 4.2.3 and 4.2.4. for fixed stop service and hail stop service respectively.

For convenience, we further refine our notations by introducing subscript 1 and 2 to represents fixed stop and

hail stop services respectively e.g. $Z_1$ = value of Z when fixed stop is considered and $Z_1$ = value of Z when Hail stop is considered.

#### 4.2.3.1 FIXED STOP OPERATION

The numerical values contained in Table 4.1 specified for model were applied to the total system cost model. The minimum total system cost for peak and off peak periods were found to be ₦15.75 and ₦11.27 respectively. The users' cost component of the system cost per passenger are ₦10.78 and ₦6.83 for the peak and off-peak respectively. And the corresponding operating cost component are ₦4.97 and ₦4.44 respectively. The result of the first level sensitivity analyses is shown in Table 4.4.

What is evident from Table 4.4 is that $V_0$ is the most important variable at both demand period. Other important variables in increasing order of influence are L, $\gamma_1$ and g for both demand periods. Changes in g, L and $\gamma_1$ have greater effect on the total system cost in the off peak than peak. Increasing g tends to reduce the value of total system cost while other variables increases its value. The walking speed is more important at the peak than off peak, however, it is not selected for further analysis there is a little scope for variation of average walking speed, its influence could only be felt in increasing out-of-vehicle cost when its value is reduced.

Table 4.4: Sensitivity analyses on total system costs for fixed stop operations (Variable increased by 10% in each case).

| Variables | Peak demand Period | | Off-peak demand period | |
|---|---|---|---|---|
| | Value of $Z_l$ (₦) | % change in $Z_l$ | Value of $Z_l$ (₦) | % change in $Z_l$ |
| Base values | 15.747 | - | 11.266 | - |
| $\gamma_{II}$ | 16.227 | 3.05 | 11.694 | 3.8 |
| L | 16.436 | 4.37 | 11.764 | 4.42 |
| n | 15.704 | -0.27 | 11.256 | -0.09 |
| $L_p$ | 15.757 | -0.07 | 11.277 | -0.08 |
| $\gamma_s$ | 15.757 | -0.07 | 11.277 | -0.08 |
| $t_d$ | 15.757 | -0.07 | 11.277 | -0.08 |
| $\sigma$ | 15.911 | 1.04 | 11.325 | 0.52 |
| $V_j$ | 15.911 | 1.04 | 11.325 | 0.52 |
| K | 15.758 | 0.07 | 11.271 | 0.04 |
| g | 15.299 | - 2.84 | 10.862 | -3.59 |
| $V_0$ | 16.655 | 5.77 | 11.884 | 5.49 |
| $t_p$ | 15.797 | 0.32 | 11.286 | 0.18 |
| u | 15.349 | - 2.53 | 11.089 | -1.57 |
| V | 15.653 | -0.6 | 11.234 | -0.28 |
| W | 16.060 | 1.98 | 11.405 | 1.23 |

The variables g, L, $V_0$ and $\gamma_{II}$ were selected for the second level sensitivity analyses the result are shown in Figs. 4.5 and 4.6 for peak and off peak periods respectively. For the peak period - 50 percent change in $V_0$ produces the highest influence on the system cost with 32 percent reduction in the total system cost per passenger. g is the most influential at 50 percent reduction in all variables in turn at the off-peak, almost as influencial is $V_0$. It is interesting to note at period of low demand (off-peak) reduction in g affects sytem cost most rather than time cost ($V_0$).

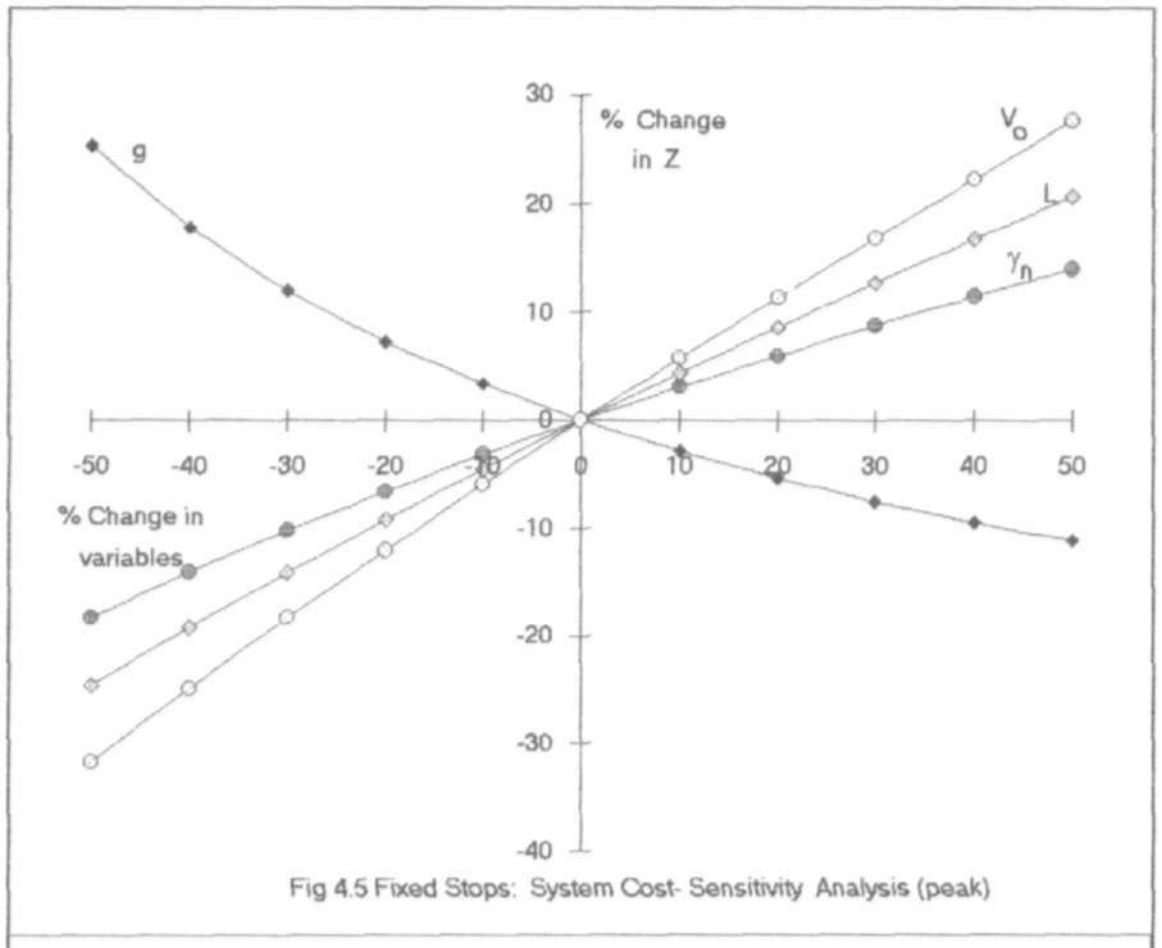



Fig 4.5 Fixed Stops: System Cost- Sensitivity Analysis (peak)

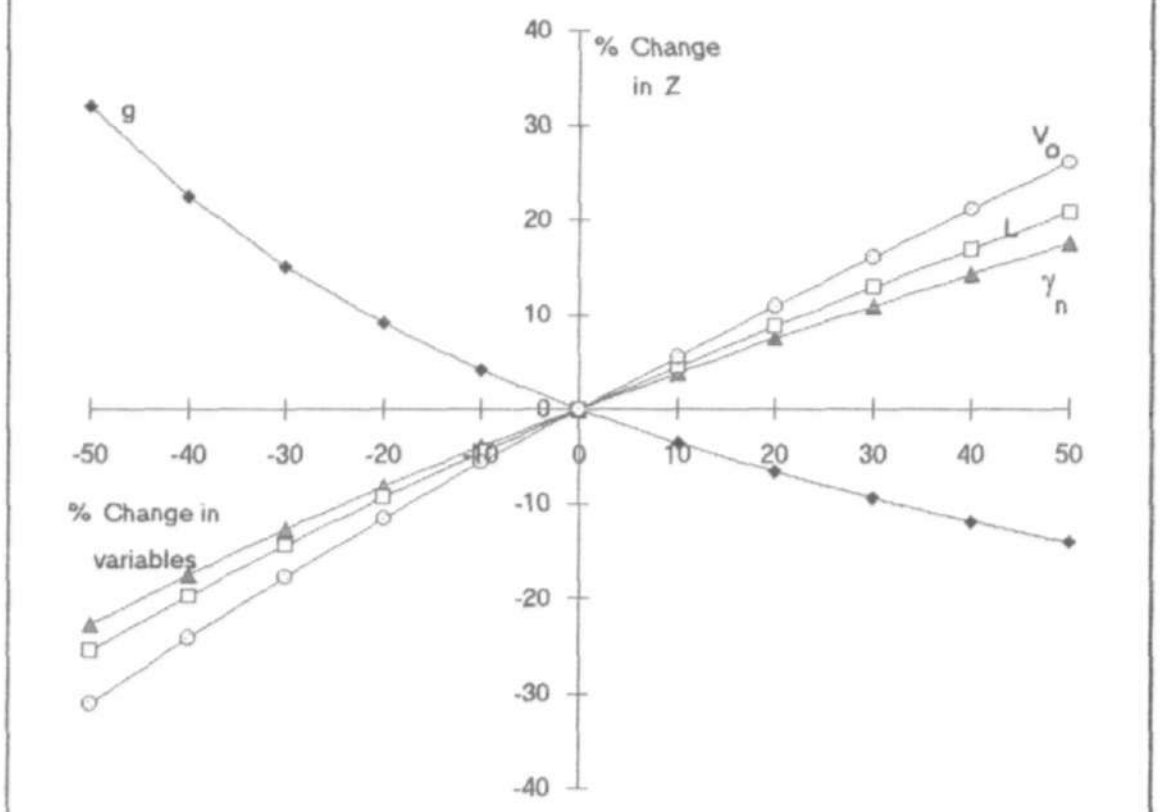



Fig 4.6 Fixed Stops: System Cost- Sensitivity Analysis (offpeak)

### 4.2.4. HAIL STOP OPERATION

The total system costs per passenger were found to be ₦14.44 and ₦10.70 respectively for peak and off peak periods when the numerical value of variables specified in Table 4.1 were used in Hail stop cost model (Equation 3.12). The users' cost component of the total system cost per passenger are ₦9.23 and ₦6.13 for the peak and off-peak period respectively. While the corresponding operators component per passenger are ₦5.21 and ₦4.57 respectively. Like the fixed stops operations sensitivity analyses of the total cost were performed. The result of the first level analysis is shown in Table 4.5.

Table 4.5: Sensitivity Analyses on Total System Costs for Hail Stop Operations (Variable increased by 10% in each case)

| Variable | Peak demand period | | Off peak demand period | |
|---|---|---|---|---|
| | Value of $Z_1$ (₦) | % change in $Z_1$ | Value of $Z_1$ (₦) | % change in $Z_1$ |
| Base Values | 14.441 | - | 10.699 | - |
| $\gamma_n$ | 14.947 | 3.51 | 11.142 | 4.14 |
| L | 15.039 | 4.14 | 11.163 | 4.33 |
| $\sigma$ | 14.603 | 1.12 | 10.761 | 0.58 |
| $V_i$ | 14.603 | 1.12 | 10.761 | 0.58 |
| $K_i$ | 14.503 | 0.43 | 10.730 | 0.28 |
| g | 14.025 | -2.88 | 10.316 | -3.58 |
| $V_0$ | 15.191 | 5.20 | 11.242 | 5.07 |
| $L_p$ | 14.452 | 0.08 | 10.713 | 0.13 |
| $\gamma_s$ | 14.444 | 0.02 | 10.702 | 0.03 |
| $t_d$ | 14.441 | 0 | 10.699 | 0 |
| u | 14.157 | -1.97 | 10.573 | -1.18 |
| V | 14.347 | -.65 | 10.668 | -0.29 |
| W | 14.753 | 2.16 | 10.838 | 1.30 |

From table 4.5 the most significant influence on cost is also that caused by increase in $V_0$. Also the same variables have been found to exert similar influences in the

total system per passenger as the fixed stop service. In the case of hail stop influences of these variables (g, L, $V_0$ and $\gamma_{\beta}$) are more marked.

These most influential variables are then selected for the second level sensitivity analyses. The results are shown in Figs. 4.7 and 4.8 for peak and off peak periods respectively.

It is not difficult to know why for both services (i.e. hail stop and fixed stop) the costs at offpeak period were less than the peak. What is perhaps, surprising is the total system cost of operating a fixed stop service per passenger is higher than that of hail stop service. When it is known that fixed stop is more efficient in terms of cost to the operators and higher productivity. It does then appears that the savings in cost accruing to the operators by limiting the number of stops is outweighed by increased waiting and walking costs incurred at the value of time assumed.

When we compared the sensitiveness of total system cost to variation in key parameters we can make useful deductions that guides on when one or the other of fixed stops and hail stops service is more suitable. The following deductions are evident from Figs. 4.5 - 4.8.

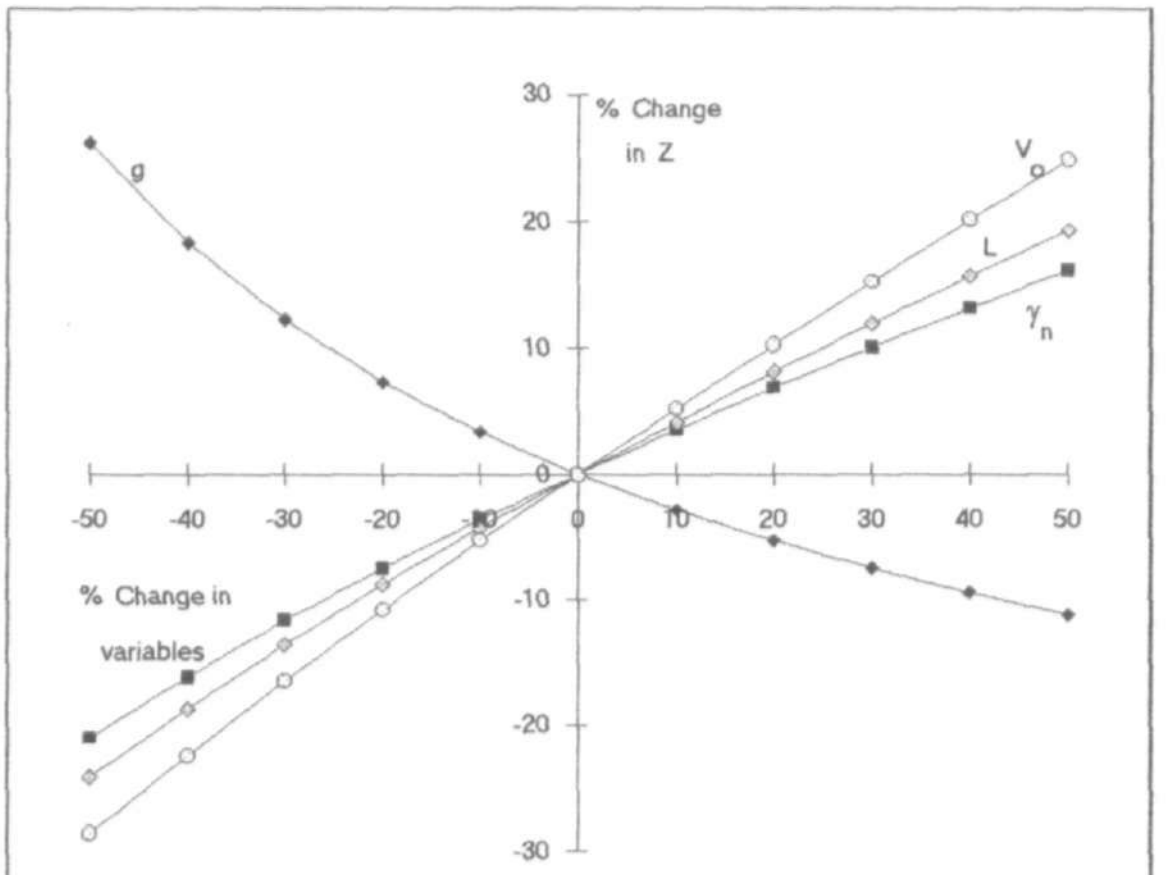



Fig 4.7 Hail Stops: System Cost - Sensitivity Analysis (peak)

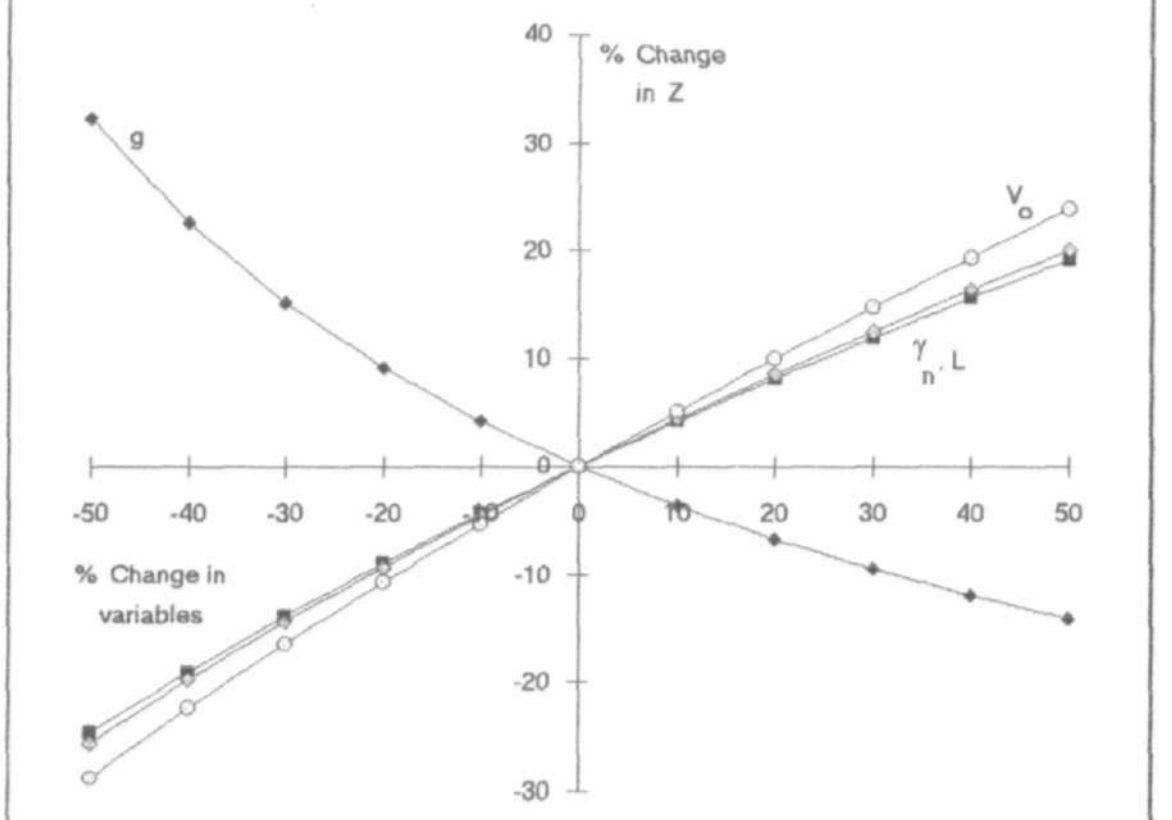



Fig 4.8 Hail Stops: System Cost- Sensitivity Analysis (offpeak)

(a) $Z_1$ decreases at faster rate than $Z_2$ when $V_0$ is reduced

(b) $Z_1$ increases at faster rate than $Z_2$ when $V_0$ is increased

(c) $Z_2$ increases at a faster rate than $Z_1$ when g is reduced

(d) $Z_2$ and $Z_1$ reduces at about same rate as g increases

(e) $Z_2$ increases at faster rate than $Z_1$ as $\gamma_{II}$ increases

(f) $Z_2$ decreases at faster rate than $Z_1$ as $\gamma_{II}$ reduces

(g) $Z_2$ increases at faster rate than $Z_1$ as L increases

(h) $Z_2$ decreases at faster rate than $Z_1$ as L reduces

From the deductions above, further inferences on the relative performance of the two services under consideration can be drawn. Let us consider, firstly, the case where Hail stop service performs better than the Fixed stop at $g_h$ i.e $Z_2 < Z_1$ at $g = g_h$. Then the following can be deduced.

(1) Whenever L is reduced, or value of time increases or the operating costs reduces or in combination with others, the hail stop service will still perform better for all higher demands.

(2) However if L increases or value of time decreases or operating cost increases further investigation are required.

For the case where fixed stop is found superior to hail stop at $g = g_f$ the following can be deduced.

(1) If value of time decreases, or operating cost increases or L increases then fixed stop will perform better for all demand level.

(2) However, when condition stated (1) is otherwise further

investigations are required.

From the deductions above two hypotheses are advanced

**Hypothesis 1:** If the hail stop service is found to perform better than the fixed stop at $g_h$ i.e $Z_1 < Z_f$ at $g = g_h$. It will still perform better at all higher demand levels if the following changes are made on the bus route.

(a) Length of route is reduced or

(b) The value of time increased or

(c) Operating costs reduces.

**Hypothesis 2:** If the fixed stop is found superior to hail stop at $g = g_f$. Then it will still be found better atleast for all higher demand levels. Whenever

(a) length of the route is increased or

(b) The value of time decreases or

(c) Operating cost increases

If, however, the conditions stated in (1) and (2) above are otherwise further investigation are required.

The hypotheses stated above are applicable if it is known that one service is better than the other. However, intelligent guess may also be made on the service to employ based on the results of the sensitivity analyses, particularly when new service are to be introduced. Table 4.6 provides a crude guide on conditions that are considered favourable to operating the two services.

Table 4.6: Condition Considered Favourable to Hail and Fixed Stop Operations

| Type of service | Conditions | | | |
|---|---|---|---|---|
| | Route Length | Value of Out-of-vehicle time | Operating cost | Demand |
| Fixed Stops | long | low | high | high |
| Hail Stop | short | high | low | low |

The stage is set for the deductions made from the results of the sensitivity analyses, and subsequent hypotheses advanced to be tested and consequently refined using analytical charts. This is a subject addressed in chapter five.

# CHAPTER 5

## COMPARISON OF THE MODE OF SERVICES

### 5.1 PREAMBLE

The two modes of service are compared in this chapter at optimal states so as to determine under what conditions one is better than the other.

The objective that guides the comparison is that of minimisation of total system cost. The situation where fixed stop operation is better is typified by equation 5.1, i.e.

$$Z_1 \leq Z_2 \qquad 5.1$$

Substituting equation 3.12 and 4.10 in 5.1, we have

$$\sigma V_i(t_{ns} + Kgh_1^* + nt_p) + V_o[\frac{W}{2u} + \frac{L}{2un} + ah_1^*] + \frac{\gamma_n}{gh_1^*}(L + 0.1nL_p) + \gamma_s(K + \frac{nt_d}{gh_1^*}) \leq \sigma V_i(t_{ns} + K'gh_2^*) + V_o[\frac{W}{2u} + ah_2^*] + \frac{\gamma_n}{gh_2^*}(L + 0.1gh_1^*L_p) + \gamma_s(K + jt_d) \qquad 5.2$$

The condition expressed in equation 5.2 will hold, depending on transit demand level, the value of riding time, ratio of riding time to out vehicle time, costs of operating the vehicle, the length of route under consideration, the size of service area.

Comparisons of the two services are undertaken in two parts namely: (i) comparing the optimum headway and (ii) comparing the total system cost. The next section considered

the optimum headways.

## 5.2 OPTIMUM HEADWAYS

The inspection of cost minimising headways derived in chapter 4, equation 4.10, reveals that the headways do not depend on the magnitude of the cost elements but on cost ratios (e.g $\gamma_w/V_i$, $\gamma_s/V_i$, $V_0/V_i$). The equation 4.10 for the optimum headways, if these ratios are introduced now becomes:

$$h^* = \begin{cases} \sqrt{\dfrac{C_1(L + 0.1nL_p) + C_2 n t_d}{\sigma K g^2 + C_3 a g}} & \textit{Fixed Stops} \\ \sqrt{\dfrac{C_1 L}{\sigma K' g^2 + C_3 a g}} & \textit{Hail Stops} \end{cases} \qquad 5.2$$

$$\textit{where } C_1 = \frac{\gamma_n}{V_i} \; ; \quad C_2 = \frac{\gamma_s}{V_i} \; ; \quad C_3 = \frac{V_o}{V_i}$$

The numerical values of the model variables specified in Table 4.1 in chapter four are used to explore variation in optimum headways. When these values are applied to equation 5.2 the default values of the cost ratios are :

$C_1 = 1.12$ $\quad C_2 = 0.5333$ $\quad C_3 = 2.0$ at peak period

$C_1 = 2.80$ $\quad C_2 = 1.3333$ $\quad C_3 = 2.0$ at off-peak period

### 5.2.1 VARIATION OF OPTIMUM HEADWAYS: FIXED STOPS

Fig. 5.1 and Fig. 5.2 show the variation of optimum headways at various demand levels and at different values of $C_1$ (RATIO). The other cost ratios were kept fixed. The optimum headways at the peak respond more to changes in $C_1$. The optimum headways increase with increase in ratio for both periods. As demand increases the optimum headway reduces. A higher value of optimum headway is recorded for the same ratio at the off-peak as expected since value of time is less at the off-peak period. Variation of $C_1$, i.e the of ratio operating cost to value of in vehicle time may either due to operating cost or in-vehicle cost. For example, when $C_1$ is on the increase then it is either operating cost that is increasing or the value of time is reducing.In any case this will invariably lead to increase of the optimum headway.

### 5.2.2. VARIATION OF OPTIMUM HEADWAYS: HAIL STOPS

Fig. 5.3 and Fig. 5.4 show also the variation of optimum headways at peak and off peak periods respectively. A similar trend is observed in hail stop operation as in fixed stop operation as regard effect of increase in $C_1$ and when off-peak and peak periods are compared.

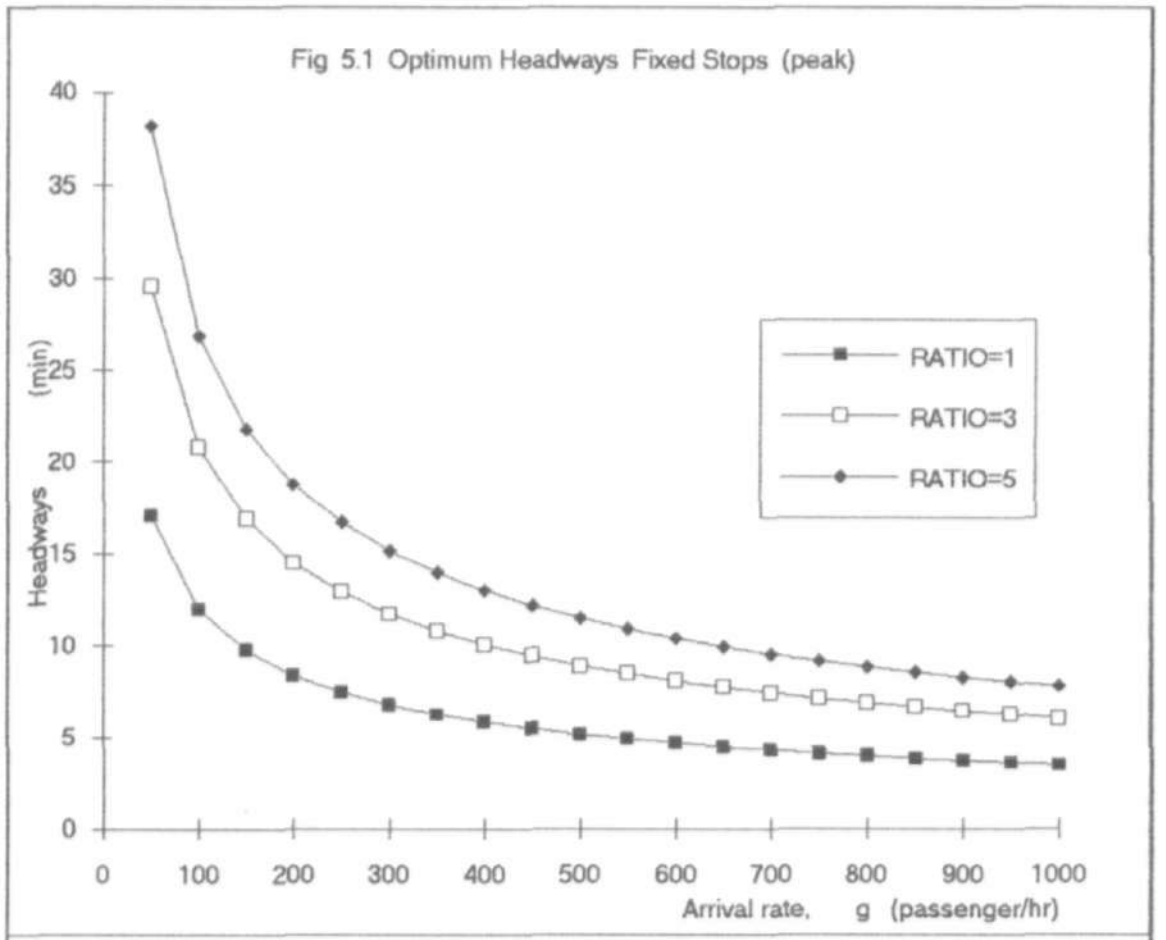



Fig 5.1 Optimum Headways Fixed Stops (peak)

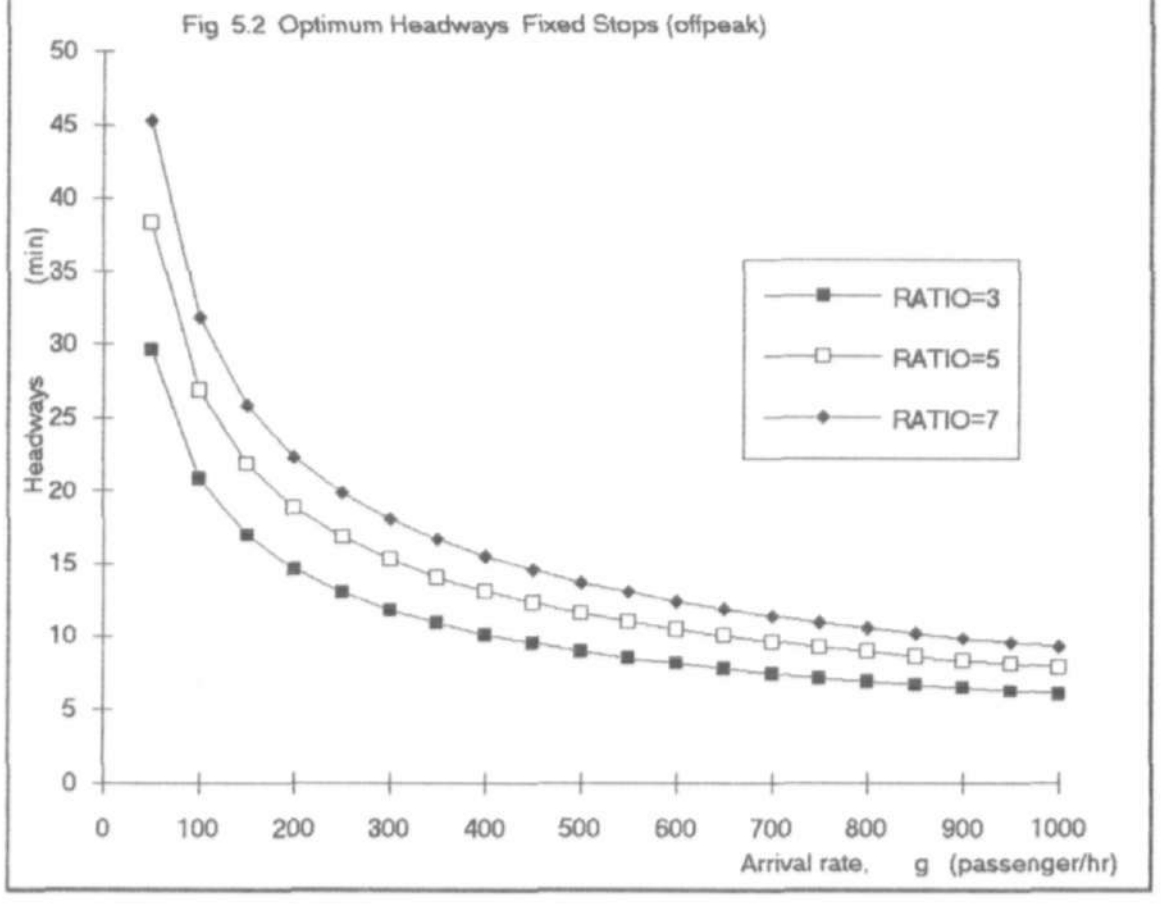
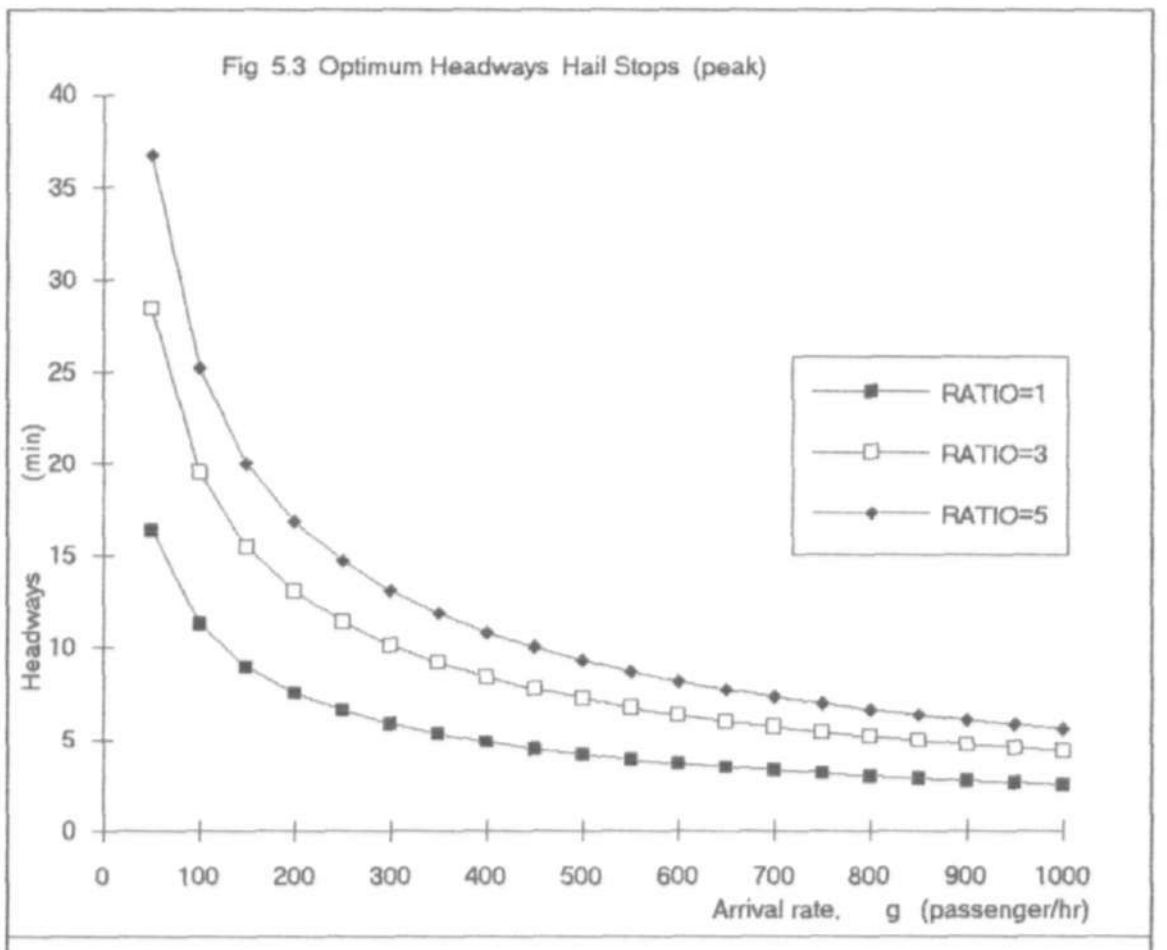
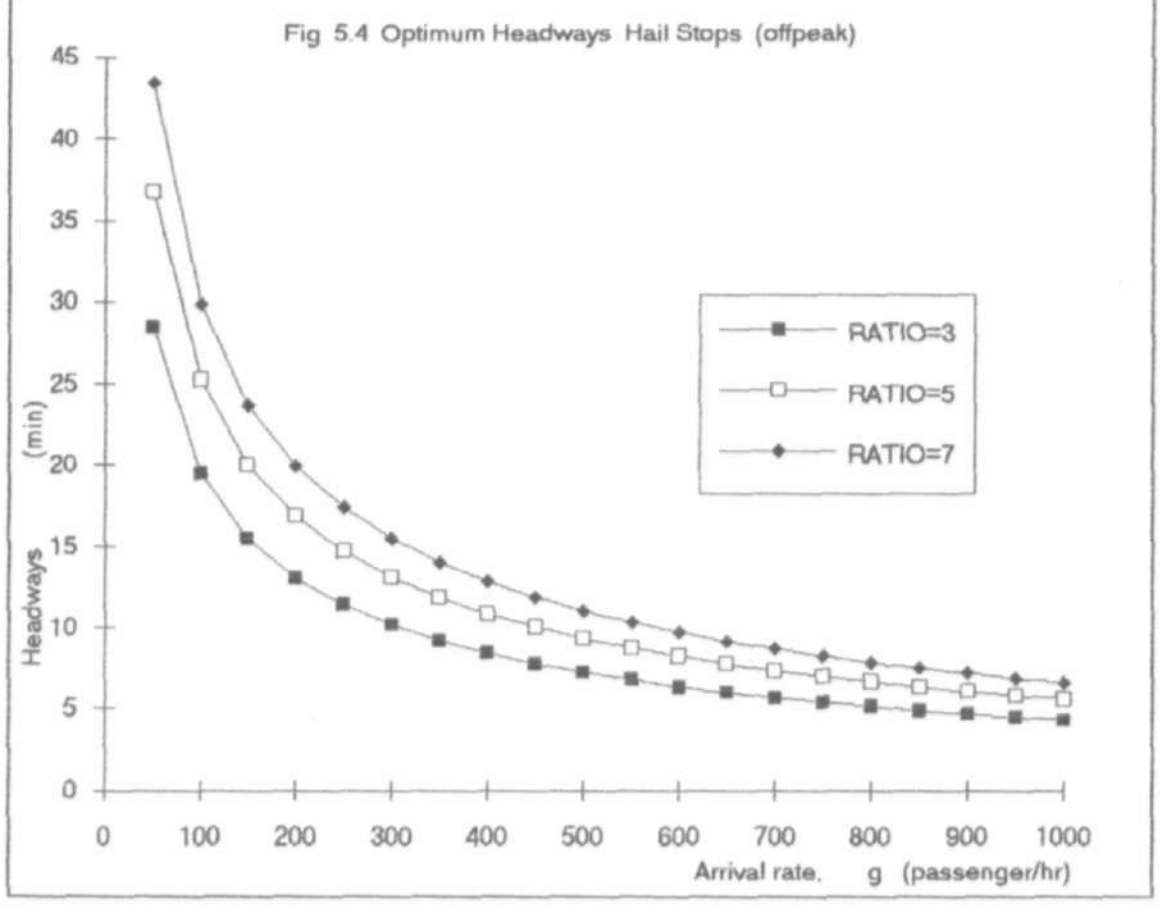



Fig 5.2 Optimum Headways Fixed Stops (offpeak)


Fig 5.3 Optimum Headways Hail Stops (peak)
Headways (min)
0
5
10
15
20
25
30
35
40
0
100
200
300
400
500
600
700
800
900
1000
Arrival rate, g (passenger/hr)
RATIO=1
RATIO=3
RATIO=5


Fig 5.4 Optimum Headways Hail Stops (offpeak)
Headways (min)
0
5
10
15
20
25
30
35
40
45
0
100
200
300
400
500
600
700
800
900
1000
Arrival rate, g (passenger/hr)
RATIO=3
RATIO=5
RATIO=7

### 5.2.3. VARIATION OF OPTIMUM HEADWAYS: COMPARISON

The variation of optimum headways with changing ratios are compared at peak period for both services.

It is evident from Figs. 5.5 - 5.7 that optimum headways are higher for fixed stop than for the hail stop operation for all demand levels. It can also be seen that as demand increases the difference in optimum headways between the two services also increases. Thus optimum headway reduces at a faster rate in hail stop service than fixed stop with increasing demand.

When the ratio increases higher value of optimum headways are recorded and difference between $h_1$ and $h_2$ is slightly more. Thus, the difference between the average vehicle loads also increases. Hence when the same demands are served and vehicle sizes are the same for both modes of service, the fixed stop reaches capacity operation quicker. It has already been mentioned that capacity operation is reached when the probability of boarding the first arriving vehicle becomes small, associated with this is the high average waiting time that gradually becomes unstable and unreliable.

The average vehicle load could be taken as proxy for comfort as well as guide upon the type of vehicle in terms of size to use so as to enable the system to operate at or near capacity. We also note that as passenger throughput increases the average vehicle load also increases. Therefore, the effect vehicle size will have on the modes of service depend on the passenger throughput. Since at a higher

Fig 5.5 Comparison of Optimum Headways when Ratio = 1

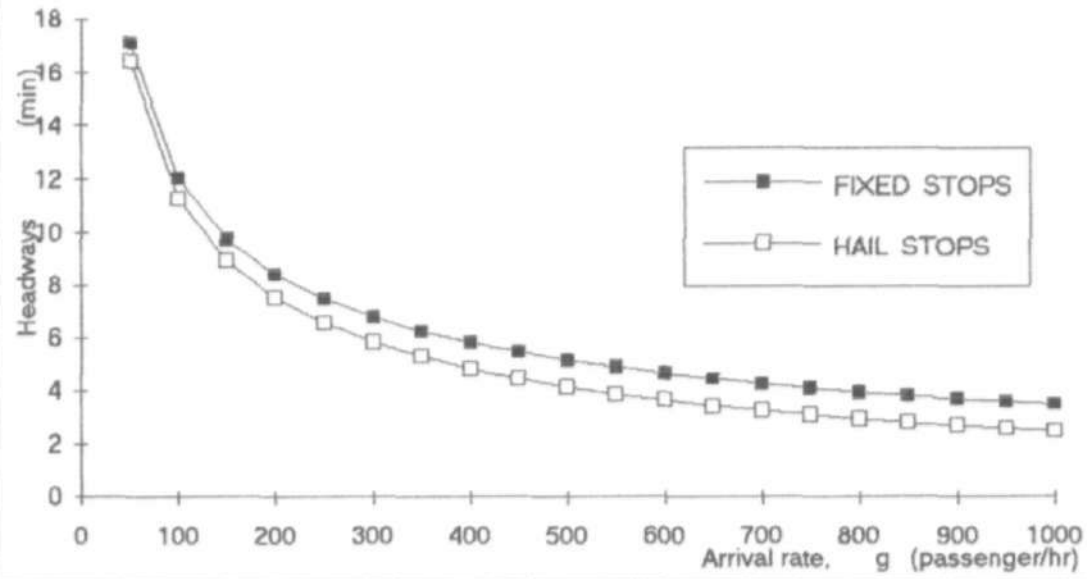



Fig 5.6 Comparison of Optimum Headways when Ratio = 3

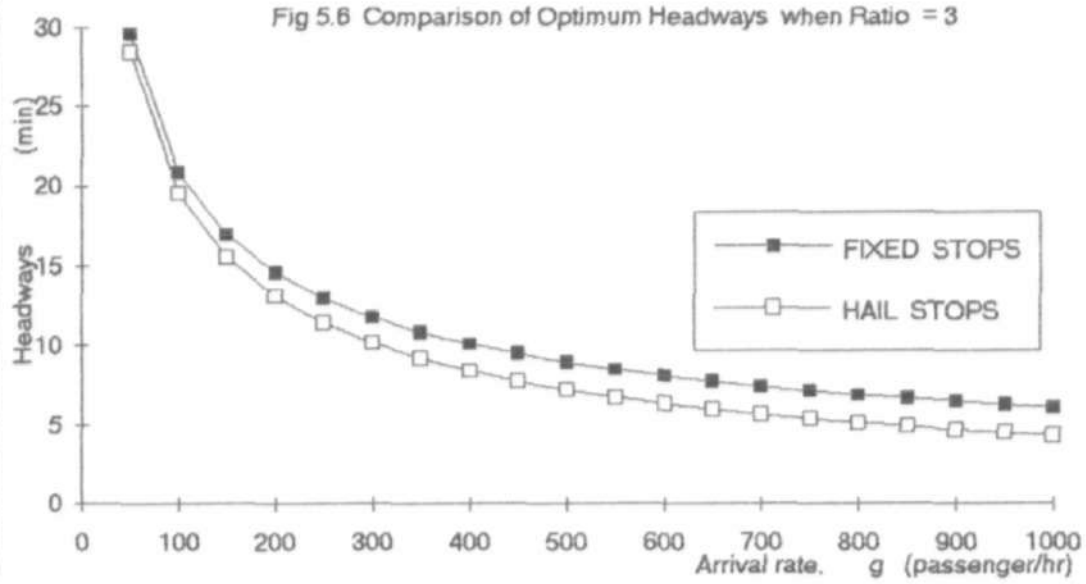
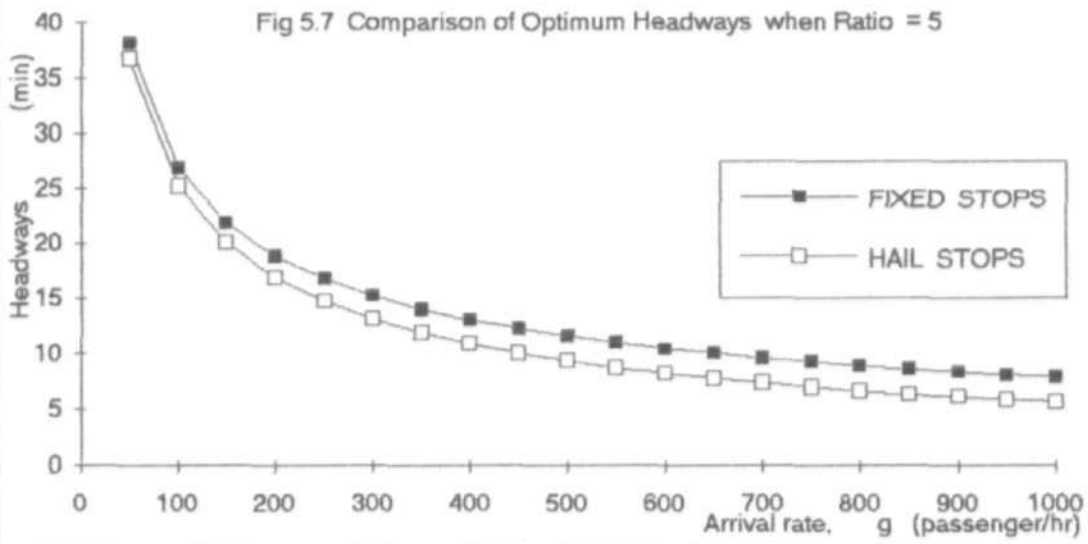



Fig 5.7 Comparison of Optimum Headways when Ratio = 5



passenger arrival rate the average passenger served per bus trip increases and the difference between average load between the service becomes more significant. Thus, a higher capacity vehicle is more appropriate and it is quite possible that vehicle types that are more suitable to achieve a given level of service for one mode of service are different from the other; larger vehicle for the fixed stop and smaller vehicle for hail stop

To facilitate a brief comparison, however, between the vehicle types used by the modes of service, we consider the case where the current demand on the route is 300 pass/hr (38 pass/km$^2$/hr). We also assume that the effect the change in vehicle size on total system cost is to increase the operating cost ratio $C_1$.

Table 5.1 summarises the results of the comparison of the effect of vehicle size on the modes of service for a limited number of options

**Table 5.1 Comparison of Effect of Vehicle Size on Modes of Service g = 300 pass/hr (38 pass/km$^2$/hr)**

| Vehicle Type | Vehicle Capacity normal/crush | $C_1$ | $Q_1^*$ | $Q_2^*$ |
|---|---|---|---|---|
| Minibus | 24/34 | 1 | 34 | 29 |
| Minibus | 50/60 | 3 | 59 | 51 |
| Minibus | 60/90 | 5 | 76 | 65 |

* $Q_1$ and $Q_2$ are the values of the average vehicle loads for fixed and hail stop services at the indicated $C_1$ values.

What is evident from Table 5.1 is that when a 24 seat minibus is used the vehicle is filled to its limit with associated overcrowding and inconveniences to the passenger for the fixed stop operation. For the hail stop congestion

is not so critical. As the vehicle size becomes larger however, there is an improvement in the fixed stop operation to provide a given level of service. On the other hand the hail stop operation becomes increasingly inefficient as vehicle size increases. It can be seen that when the 60 seat minibus is used that 25 passengers are still needed to be carried for the vehicle to be at its capacity for the hail stop. While the fixed stop only 14 passengers are required. It appears that for the three vehicles types indicated in table 5.1 that the 60-seat minibus is better suited for the fixed stop at the level of demand (300pass/hr), when the passenger convenience and comfort chiefly considered. While for the hail stop the 50-seat appears more appropriate for the same consideration as the fixed stop.

On the whole it could be said that factors that affect the average vehicle loading or more appropriately the headway determines the vehicle size to use. Though demand is a very significant factor, high demand requiring large capacity vehicle; low demand small capacity vehicle. We already know that apart from demand there are three other major factors affecting the headway. We also know that long route, low value of time and high cost of operating vehicle are factors that favour the fixed stop service. All this factors, however, serve to increase the headway and consequently the average vehicle load which suggest the used of larger capacity vehicle.

On the contrary factors known to be favourable to the hail stop services serve to reduce the headway and thus the

average vehicle load which make smaller capacity vehicle more appropriate.

## 5.3 TOTAL SYSTEM COST

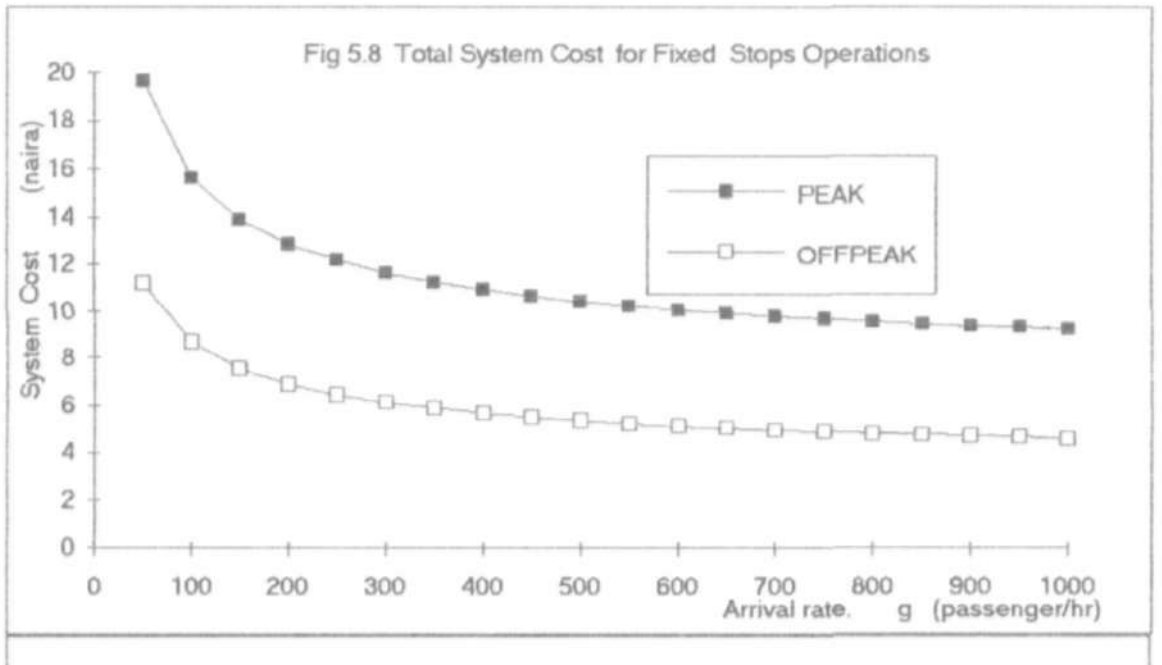
The expression for total system cost is for convenience, slightly modified to allow for cost ratios introduced in section 5.2. Thus, equation 3.12 now becomes:

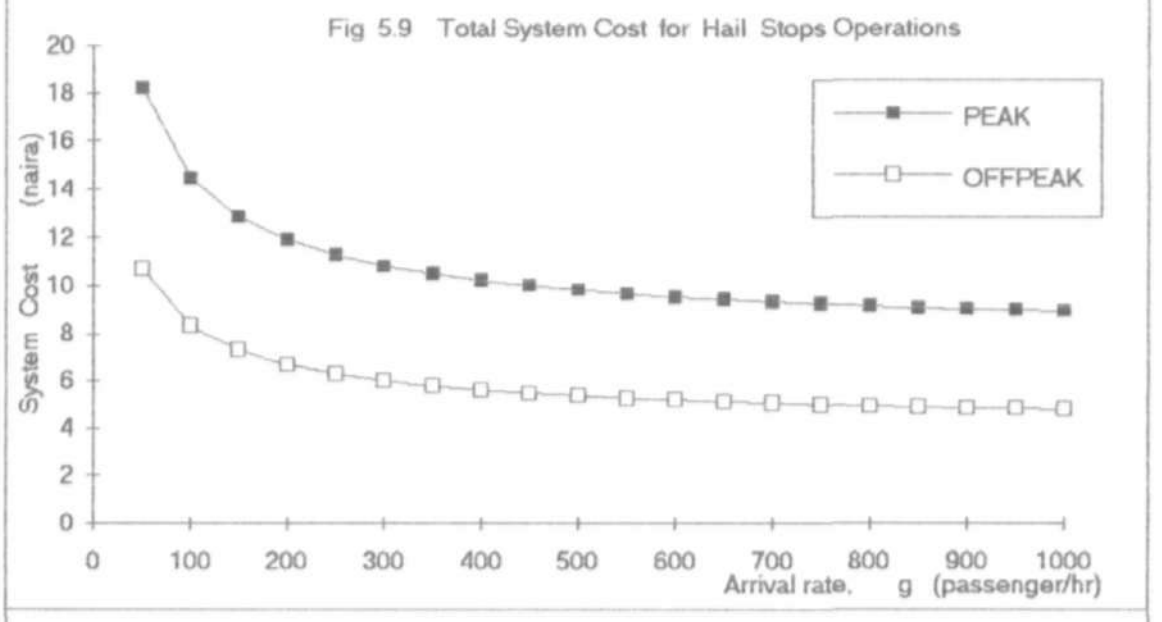
$$Z = \begin{cases} \sigma V_i (t_{ns} + K g h_1^* n t_p) + C_3 V_i [\frac{W}{2u} + \frac{L}{2us}] \\ + \frac{C_1 V_i}{g h_1^2} (L + 0.1 n L_p) + C_2 V_i (K + \frac{n t_d}{g h_1^*}) \quad \textit{Fixed stops} \\ \\ \sigma V_i (t_{ns} + K' g h_2^*) + C_3 V_i [\frac{W}{2u} + a h_2^*] \\ + \frac{C_1 V_i}{g h_2^*} (L + 0.1 j g h_2^* L_p) + C_2 V_i (K + j t_d) \quad \textit{Hail stops} \end{cases}$$

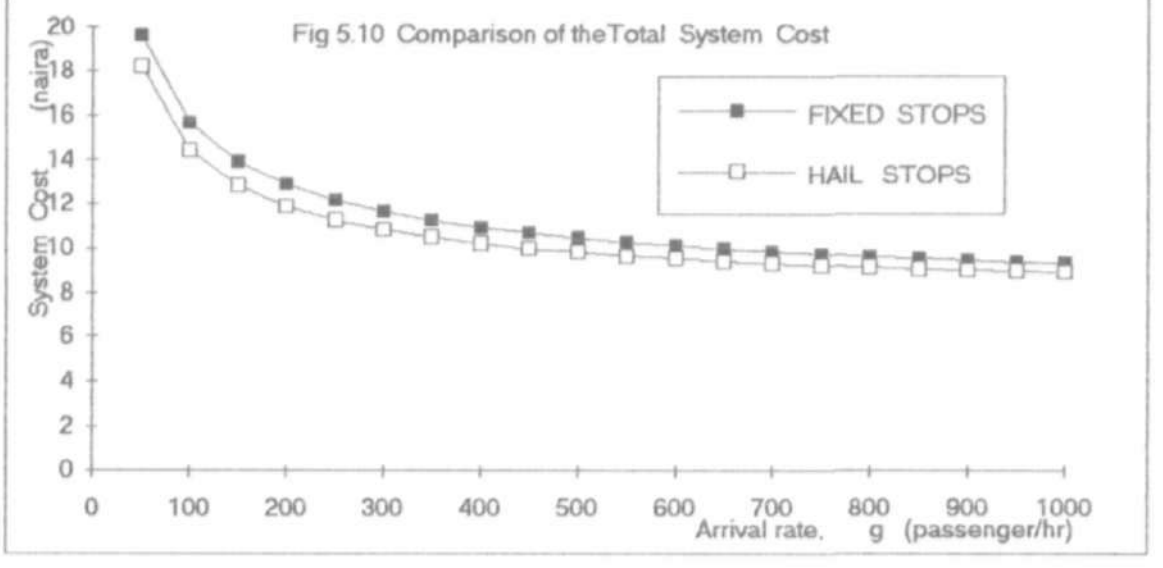
The numerical values specified for model variables in Table 4.1 are used as the default values of variables in total cost equations. In the comparisons that follow, it may be necessary to change the value variables in order to facilitate the comparisons. The variables changed will be specifically mentioned.

### 5.3.1 COMPARISON OF TOTAL SYSTEM COSTS: DEFAULT VALUES

The total system cost at various demand levels are shown for fixed stops and hail stops in Figs. 5.8 and 5.9 respectively, for both peak and off peak periods. It is apparent that cost always decrease with increasing demand.


Fig 5.8 Total System Cost for Fixed Stops Operations
System Cost (naira)
20
18
16
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
700
800
900
1000
Arrival rate, g (passenger/hr)
PEAK
OFFPEAK


Fig 5.9 Total System Cost for Hail Stops Operations
System Cost (naira)
20
18
16
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
700
800
900
1000
Arrival rate, g (passenger/hr)
PEAK
OFFPEAK


Fig 5.10 Comparison of theTotal System Cost
System Cost (naira)
20
18
16
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
700
800
900
1000
Arrival rate, g (passenger/hr)
FIXED STOPS
HAIL STOPS

The cost at off-peak periods are less than peak. However, direct comparison at particular demand levels are not to be made since off-peak represents a period of fall in demand as well as value of time.

In Fig. 5.10 the comparison $Z_2$ and $Z_1$ are made. It can be seen that the hail stop service performs better for all demand level considered. It should be pointed out that operating cost per passenger is always higher for the hail stop service while the out-vehicle cost per passenger is higher for fixed stop. In-vehicle costs are lower for fixed stop, however, user cost per passenger and users cost per naira operating cost is lower in hail stop. The ratio of users cost to operating costs becomes increasingly lower as demand for hail stop service.

### 5.3.2. COMPARISON OF TOTAL SYSTEM COST: VARIATION IN OPERATING COST RATIO, $C_1$ (RATIO) AT $C_1 = 2.0$

Fig. 5.11 and Fig. 5.12 show the effect of the variation of cost ratio, $C_1$, at various demand level on the total system cost per passenger. Generally, the total system cost per passenger increases with $C_1$ (ratio). It could be observed that the fixed stop responds more to changes in ratio. Hence as the ratio increases the total system cost per passenger decreases more with the fixed stop as demand increases. Thus, fixed stop will perform better with increase in ratio. This is further illustrated in Figs. 5.13-5.15, where the comparison between hail stop and fixed stop are made. Also shown in Table 5.2 are results of this comparison.

Fig 5.11 Total Sytem Cost for Fixed Stops Under Various Cost Ratios

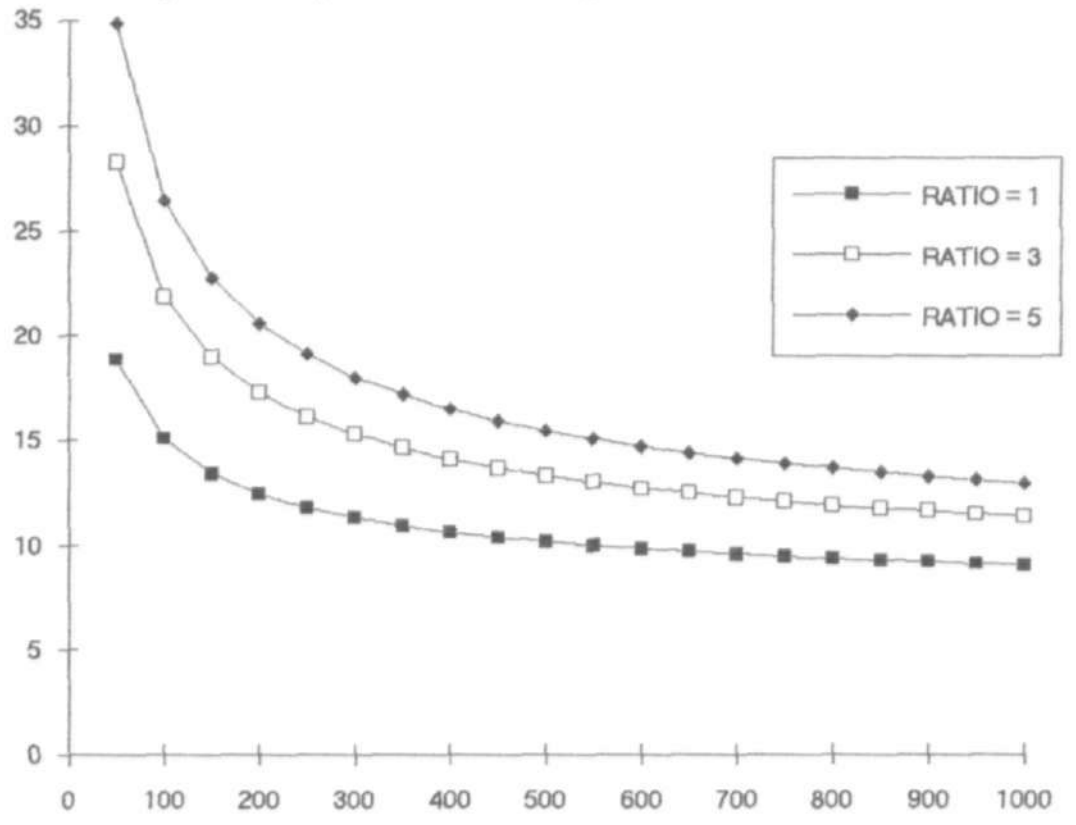
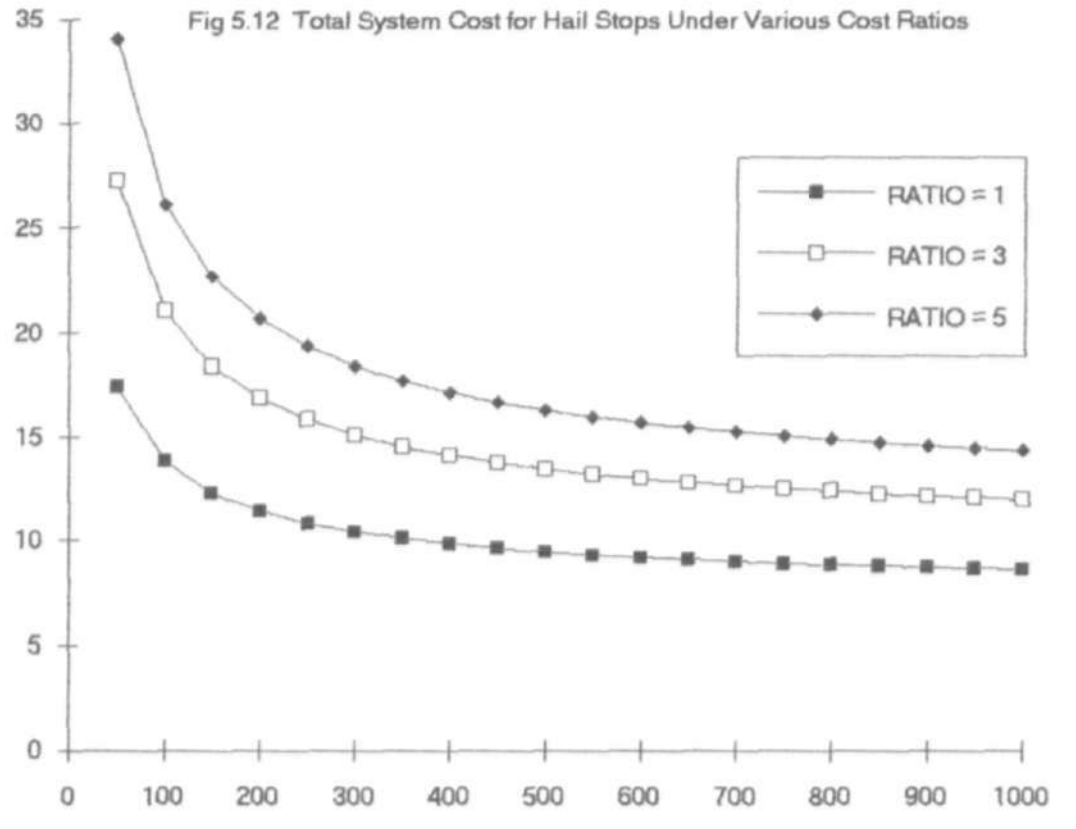



Fig 5.12 Total System Cost for Hail Stops Under Various Cost Ratios



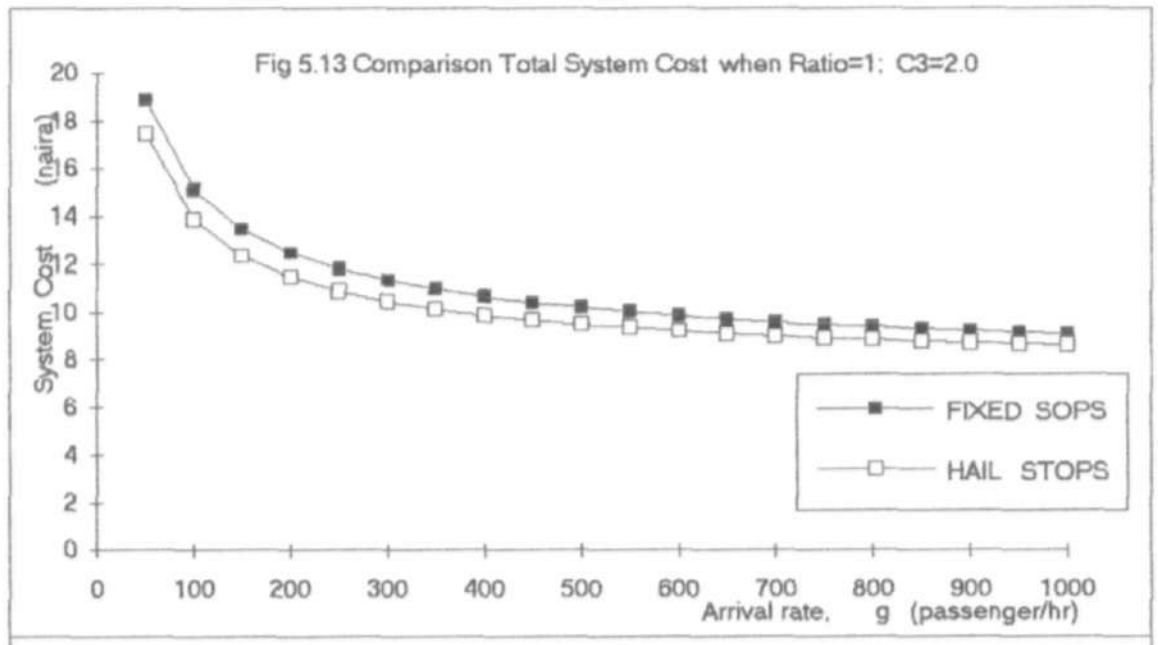



Fig 5.13 Comparison Total System Cost when Ratio=1; C3=2.0

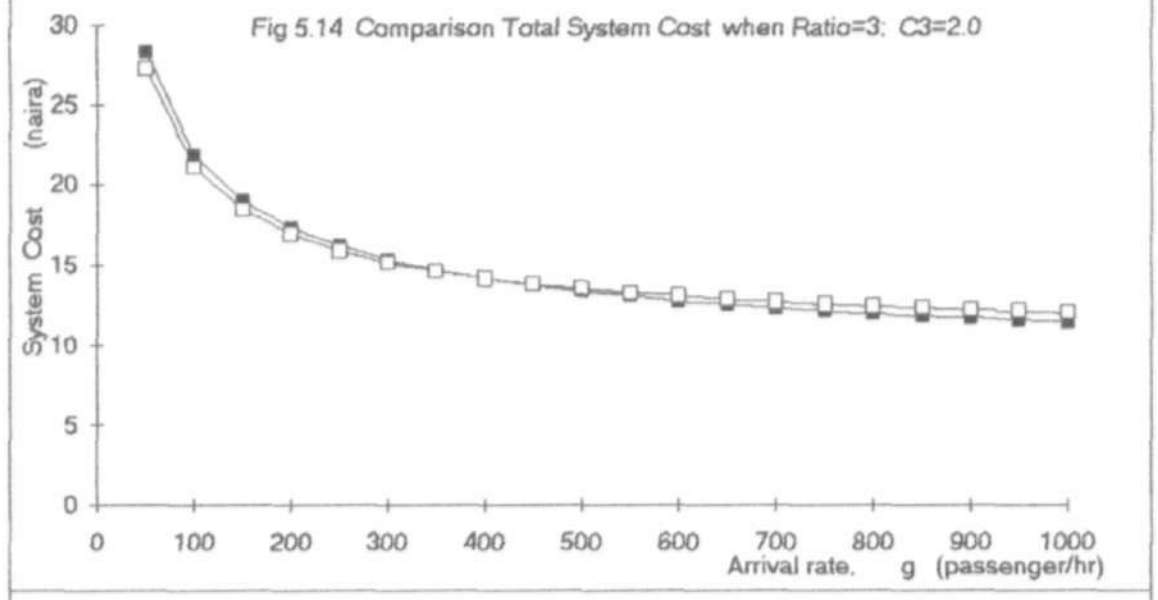



*Fig 5.14 Comparison Total System Cost when Ratio=3; C3=2.0*

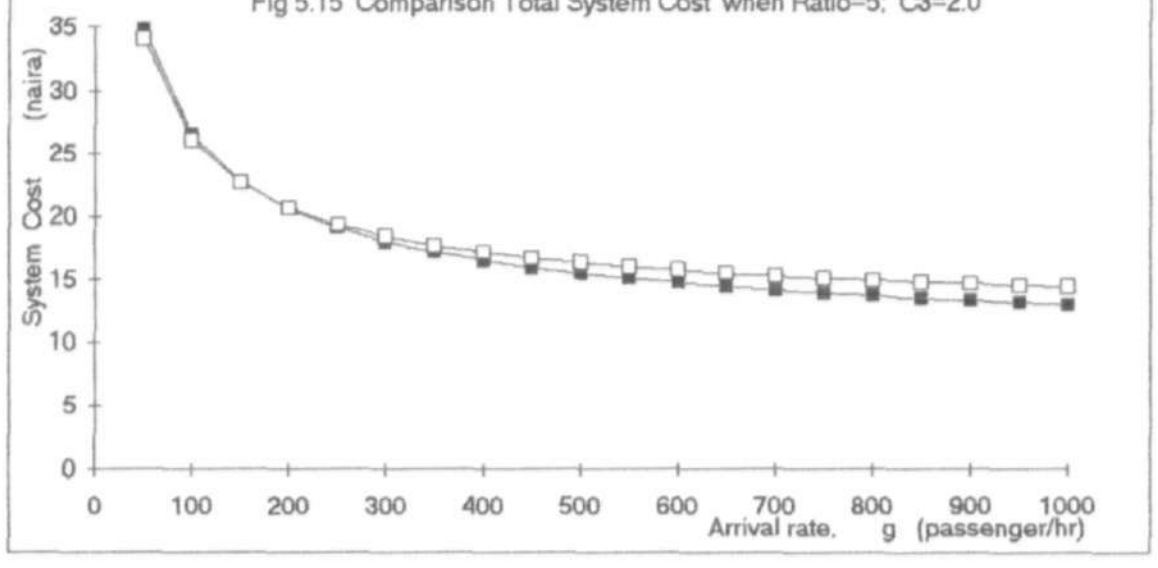


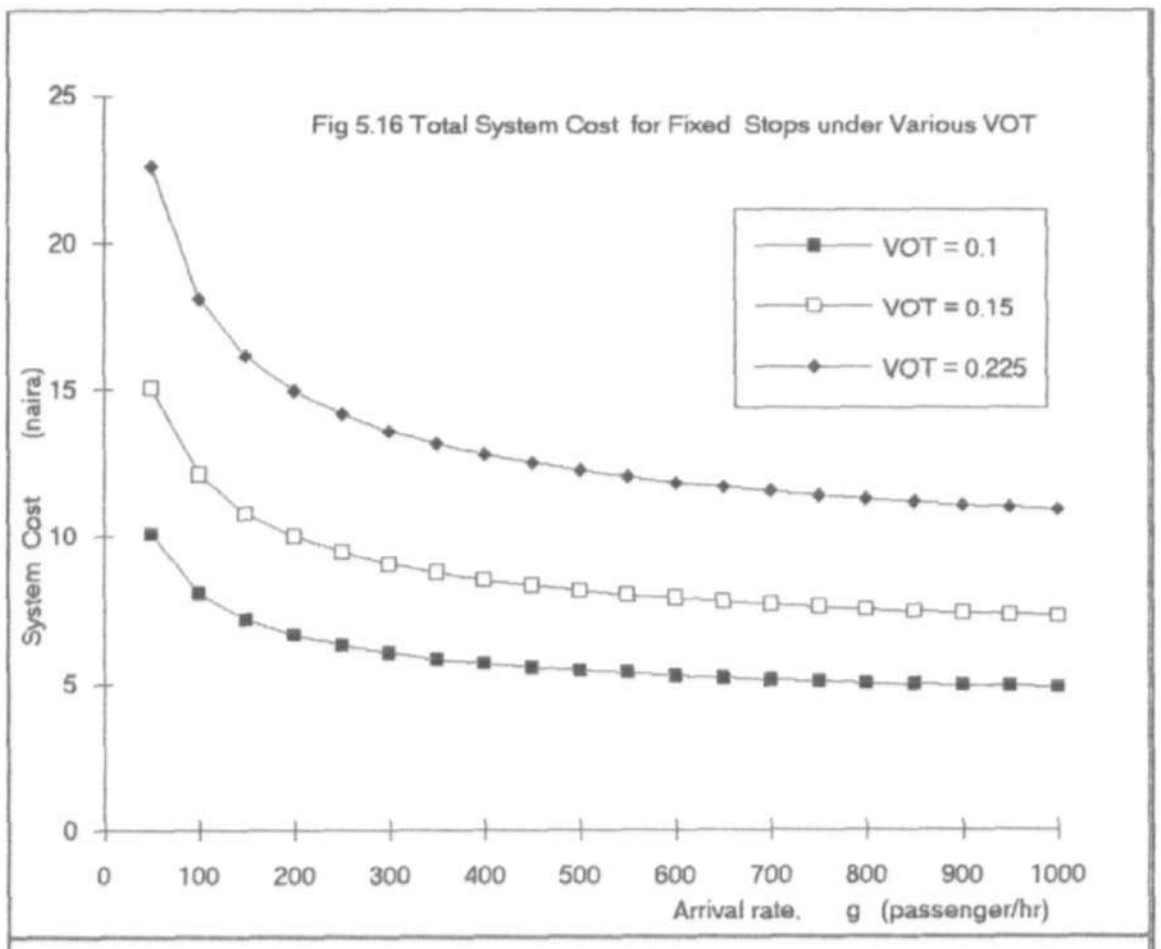

Fig 5.15 Comparison Total System Cost when Ratio=5; C3=2.0

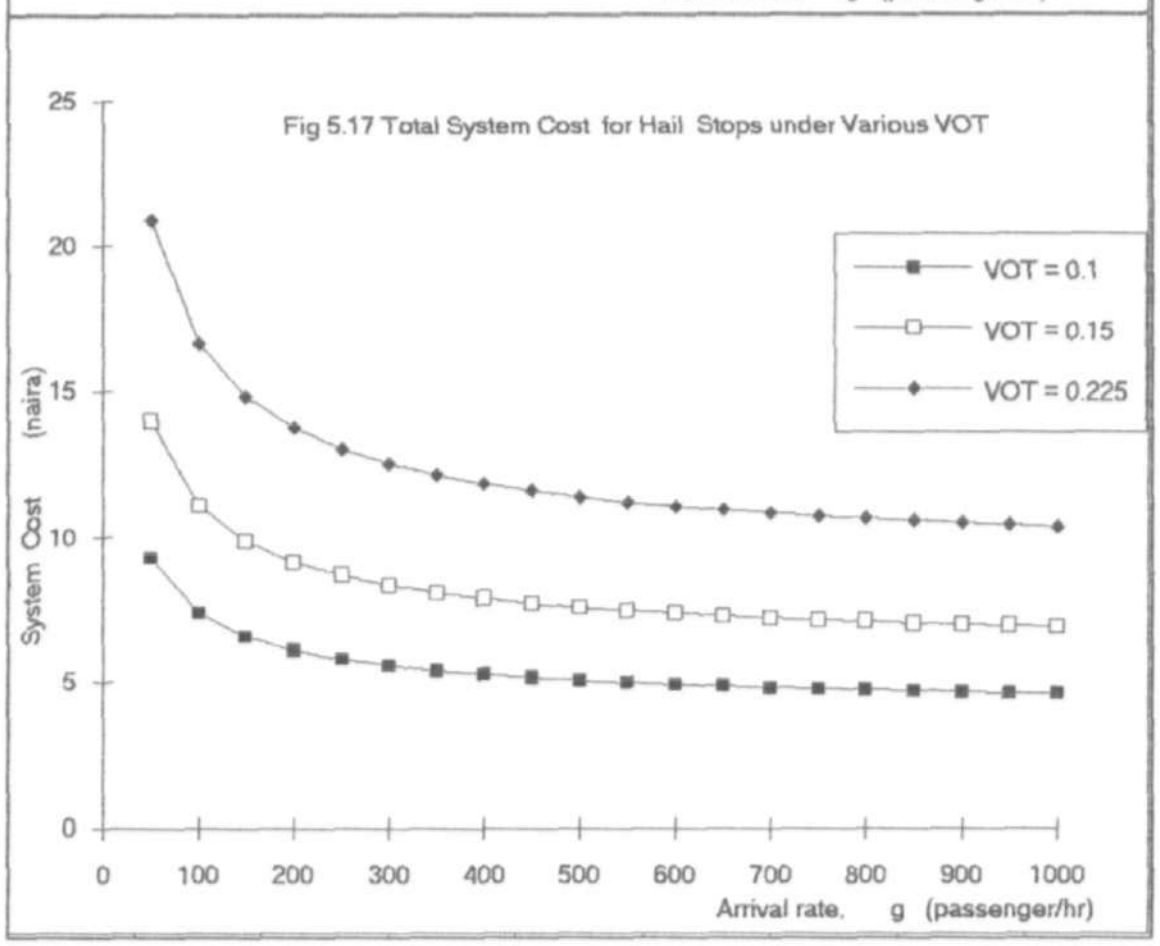
Table 5.2 Comparison of the Total System Cost Under Various Operating Cost Ratios ($C_1$), when $C_3$ = 2.0

| Figure | Ratio | Demand pass/hr (pass/km²/hr) | Remarks |
|---|---|---|---|
| 5.13 | 1 | 50 - 1000 (6.25 - 125) | $Z_2 < Z_1$ |
| 5.14 | 3 | 50 - 350 (6.25 - 43.75) | $Z_2 < Z_1$ |
| | | 400 - 1000 (50 - 125) | $Z_1 < Z_2$ |
| 5.15 | 5 | 50 - 150 (6.25 - 18.75) | $Z_2 < Z_1$ |
| | | 200 - 1000 (25 - 125) | $Z_1 < Z_2$ |

### 5.3.3. COMPARISON OF TOTAL SYSTEM COST: VARIATION IN VALUE OF TIME (VOT)

The effect of change in in-vehicle time has on total system cost is investigated by varying value of time from ₦6.00/hr (₦0.1/min) to ₦13.5/hr (₦0.225/min). The results are shown in Figures 5.16 and 5.17 at peak period for fixed and hail stop service respectively. Evidently the two services exhibited similar responses to variation in the value of in-vehicle time. Hence, when compared hail stop will perform better at all relevant value of time assumed as indicated in the Figures. What may perhaps lead to an interesting result will be when the ratio, $C_3$, of out of vehicle time to in-vehicle time is reduced to one as against the default value of two. Fig. 5.18 shows the result of when ratio $C_1$, is one. It can be seen that $Z_2 < Z_1$ when demand is less than 300 passenger per hour (37.5 pass/km²/hr). But at


Fig 5.16 Total System Cost for Fixed Stops under Various VOT
VOT = 0.1
VOT = 0.15
VOT = 0.225
System Cost (naira)
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
900
1000
Arrival rate, g (passenger/hr)


Fig 5.17 Total System Cost for Hail Stops under Various VOT
VOT = 0.1
VOT = 0.15
VOT = 0.225
System Cost (naira)
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
900
1000
Arrival rate, g (passenger/hr)

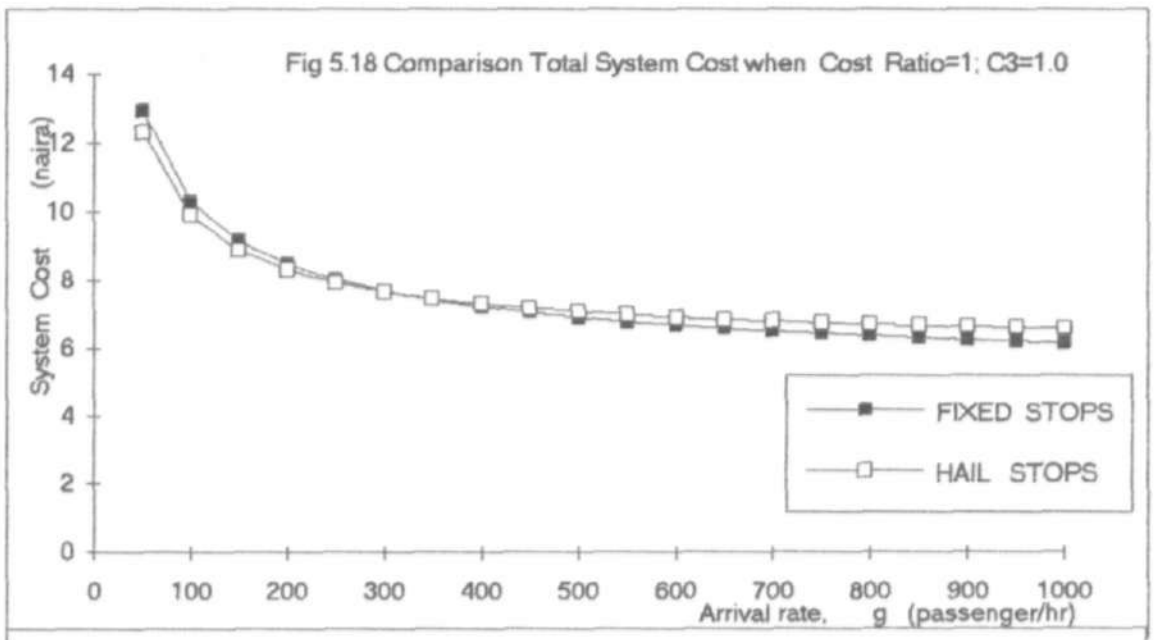



Fig 5.18 Comparison Total System Cost when Cost Ratio=1; C3=1.0

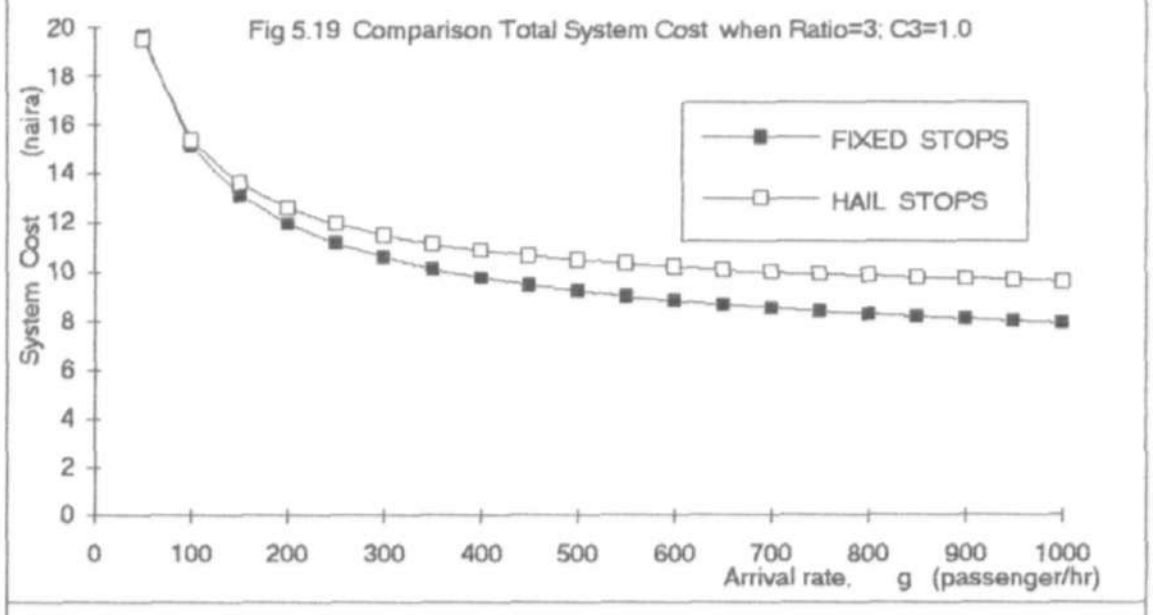



Fig 5.19 Comparison Total System Cost when Ratio=3; C3=1.0

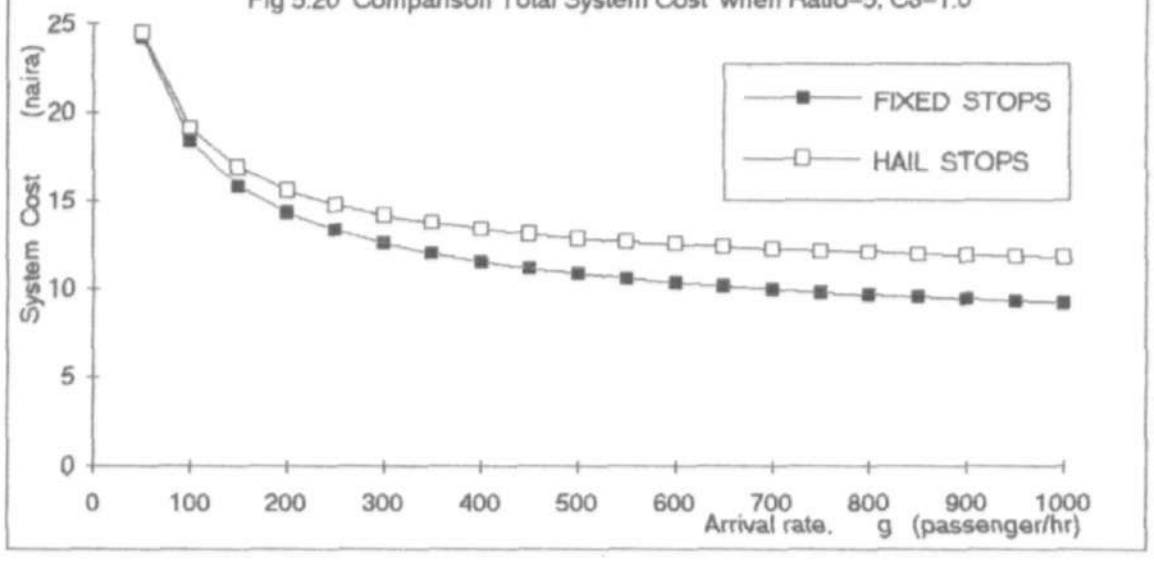



Fig 5.20 Comparison Total System Cost when Ratio=5; C3=1.0

higher demand as shown in Table 5.3 , $Z_1 < Z_2$. As expected as ratio $C_1$ increases $Z_1 < Z_2$, particularly at higher demand levels as shown in Figs. 5.19 and 5.20.

Table 5.3 Comparison of the Total System Cost Per Passenger Under Various Operating Cost Ratios, When $C_3$=1.0

| Figure | Ratio | Demand pass/hr (pass/km/hr) | Remarks |
|---|---|---|---|
| 5.18 | 1 | 50 - 300 (6.25 - 37.5) | $Z_2 < Z_1$ |
| | | 350 -1000 (43.75 - 125) | $Z_1 < Z_2$ |
| 5.19 | 3 | 50 (6.25) | $Z_2 < Z_1$ |
| | | 100 - 1000 (12.5 - 125) | $Z_1 < Z_2$ |
| 5.20 | 5 | 50 - 1000 (6.25 - 125) | $Z_1 < Z_2$ |

When the results in Tables 5.2 and 5.3 are compared clearly there is a marked improvement in the performance of the fixed stop service over the hail stop service especially at higher ratio (i.e $C_1$)

### 5.3.4. COMPARISON OF TOTAL SYSTEM COST: FAVOURABLE CONDITIONS FOR OPERATING THE SERVICE MODES

It had already been stated in chapter four that conditions that favour hail stop obtains when route length is small, value of time high and operating cost low. The default values of length is changed from 8km to 4km. The resulting effect on total system cost is graphed in Fig. 5.21.

Fig 5.21 Comparison of Total System Cost : Favourable Conditions for Hail Stop L= 4 km

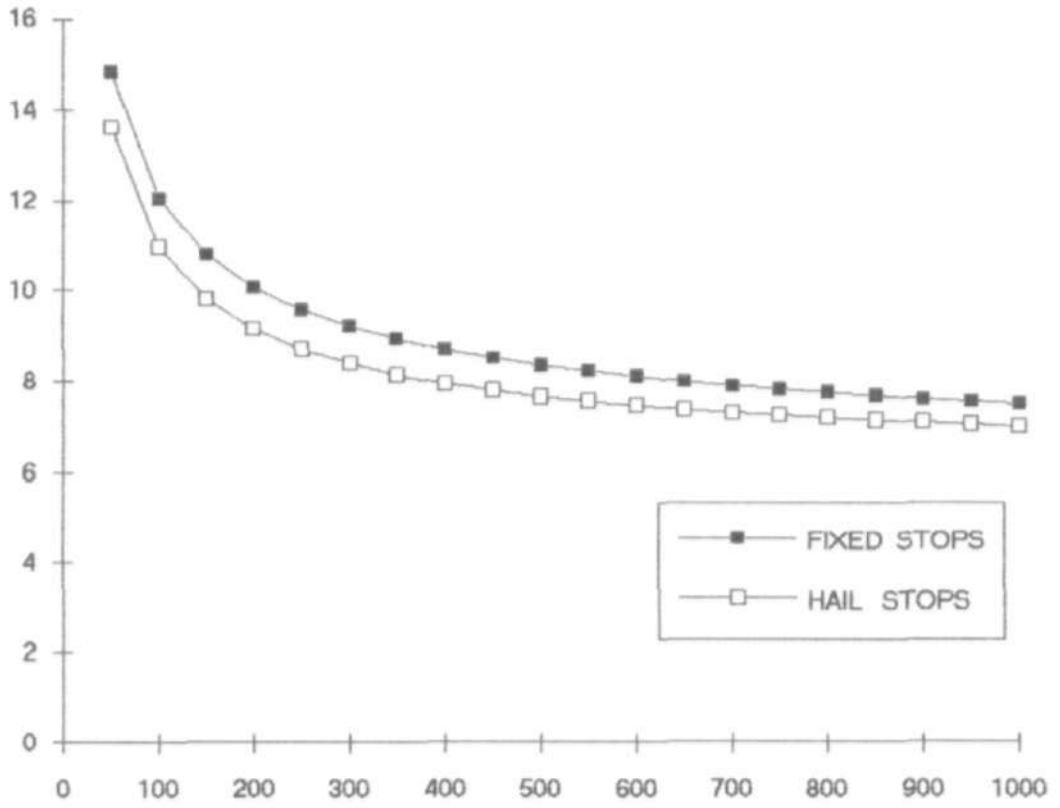
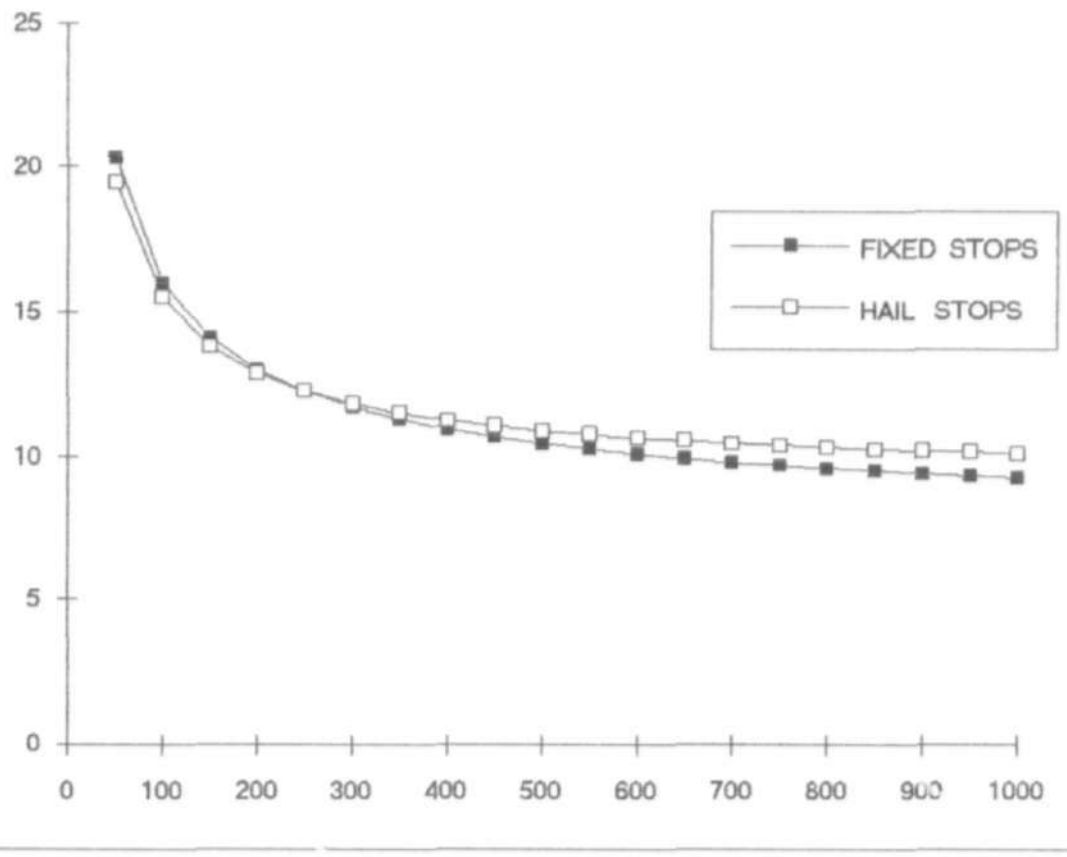



Fig 5.22 Comparison Total System Cost : Favourable Conditions for Fixed Stop L = 16 km



It has also been mentioned that fixed stop will perform better when the route length is long and value of vehicle time is small. The case where the L = 16km, value of out vehicle time is reduced to half (i.e. $C_3$ = 1.0) and operating cost, $\gamma_1$ = ₦15 is thought to be favourable for fixed stop operation. Fig. 5.22 shows the result of this example.

The results of these comparisons are shown in Table 5.4.

**Table 5.4 Comparison of Favourable Conditions for Operating Fixed Stop and Hail Stop Service**

| Figure | Demand pass/hr (pass/km²/hr) | Remarks |
|---|---|---|
| 5.21 | 0 - 1000 (0 - 125) | $Z_2 < Z_1$ When compared to the default case $Z_2$ performs even better |
| 5.22 | 0 - 200 (0 - 25) | $Z_2 < Z_1$ |
| | 200 - 1000 (25 - 125) | $Z_1 < Z_2$ |

### 5.3.5. COMPARISON OF TOTAL SYSTEM COST ; CONDITIONS FAVOURABLE TO THE HYPOTHESES

Section 5.3.4. contained two examples to show how the total system cost behave when the conditions thought favourable to the two services under consideration were applied. It is on this basis we now test the two hypotheses stated in chapter four. To aid us in this we will consider two examples designed to confirm or rather support these hypotheses; perhaps even reject them.

Let us consider, firstly, the hypotheses one. We shall

retain the condition specified in section 5.3.4 for the example where L = 4km but modify the operating cost ₦11/km. The result on system cost is shown in Fig. 5.23.

Second example is used to test hypothesis two, condition stated in second numerical example in section 5.3.4 is adopted with changes to $\gamma_{\text{II}}$ and L as follows: $\gamma_{\text{II}}$ = ₦20 and L = 20km. Fig. 5.24 shows the resulting effect on system cost.

Table 5.5 shows the results of the comparisons.

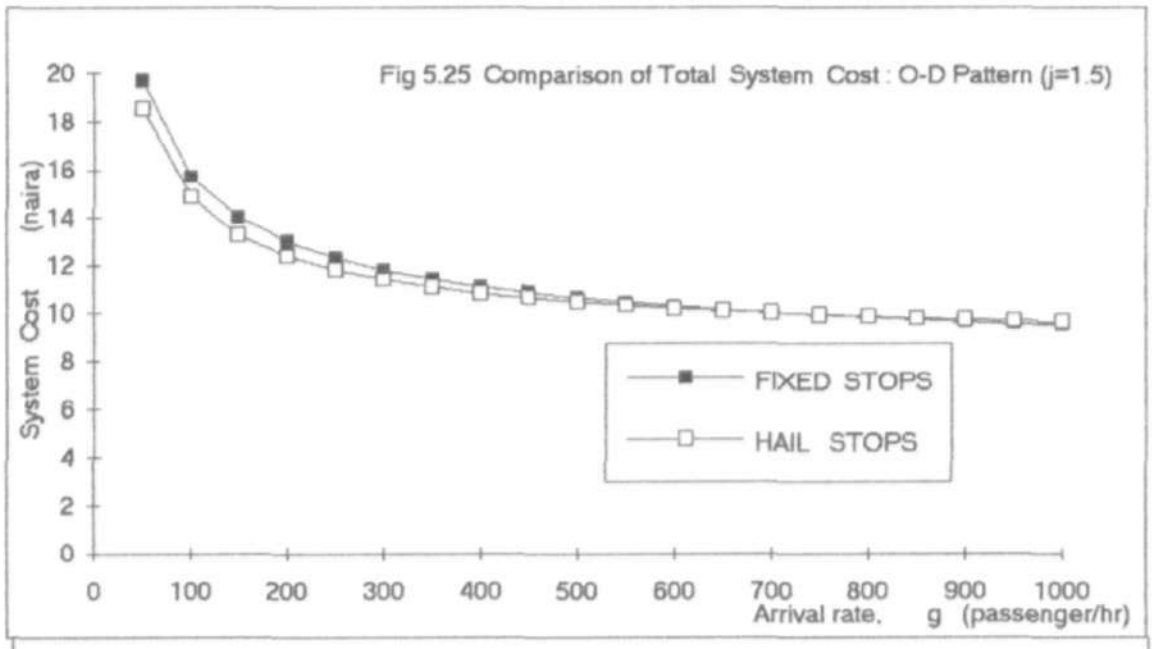
**Table 5.5 Comparison of Total System Cost Per Passenger Under conditions Favourable to the Hypotheses**

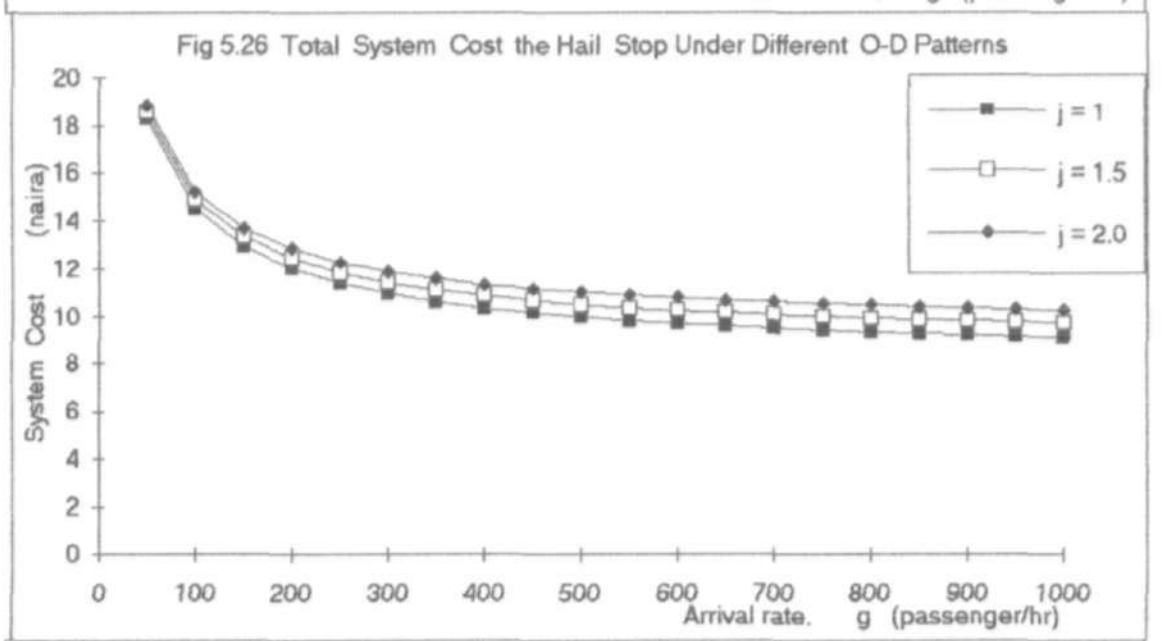
| Figure | Demand pass/hr (pass/km²/hr) | Remarks |
|---|---|---|
| 5.23 | 0 -1000 (0 - 125) | $Z_2 < Z_1$ When compared to results in Fig 5.21, hail stop performs even better. This has confirmed the hypothesis one |
| 5.24 | 0 -150 (0 - 18.75) 200 - 1000 (25 - 125) | $Z_2 < Z_1$ $Z_1 < Z_2$ The result indicated here when compared to that of Fig 5.22 confirms the validity of hypothesis two. |

### 5.3.6. COMPARISON OF THE EFFECTS OF O-D PATTERN ON TOTAL SYSTEM COSTS

This research had focussed on situations where either many - to - one or one - to - many O-D patterns is in place. The situation now considered is when other O-D patterns obtains. The variables to be affected are passenger service time when fixed is considered (K) and passenger service time when hail stop (K'), the coefficient j relating number of stop made to passenger carried. For many - to - one and one - to - many j = 1 and situation where no common origin and destination assumed j = 2 implying the number of stop made is twice the number of passenger carried for hail stop service.

Three examples are used to illustrate the effect, of changing O-D pattern on Total system cost. Example one uses same values for the variables as default except the service time are changed to reflect the assumed j which in this case is 1.5. The results are shown in Fig 5.25. Example two is used to illustrate the effect on total cost of providing hail stop service since for any given O-D the maximum number of stop is known for fixed stop but for hail stop it depends on value of j. The effect of different values of j are shown in Fig. 5.26. Example three provides an example to demonstrate the effects on total system cost when the route is very long (20km) and O-D pattern dictate that j = 1.5 and ratio $C_j$ = 1.0 . The results of this demonstration is shown in Fig 5.27 and Table 5.6.


Fig 5.25 Comparison of Total System Cost : O-D Pattern (j=1.5)
System Cost (naira)
0
2
4
6
8
10
12
14
16
18
20
0
100
200
300
400
500
600
700
800
900
1000
Arrival rate, g (passenger/hr)
FIXED STOPS
HAIL STOPS


Fig 5.26 Total System Cost the Hail Stop Under Different O-D Patterns
System Cost (naira)
0
2
4
6
8
10
12
14
16
18
20
0
100
200
300
400
500
600
700
800
900
1000
Arrival rate, g (passenger/hr)
j = 1
j = 1.5
j = 2.0

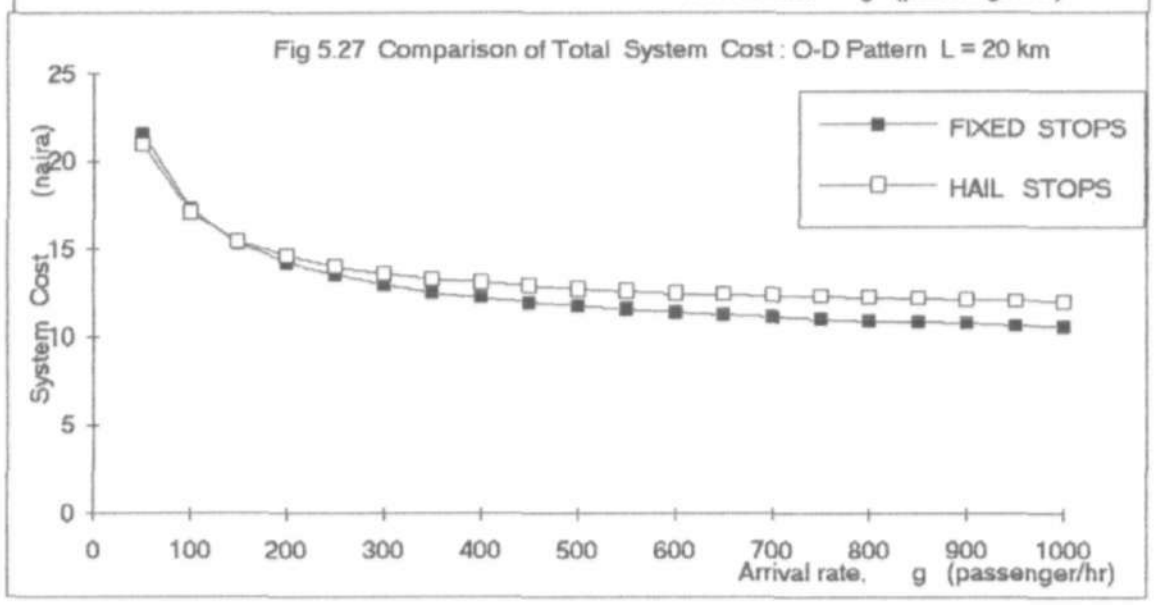

Fig 5.27 Comparison of Total System Cost : O-D Pattern L = 20 km
System Cost (naira)
0
5
10
15
20
25
0
100
200
300
400
500
600
700
800
900
1000
Arrival rate, g (passenger/hr)
FIXED STOPS
HAIL STOPS

Table 5.6 Comparison of the Effects of O-D Pattern on Total System Costs

| Figure | Demand pass/hr ($pass/km^2/hr$) | Remarks |
|---|---|---|
| 5.25 | 0 - 600<br>(0 - 75)<br>750 - 1000<br>(93.75 - 125) | $Z_2 < Z_1$<br>$Z_1 < Z_2$ |
| 5.27 | 0 - 100<br>(0 - 12.5)<br>150 - 1000<br>(18.75 - 125) | $Z_2 < Z_1$<br>$Z_1 < Z_2$ |

# CHAPTER 6

## SUMMARY AND CONCLUSION

### 6.1 SUMMARY OF FINDINGS

The relative performances of the fixed stop and hail stop mode of service have been evaluated and compared. The objective that guided the comparison is the minimisation of the total system cost.

Models for total system costs made up of total bus operating costs plus total travel time costs per passenger are set up and the optimum headways for each service determined.

Numerical values for some of the variables contained in the model were specified to be reasonably reflective of current situations in the Nigerian environment based on published findings largely from developing countries to facilitate the manipulation of the derived models.

Sensitivity analyses have also been used to isolate the key parameters affecting the total system costs and the optimum headways. The variables which were found to be insignificant were discarded from further consideration since variation in their values are not likely to significantly influence system performance in real-life cases.

Results from the sensitivity analyses were then used to generate guidelines for comparing the two modes of service under consideration and isolate the conditions under which one service is more appropriate than the other. On the

latter, two hypotheses were advanced.

Highlights of the results are summarised below

1. Optimum headways have been found to depend mainly on the demand on the route, length of the route, value of out-of-vehicle time and the normal operating cost. The most significant influence on the optimum headway, however, was that of demand. It has been observed that the optimum headways for the fixed stop service are higher than the hail stop service. Similarly, off-peak optimum headways are higher than the peak. Optimum headways are found to decrease when either patronage and/or value of users' travel time increase. On the other increases in optimum headways are observed when operating cost or length of route increases.
2. Optimum headways have also been shown to depend on cost ratios but not the magnitude of cost elements. For example, when the ratio of normal operating vehicle operating cost per kilometer to users' out-of-vehicle time cost per hour (i.e $C_1$) is increased the optimum headway increases.

The influence of cost ratios on the total system cost were also investigated. In particular, the ratio $C_1$ was extensively studied. When the ratio increases the total system cost decreases faster with fixed stop service. The hail stop was shown to perform better as the ratio decreases. When the ratio of out-of-vehicle travel time to in-vehicle time ($C_3$) was reduced to one,

fixed stop perform better especially as $C_1$ increases.

3. Vehicle productivity, measured in terms of the average vehicle load, is determined by the headway. Thus, optimum headways have influence on vehicle productivity and factors affecting optimum headways would affect vehicle productivity but the degree of influence is different. For instance, when there is fall in demand even though optimum headway will increase it has been shown that vehicle productivity will reduce. Based on this the effect of vehicle size on the modes of service was undertaken. It was found that when fixed stop is considered higher capacity vehicle are more appropriate to be used and smaller capacity vehicle seems likely to be used with hail stops.

4. Variables found to exert greatest influences on the optimum headway were found to have similar influences on the total system cost. A major difference, however, was noticed with the value of users out-of-vehicle travel time. Increases in its value reduces optimum headways but increases the value of the total system costs. In addition the value of users' out-of-vehicle travel time was found to be the most important variable influencing the total system costs at the peak period for both services.

5. Perhaps surprisingly, the total system costs associated with hail stop service were found to be less than fixed stop service for the representative values of variables used in the model for nearly all of demands considered.

As may be expected, total system costs at off-peak periods are less than at peak for both services. In terms of users cost the hail stop also generally gives lesser values. But operating cost is generally higher for the hail stop.

6. The sensitiveness of total system costs to variation in key parameter identified as influential was compared for the two services. The results of the comparison generate two hypotheses. These hypotheses were validated by means of two numerical examples.

   Hypothesis 1 state that if the hail stop service is found to perform better than the fixed stop at $g_h$ i.e at $g = g_h$. It will still perform better at all higher demand levels. If the following changes are made on the bus route (a) Length of route is reduced or (b) Value of time increases or (c) operating costs reduces.

   Hypothesis 2 state that if fixed stop is found superior to hail stop at $g = g_f$. Then it will still be found better at least for all higher demand levels. Whenever (a) length of the route is increased or (b) the value of time decreases or (c) operating cost increases.

   In addition, indications from the hypotheses are that whenever the route is short, demand low, operating cost low, the hail stop service may well be better. There are evidences which support these prepositions.

7. When the O-D patterns are changed from the simple ones assumed (i.e many-to-one and one-to-many) in order to manipulate our models, it was observed that the

performance of fixed stop improved. The situation where length of route is long (20 km), $C_j$ = 1.0, j = 1.5 the fixed stop performs much better. It was also shown that the hail stop responds more to changes in the O-D pattern assumed. As the number of stop increases the cost of service also increases.

## 6.2 METHODOLOGY FOR COMPARING THE SERVICE MODES

The hypotheses 1 and 2 indicate that if service changes are to be made and if a bus operator wants to choose between the fixed stop and hail stop modes of service, the operator needs to know the current conditions on the route particularly as it pertain the following parameters, route length, value of time, operating cost and demand on the route. Hypothesis 1 indicates that if the hail stop performs better at current conditions on the bus route, then it will for most practical situations perform better if any of these changes are made on the bus route (a) route length is reduced (b) value of time increases (c) operating cost reduces. Similarly, the hypothesis 2 indicates that changes aimed at increasing service coverage (e.g increasing route length), or increasing operating cost are introduced and fixed stop had been found to be superior at current conditions, then it will continue to perform better especially when demand also increases.

In cases indicated above it will be better to retain the service found superior. However, if changes are not as

indicated further investigations are required. In addition when a new service is to be introduced, a bus operator needs also to know operating cost ratio ($C_1$) and in-vehicle time to out-of-vehicle ratio $C_3$ . The bus operator could then compare the fixed stop and hail stop, but he should note that when conditions that lead to increasing $C_1$ are likely to be met and/or when the value of $C_3$ is low then fixed stop will invariably be better particular at high demand; when demand is low and the route length is small, quite likely the hail stop is better.

The mode of service should not quite literally be taken as a 'catch-all' to be used exclusively on a route. It appears possible that when a long route passes through a predominantly residential location, hail stop may be used at this location to seize its advantage of easier accessibility to let off passenger burdened down by shopping say and fixed stop used at the remaining part of the route.

Furthermore,in situations where fixed stop is to be adopted, large vehicles are likely to bring advantages, but where the hail stop is adopted small vehicles are preferable because they could provide the more frequent service needed for the hail stop at more agreeable vehicle loadings.

## 6.3 CONCLUSIONS

The models developed in this research have been conceptualised to capture conditions that are existent in developing countries. It could be argued that transferring models developed to respond to the needs and resources of

developed to developing countries may lead to doubtful or sub optimal results because of differences in socio-economic climate (culture, educational, norms, etc.). However exchange of models between developing countries faced with similar conditions are possible. Care should however, be exercised to limit the data errors which can arise due to estimation of model's parameters, calibration, etc. Although this study is biased to developing countries, effort was made to maintain a sound theoretical base for models developed. Attempts were also made to avoid modelling efforts that require sophisticated calibration efforts.

The model specification was used to demonstrate how planners faced with limited data information rely on published data to estimate model parameters, hence the minimum data required to use model is also shown.

It has been shown that choosing between fixed stop service and hail stop service depends on the relative combinations of four principal variables namely, the demand on the route, length of the route, value of out-of-vehicle time and the normal operating cost. Furthermore, hypotheses advanced provide a rough guide to the operators as to directions to follow when the existing conditions on bus route are to be changed. For one, they help the operators make preliminary decisions on whether to retain current service or whether further investigations are needed. Hypothesis one indicate that if hail stop is found to be superior for current conditions, it will still be better if service changes that are aimed at reducing the route length

(e.g trip cutting) or when operator costs is subsidised are contemplated.

Numerical examples are set to show how the models adapt readily to different environment by changing the O-D pattern assumed in manipulating the model specifications. This shows that the models are not too restrictive to conditions under which they are formulated and hence not applicable to unique situations only.

It has been noted that for many-to-one and one-to-many O-D patterns that hail stop service tends to perform better at most relevant demand levels particularly at low demands. However, when many-to-many is assumed and route length is long it has been shown that fixed stop service are more superior at higher demand levels. Against this background it is recommended that hail stop service should be used to collect patron from residential locations to high activity centres and to distribute them from high activity centres to residential areas. And the fixed stop service should be employed to provide line haul service between major activity centres in urban areas.

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