TRAFFIC ASSIGNMENT
A COMPUTER PROGRAM FOR THE INVESTIGATION OF THE EFFECTS OF CHOSEN FACTORS IN CAPACITY RESTRAINED SOLUTIONS

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ABSTRACT

This dissertation is concerned with a discussion of various aspects of traffic assignment and the writing and development of a computer programme to investigate the effects of some of the factors influencing the solutions given by certain capacity restrained assignment techniques.

A short review of the planning process is followed by a survey of modern traffic assignment processes with particular reference to capacity restrained methods, and a discussion of factors affecting these solutions. A detailed discussion of the assessment of the convergence of capacity restrained methods is included. Programmes are written to allow the use of three different loading methods and three different speed/flow relationships in the investigation of the approach to a solution of three different capacity restrained methods as indicated by five different measures of convergence.

Suggestions are made for the development of the programmes and areas in which they may be used for further research into the functioning of capacity restrained traffic assignment techniques.

INTRODUCTION

In recent years attitudes to planning have tended to polarise towards two extremes. One school of thought assumed that everything could be solved analytically while the other assumed that there was no substitute for plain common sense (101). One of the main reasons for this divergence of opinion was the arrival of the electronic computer which opened up vast new horizons for problem solving, for the first time making it possible to apply rigorous mathematical approach to many planning problems. A mathematical approach has become the rule than the exception in transport planning.

The past decade has seen a number of achievements in transport planning such as the development of a new breed of transport models designed more closely to answer the problems of the moment. Technical advances include the introduction of synthetic trip end estimation procedures, multiple route assignments, use of speed/flow equations as part of the transport model, and the development of a suitable method for the economic evaluation of alternative transport networks. Following these almost immediately were new models which included an allowance for the effect of traffic congestion on trip distribution, generation and modal split as well as assignment.

Yet there are still avenues for research into development of means of increasing the sensitivity and accuracy of the models and the model results. In this dissertation the author is concerned with a discussion of various aspects of traffic assignment and the writing and development of a computer programme to investigate the effects of some of the factors influencing the solution given by certain capacity restrained assignment techniques.

1. THE LAND USE/TRANSPORTATION STUDY - TRAFFIC ESTIMATION

In a broad sense the objectives of the land use/transportation planning process is to develop a pattern of land use and transport to serve it which will enable people and goods to travel safely and economically.

The problem of planning for the motor car had arisen in U.S. as far back as the early 1950's. It was realised then that movement desires were controlled by land uses at origins and destinations. This approach was successfully applied in the Detroit Area Traffic Study (1953) (l 25), and it is still used in the larger urban transportation studies supported by the U.S. Bureau of Public Roads (104). And in fact to qualify for financial assistance for road construction, Urban areas over 50,000 population in U.S.A. must carry out a continuing comprehensive land use/transportation study.

In Great Britain highway planning in urban areas started with the emphasis placed on forecasting demands for road traffic alone. This could be seen in The London Traffic Survey (1960) (1:6), the SELNEC Highway plan of 1962 (126) and the Merseyside Conurbation Traffic Survey to mention a few. The first full-scale attempt in Great Britain to relate land use and transportation in planning for a sizeable urban area was the West Midlands Transportation Study (102) commissioned in April 1964. The objective was to undertake a comprchensive survey of all forms of transport in the West Midlands Conurbation; to analyse its relationship to types

of land use and all other factors affecting the demand for and movement of transport; and to make forward projections with the aim of providing guidance on the desirable pattern of road development and public transport facilities.

The land use/transportation planning process is a dynamic process in the sense that it must respond to changes of land uses, economic conditions and travel patterns. Where there is a degree of free choice it becomes a behavioural science; that is, a science concerned with human conduct. But transportation cannot be viewed outside decisions coming from the individuals. Where a group of people are involved, political, economic and social factors play an important part in their choice making. Moreover these factors cannot be limited to a small community, their effect may well be nationwide or worldwide. For example the channel tunnel is a government decision which will have various effects on transportation within the British Isles as a whole, in Northern Europe and in the bridgeheads of Kent and Flanders.

Hogden (106) has observed that it is often easy to obtain very accurate information in one part of transportation planning process while assumptions and relatively inaccurate approximations are made in other parts. This is especially true of traffic assignment studies.

1.1 THE GOALS AND OBJECTIVES

The transportation planning process has a number of goals and objectives.

The first set of goals and objectives (110) could be taken as to include attempts to

1. Minimize travel time
2. Minimize travel cost
3. Provide adequate transportation system capacity
4. Provide adequate transportation system safety
5. Provide adequate transportation system reliability

The second set of goals and objectives (110) might be to

1. Provide for equitable distribution of regional accessibility for employment, health, education shopping and recreation
2. Forster desirable arrangement of land use and transportation facilities
3. Minimize community disruption
4. Minimize the impairment of the environment

The above objectives must be measureable so that costable and quantifiable criteria may be properly expressed. Objectives containing these attributes can be called 'operational objectives'

1.2 TRAFFIC ESTIMATION

The transportation planning process as we know it today has been made possible only through widespread use of large storage electronic computers. The process consists of interdepen-

dent steps which can be divided up as shown in the chart for the West Midlands Transportation Study given below. The comprehensive nature of the planning process requires that large amounts of data must be gathered. The type of data collected, however, should be based on the requirements of the goals and objectives described above. Having gathered the data, the traffic estimation is made using the models discussed below.

THE WEST MIDLANDS TRANSPORTATION STUDY

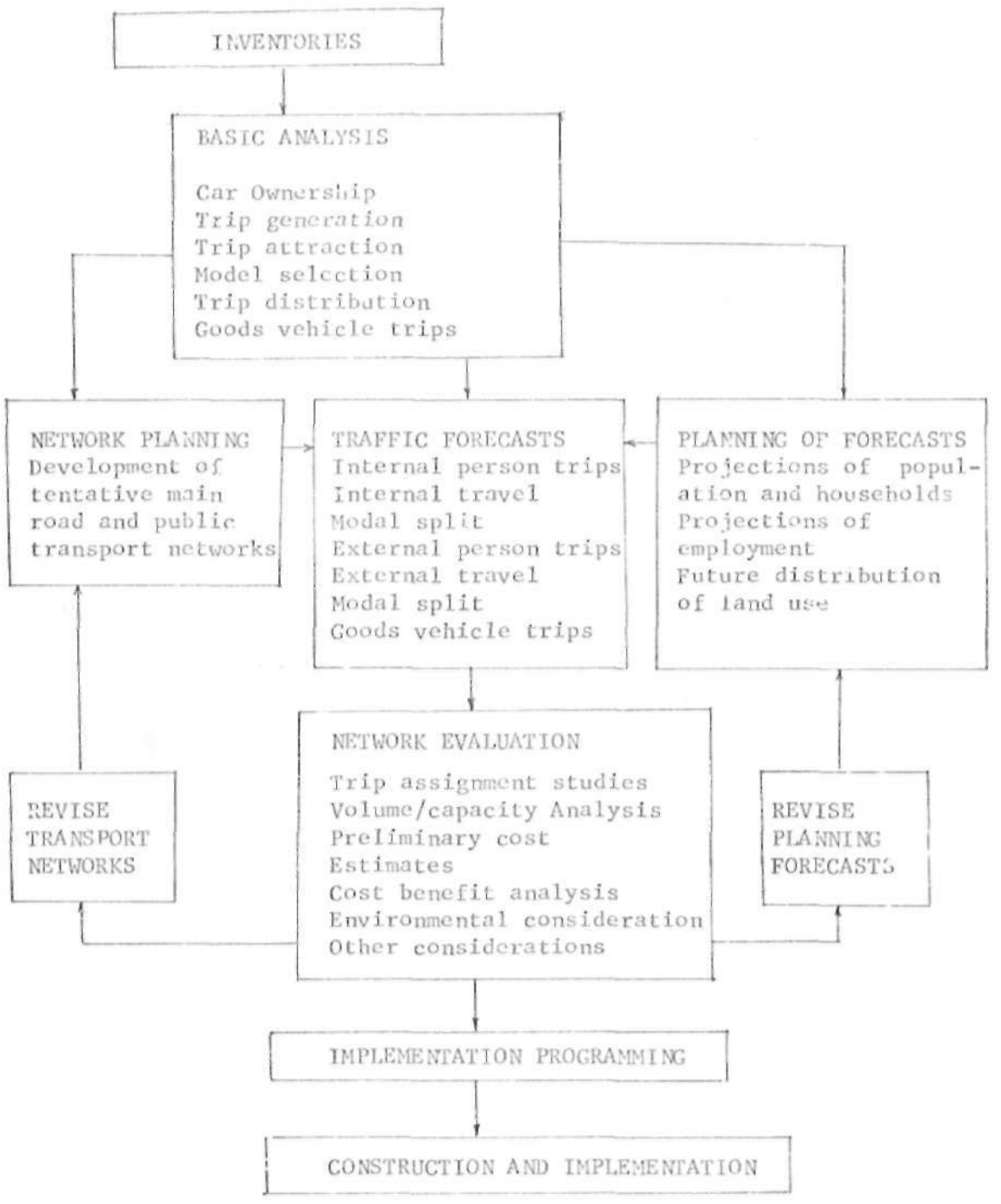


TABLE 1.2

1.3 THE MODELS FOR TRANSPORT PLANNING

Models are built during the analysis of the inventories collected at the survey stage. The inventories form the base upon which the planning process takes shape. Typical elements for which inventories and analysis are required are:

1. Economic factors affecting development
2. Population
3. Land use
4. Transportation facilities
5. Travel patterns
6. Terminal and transfer facilities
7. Traffic Control features
8. Zoning ordinances, subdivision regulations, building codes etc.
9. Financial resources
10. Social and community-value factor

In the analysis and calibration phase, the data obtained through the inventories are analysed and techniques are developed (model calibration) for estimating future travel demands. Tasks usually included in this phase are

1. Derivation of models for estimating population and economic activity (110)
2. Land use forecasting techniques (110)

3. Trip generation (101, 110)
4. Trip distribution (101, 110)
5. Modal split (101, 110)
6. Traffic Assigrment (101, 110)
7. Evaluation (101)

1.3.1 DERIVATION OF MODELS FOR ESTIMATING POPULATION AND ECONOMIC ACTIVITIES (101,110)

This task involves the development of methods of forecasting population, employment, income and car-ownership for the Study area or region.

The population estimating procedures widely used in the past transportation studies have been based on established techniques from the field of demography. The most widely used methods in population forecasting can be placed in three categories: (110)

a) Trend-based methods, which employ graphical or mathematical projection of the curve of past population growth.
b) Ratio methods, which are based on the relationship of population growth in one area to that in another
c) Component methods, which are based on analysis of net migration and natural population increase

The methods of forecasting economic activity for transportation study purposes may be categorised also as follows

i) Trend Line Projection, which employs time series data for the desired economic indicator which is to be forecast. The process involves fitting a trend line to historical data.

ii) The step-down method, which relates the economic activity in the study area to that of a larger economic region which includes the study area

iii) Sector Analysis, which is similar to the component method used in population forecasting as mentioned above

iv) The Economic Base Multiplier Method, which assumes that the local economy depends primarily on a group of 'basic' sectors. These are the ones whose roles are primarily expanded to points outside the study area. It is assumed that the changes in the 'basic' sectors will generate changes in the 'non basic' sectors of the local economy. Past data is analysed to develop a 'multiplier ratio' between total employment and basic employment. Thus if future demands on the 'basic' sectors are estimated, a forecast of the local economy can be made.

v) The Input-Output Model, which is a method that explicitly relates the interaction of the major economic activities which affect one another. It consists of statements which equate the output (or product) of each subsystem of the inputs (or consumption) of the other systems.

1.3.2 LAND USE FORECASTING TECHNIQUES

The distribution of the end products of the regional population and economic forecasts to the small areas (analysis zones) located within the region is part of the land use forecast. Since

travel is largely dependent on the spatial arrangement intensity, and character of the land use, this phase becomes an extremely important component of the transportation planning process.

A number of techniques have been developed for forecasting land use and some of them are outlined below (110).

1. Judgement and trend analysis, which involves simple visual extrapolation of data
2. Density-Saturation Gradient Method, in which the area is divided into concentric ring zones about the high-value-corner usually the (CBD). Regularities in historical land developments are observed, and curves which estimate these patterns are developed. One then makes intuitive judgements about the nature of further development, and extrapolates future land usage on basis of historical patterns.
3. Accessibility Model, which describes in explicit mathematical form some of the factors which influence land development such as measure of activity in a zone (total employment) and travel separation factors between zones in the area.
4. Intervening Opportunity Model, which is based on the hypothesis that the probability of a residential opportunity being chosen for development is a monotomically decreasing function of the number of intervening opportunities between a point within the centre of the city and a location where a newcomer would find a site in which to build.

5. Multiple Linear Regression Techniques, which develops an equation of the form discussed in (Sect. 1.3.3) expressing the measure of land use in terms of vacant land, land value, accessibility to employment and other measures like zone size and population.

1.3.3 TRIP GENERATION

The trip generation phase of transport planning examines the relationship between the number of trips made and certain quantifiable parameters. Some of the quantifiable parameters usually included are household income, car-ownership, intensity of land use and distance of the origin from the central area.

Trip generation models are established according to trip purpose, such as journey to work, journey to school or to the shops etc; and the techniques used in the models fall into the following main groups

1. Regression Analysis, which uses multiple regression techniques to calibrate a model when more than two variables are being considered. The general form of a multiple regression equation is

$$Y_p = A_1 + A_2 X_2 + A_3 X_3 + \ldots\ldots\ldots A_k X_k + U$$

where

Y = number of trips for specified purpose p

$A_1 \ldots\ldots A_k$ parameters fixing a unique linear function

X_1 ..... X_k zonal planning input factors (the independent variables) such car-ownership household income and other quantifiable parameters

U is a disturbance term.

2. Category Analysis, which assumes that there are three factors which are of prime importance in affecting the amount of travel a household generates. These variables are

   a) car-ownership (101, 114)

   b) household structure and (101, 115)

   c) household income (101, 114)

   Other variables considered to influence the number of trips are population, residential density, nature of public transport available and the nature of highway system.

   The trips are also stratified according to trip purpose, person types and whether home-based or not. The method is further based on the assumption that a number of ranges within each variable can be established in such a way that all households can be described by a limited number of categories of household. A trip rate is then assumed for each category of household.

3. Mode Availability, which makes separate trip generation analysis by disaggregating the trip generation variable into categories of modal opportunity groups. The groupings might be as follows:

i) individuals who have only public transport available

ii) individuals who have public and private transport available

iii) individuals who have only private transport available

This factor (modal opportunity group) can then be included in either multiple regression equations or category analysis. But this entails more work as it would be necessary to devise a more detailed household interview questionnaire to provide the basic information on mode availability to different members of the household at different times of the day and for different trip purposes. Transport Accessibility, which uses the ease of travel to and from a zone by all modes as a parameter for estimating the total number of trips. In fact all trip generation and attraction rates which are measured at a given instant of time explicitly or implicitly measure the effect of transport accessibility.

1.3.4 TRIP DISTRIBUTION

This is the analysis of the trips between zones. The trip patterns between all zones for the base or survey year, together with network information are used to establish relationhsips between these journeys, their geographical origins and destinations and the transport facilities they will use. Trip distribution analysis can be made before or after modal split. If distribution has to be carried out after modal split then it has to be assumed that journey generations and attractions can be divided for each zone into car and public transport journey generations and attractions.

Models used in trip distribution are divided principally into direct and indirect models. The former estimates the number of trips between two zones in one step; the total number of trips generated and attracted in any one zone may then be found by adding the individual values. The indirect models distribute the total trip generation of a zone between all the zones of attraction. Indirect models are used in most studies at present; growth factor and gravity models (101, 110) belong to this group of models.

Growth factor models use the base-year information for immediate design purposes and use the growth factors determined to estimate future flows. Gravity models on the other hand analyse the existing travel data in order to set up relationships between trips and measures of attraction, generation and travel resistance. The model used in the SELNEC transportation study is an example of the gravity model.

1.3.5 MODAL SPLIT

In the analysis of the urban travel it is important to be able to reproduce traffic flows on the transportation networks. To accomplish this objective, it is essential to first estimate how people will travel. Most travel taking place in Urban area is made either by private car or mass transit. Apportioning person trips between mass transit and private transporcation is called modal split. The modal split model is accomplished either before or after trip distribution phase if the level of mass transit

in a region is not expected to be significant to the extent that it will influence the growth structure of the area, then it may well to employ the modal split after distribution. If however the study area is well served by mass transit and the service is expected to continue in the future, it may be preferable to use the modal split model before the trip distribution.

The parameters affecting modal split fall into two groups those associated with the generating end of the journey such as journey purpose and mode availability, and those associated with the possible routes and journey destination such as relative travel cost or time spent parking. Thus if modal split is incorporated at the generation phase it will omit journey characteristics, and if included after distribution it will omit generation factors. The carrying out of modal split after distribution will therefore mean that the resulting public transport journeys will have been distributed using private car travel times (101). This error may be rectified by redistribution of these journeys using public transport travel times, but even then, there must be some inherent errors in the resultant trip ends.

Modal split models have been applied to the transport model in one or two forms. First, by relating the number of trip ends in a zone to certain journey characteristics, thereby introducing modal split before trip distribution. Alternatively, models of modal split could be incorporated after the distribution phase and taking the form of diversion curves or regression type of equations relating the percentage using public transport to the factors individuals are assumed to consider when choosing their mode for a particular journey. In fact modal split models range

from simple travel time ratios between the mass transit and the highway system, to more complicated and complex models.

1.3.6 TRAFFIC ASSIGNMENT

The next stage in the traffic estimation process after the distribution of trips by various modes of transport between the zones in the study area, is traffic assignment. Traffic Assignment is the process of allocating a given set of trip interchanges to a specific transportation system. This process may be considered in two main parts. First, the determination of individual routes through the network and secondly loading these trips into the paths selected. The criterion assumed when choosing the paths is the minimum distance, time or cost between the trip ends.

The required input is the complete distribution of the transportation system and a matrix of interzonal trip movements. The output is an estimate of traffic volumes on each link of the system sometimes directional turning movements at intersections. If it is assumed that there is a relationship between the volume of traffic in the system and its resistance to travel then the assigned volumes may be used to determine new patterns of modal choice and trip distribution.

There are five basic purposes for assigning traffic to a network (121). The assignment facilitates:

1. The assessment of deficiences in the existing transport-ation system by assigning the present distribution of trips to the existing system.

2. Evaluation of the effect of limited improvement by assigning estimated future trips to the modified network

3. Development of constructional priorities by assigning trips predicted for intermediate years.

4. Testing of alternative transportation system proposals

5. Provision of design hour volumes and turning movements

This dissertation is largely concerned with aspects of traffic assignment, various techniques of which are discussed in Chapter Four.

1.3.7 EVALUATION

On completion of the traffic forecasting process, the results must be examined and evaluated (101). Evaluation can be considered under four headings, numerical, operational, environmental and economic evaluation.

The numerical evaluation checks the computational validity of the forecasts; the aim being to ensure the output obtained

from the traffic forecasting process precisely reflect the input assumptions. In carrying out these checks, attention is usually directed particularly towards programming errors and errors from input information.

The operational evaluation checks if a proposed network adequately satisfied the forecast travel patterns. That is an attempt is made to answer the following questions: Can the roads take the traffic without unreasonable delay? Will the conditions on the railway network be acceptable or will the trains be grossly overcrowded? This of course depends upon a detailed examination of the traffic flows and travel speeds on different parts of the network and an understanding of the capacity limitations of different types of transport system.

The next stage of evaluation is environmental. Environmental evaluation is to a large extent a matter of judgement and it would be impossible to lay down hard-and-fast rules appropriate to all circumstances. At the moment techniques for measuring the effect of transport systems on the environment are not well developed but the most serious effects of increased traffic circulation may be taken to be noise, visual intrusion , severance, vibration, pollution and danger to pedestrians. Before any proposal is rejected on environmental grounds, therefore, two specific questions must be answered. The first is, if we reject the plan, are we sure that the best alternative (which may in fact be the do nothing at all) will not have an even worse effect on the environment? The second is, if we reject the plan on environmental grounds, is the environment worth the entire cost incurred to ensure its preservation?

Economic evaluation attempts to find the best network, where the best network in economic terms is defined as one which for a given budget constraints yields maximum benefit to the community by minimising the cost of travel. Costs in this definition include the cost of accidents, capital outlay for improvements and new facilities, together with land costs and maintenance costs. Benefits are measured by savings in operating costs, journey time savings, and a reduction in the number and severity of accidents. Detailed discussions on this subject can be found in reference (101).

2. MODELLING THE PRIVATE TRANSPORT HIGHWAY NETWORK

2.1 NETWORK REPRESENTATION

The choice of sections of the actual network to be included in the analysis is entirely at the discretion of the engineer and depends upon the size of the survey and the purpose for which it is required. The main purpose for which network descriptions are used are: to facilitate the derivation of information on the relative time or cost of travel by alternative modes so that the trip distribution and modal split analysis can be carried out, and to assign to the most appropriate routes the elements of the matrix of demands for movement. Local streets are usually omitted because their inclusion will make the network unnecessarily complicated and since they only distribute the traffic locally the flows on them will be insignificant. The usual practice is to analyse the primary and secondary distributors only but care must be taken to ensure that where sizeable flows have diverted to local streets to avoid areas of congestion, the local streets are included.

2.1.1 NETWORK DESCRIPTION FOR COMPUTER ANALYSIS

This dissertation is concerned with the assignment of traffic to the private transport network hence the discussions below have been largely restricted to this network. However, it might be useful to mention here that the public transport network differs from the private transport network in that it comprises a system of fixed services following specified routes at predetermined frequencies.

2.1.1.1 NETWORK FOR PRIVATE TRANSPORT

The highway system for private transport is defined by a series

of links and nodes. A link is usually described as a length of road which has no major intersections (204). There are two types of nodes - intersection and centroid nodes. However nodes usually represent a junction at the intersection of a number of roads except in the R R L method (226) as described later. Links are generally one-way but when there are no capacity considerations they may be two-way.

A study area is divided into several traffic zones. The aim being to define areas of uniform traffic generation and attraction. This greatly simplifies the trip generation/attraction prediction process. The traffic to and from each zone is considered to be generated and absorbed at a particular point in the zone called the zone centroid. The zone centroid represents the centre of gravity of traffic movement in the zone. Its location is in practice determined either by analytical means or by experience. When the centroid is not on an arterial link (and in many programs e.g. the TNET (224) model, the centroid is not allowed to lie on the network) it is connected to suitable network links or intersection nodes by means of dummy links with zero length and journey time inserted. The concept of traffic originating at the centroid of a zone is unrealistic, and it is impossible because of the expense of computer time, to assign a percentage of the originating or arriving traffic to all nodes in that particular zone. Minimum trees would then be required between every pair of nodes in the network rather than between every pair of zone centroids.

An alternative method of network representation has been developed by the Road Research Laboratory (226). In this method, the nodes are placed at the centre of each road and each link represents the time taken to travel from road centre to road centre. Since there is now a danger of calculating roads which proceed to their destination by a series of

U-turns, each side of the road is signed and a minimum tree algorithm (section 4.1) constrained so that each route will enter and leave each road centre at the same side of the road. This representation requires a larger amount of storage for the basic network, but has four main advantages

i) Turning penalties are included automatically since journey times are measured across the junction.

ii) All turning volumes at all junctions are found immediately, since each link represents a single turning movement. The flows along each road easily found.

iii) G and Q turns are handled without any difficulty.

iv) Banned turns are simply represented by giving the particular link infinite journey time.

2.1.1.2 REPRESENTATION OF INTERSECTIONS

For traffic planning and design of intersections, the amount of turning traffic in each direction is normally required. The network description for computer analysis may be designed to movements at selected junctions. It is essential to make selections as economically as possible. Finer representation will entail a greater number of network links and nodes which will increase computer time. This statement does not apply where nodes have been located at the centre of traffic links (RRL method).

Although the additional time required to pass through an existing interchange may be easily found, this is not necessarily so for planned intersections. When the precise nature of the intersection is not yet known an estimate of the time increment must be made. By indexing the end of each link with a sign and adding a penalty (say 30 seconds) to the minimum free everytime a sign change is experienced it is possible to

impose a global turn penalty (204). If a particular movement suffers long delays the delay can be represented by inserting an extra link. A better technique recently developed, is to code the exit type at the end of each link and tabulate the turn penalty for each intersection type, e.g. reference 226, banned turns are easily dealt with in this way by coding the particular turn as having infinite delay.

The travel time through an intersection has quite frequently been included in the travel time of the link. This means that no distinction is made between different paths through the intersection but a common increment corresponding to a certain distribution of turning movements is assumed. When this is so, routes having only a few intersections are favoured. This is desirable when it is thought that travellers choose routes that pass through as few intersections as possible. When delay does not depend on traffic movements specifically the possibility of zig-zag routes is opened up. This is particularly apparent in the grid networks that are common in American cities.

2.1.2. PUBLIC TRANSPORT NETWORK DESCRIPTIONS

This dissertation is not really concerned with public transport network but the following is included to demonstrate the principal differences between the public and private transport networks.

Public transport network differs from the road network in that it comprises a system of fixed services following specified routes at predetermined frequencies. The links and nodes may be defined as usual but the network will consist of a number of individual public transport services, each service being described by the nodes it passes through, the time between nodes and the frequency. A minimum time between any one

node and another will be found in a similar manner to that described for the private transport network, except that the total time will consist of both link travelling time and waiting time. In addition time penalties may be added for interchanges between services at certain nodes, to prevent trips being made on routes composed unrealistically of many service elements.

2.2 SPEED-FLOW RELATIONSHIPS

The network description is not fully complete until the network elements have been described in terms of length and speed or fixed time (cost) penalties depending on the method of assignment being used. For an iterative capacity restraint method it is essential that each link has a characteristic speed/flow relationship.

Hardrop (203) observed in 1952 that increases in the amount of traffic generally produce corresponding decreases in speed. He further defines link capacity as the flow at which the minimum acceptable average journey speed is produced.

The journey time is dependent on both intersection and link delays. In general T_{AB} (the journey time) may be expressed as

$$X_{AB} + l_A/r_A \quad \text{where}$$

X_{AB} is the intersection delay

L_A is the length of link A

r_A is the running speed along link A.

It is extremely difficult and costly to incorporate detailed analysis of intersection delays into a large transportation study network. This may be overcome by considering a journey time per link which includes some

allowance for the intersection delays along the link. Wardrop has assumed that most of the major intersections causing delay in an urban area are controlled by traffic signals of the vehicle-activated type. These act like fixed time signals under congested conditions.

He found that running speed

$$V_R = a(1 - \frac{q}{Q})$$

and that the delay per intersection

$$(d) = b(1-q/L_S)$$

where L_S is the absolute capacity of the junction, a and b are constants, q is the flow on the road in both directions and Q is the capacity of the road. With 'f' intersections per mile and a journey speed of 'V' m.p.h

then $1/V = 1/V_R + f.d.$

$$= 1/(a(1 - q/Q)) + f.b/(1 - q/L_S).$$

Hence a journey time for a link including delays at intersections along the link may be readily found using calibrated equations.

The running speed and intersection delays depend on environmental and traffic conditions. Of course, every street provides a different level of service and it would be an impossible task to estimate the running speed and delays along every link in a large network. For this reason, attempts have been made to relate speed under free and congested conditions to the type of road its location. Furthermore, Thomson (210) has described area speed/flow relationships for Central London. This was intended as an aid to major policy decisions concerning transportation investment but may be of use in network assignment. For these formulae to apply to towns with characterisitcs different from those of London, it

would be useful, ideally, to modify them to cover a range of values of road widths, number of intersections per mile and absolute capcity factors. Since this is not a simple matter, the D O E (209) has suggestted that for most general cases the equation should be $V_R = 31 - \frac{0.7q + 430}{3W}$ or 24 m.p.h whichever is less where V_R = running speed, in m. p.h, q = flow in p.c U/hr and W is the carriageway width in feet.

2.2.1 THE SPEED/FLOW CURVE

This is an attempt to relate the number of vehicles that pass a fixed point on a link in a certain time period to the average speed at which these vehicles move. Much research has been conducted in the field and the results in the main indicate a speed/flow curve of the form shown below.

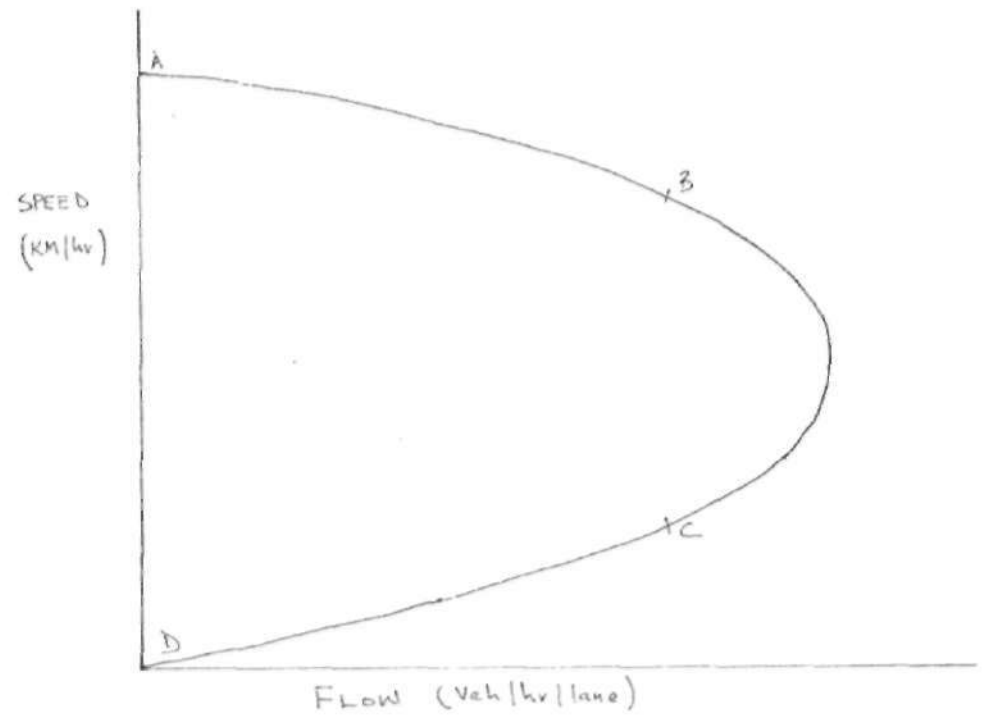


FIG.2.2.A THE SPEED/FLOW CURVE

AB represents the normal speed/flow relationship; as flow slowly increases the speed drops. BC is an unstable region in which speed may either be higher or lower at a given flow and CD is the region of forced

flow. Here traffic moves unnaturally at a slow pace due to congestion at another point in the system.

Within the range of zero and capacity flows traffic may be travelling at one of two speeds. Obviously it is impossible to predict the peed at a given flow without knowing it to be normal or forced. For direct prediction another form of the speed flow curve must be used that does not give rise to ambiguity. Some of the forms currently used are discussed in the following section.

2.2.2 REPRESENTATION OF THE CURVE FOR COMPUTER ANALYSIS

In practice the speed flow curve is usually represented authentically in the region of flow up to limiting capacity only. At or beyond this point total travel time becomes infinitely large and traffic is forced into alternative routes. The curve AB is shown below.

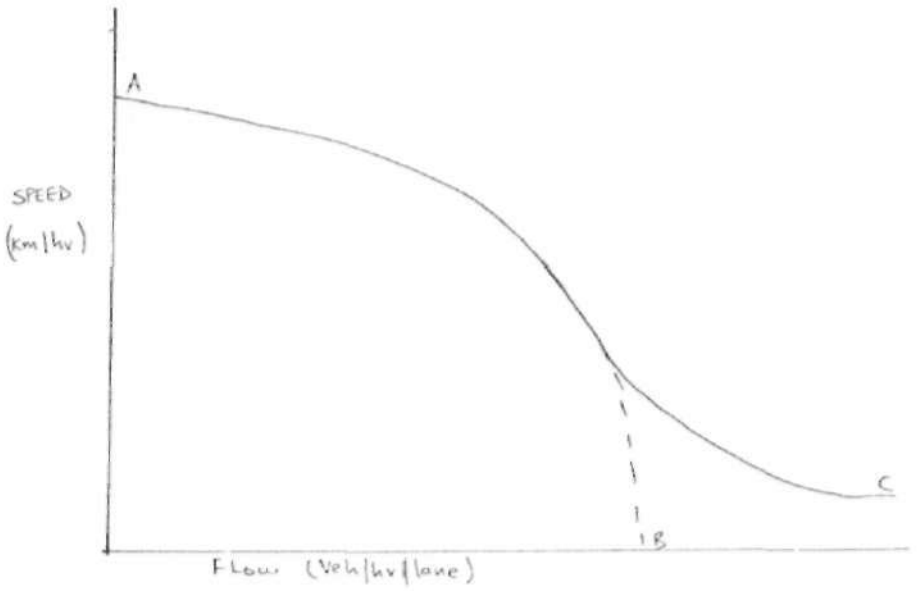


FIG.2.2.B PRACTICAL SPEED/FLOW CURVE

A variation on this curve currently use by the D O E (209) is indicated by the line AC. At flows greater than capacity the travel time increases by a large amount for relatively small changes in flow. It is

assumed that additional delays incurred at high flows result from queueing time at link ends. This being so, the end result may be the same as that for curve AB.

The IMPACT model used by Outram (208) employs a waiting time function to reflect the time spent queueing. This has the form

$$S = Sc/(1 + Sc * T/2 * N * L * (F/C - 1))$$

where S = speed on the link

Sc = speed at capacity C

L = length of the road

N = a constant

T = time on the link

F = flow on the link

Generally, considerations of qucueing time is an uncommon refinement and a basic curve of the form AB or AC only is used. The network links are divided into groups, each group having a certain speed/flow relationship. The basic parameters are usually free flow speed and limiting capacity. For high speed roads a typical design speed is 100 Km hr, for local distribution roads in towns the design speed may be only 50 Km/hr. Free flow speeds are taken normally to be about 90% of design speed. The capacity of a motorway is typically 2400 pcu/hr/lane, that of a local distributor may be 600 pcu/hr/lane.

2.2.3 THE USE OF SPEED/FLOW CURVES

In capacity restrained assignment methods the speed/flow curve may be used to match link speeds and flows after loading the traffic. The resultant speed will normally be that indicated on the characteristi curve at the assigned flow. However, as an aid to convergence of the

process this speed may be modified. Techniques for this purpose are described in Chapter 4.

2.2.4 THE DOE ADVICE NOTE 1A SPEED/FLOW RELATIONSHIPS

The DOE circular advice note 1a (209) was issued in November 1971. It contains six different forms of curves for use on Urban roads (see Fig. 2.2.C).

Generally the curves have been split into three components. Speed is assumed constant up to a limiting free flow and then decreases at a constant rate to a lower speed at limiting capacity. Beyond limiting capacity, speed is assumed to decrease at a slower rate. This portion of the curve is represented by the following formula

$$V = V_c/(1 + V_c/(8.L).(E - 1))$$

where V = speed at demand flow Q(Q Q_c, the limiting capacity)

V_c = speed at limiting capacity (1cm/hr)

L = link length (Km)

E = Q/Q_c where Q is the demand flow (pcu/hr/land).

Road types to which the relationships apply and limiting flows and speeds are shown in the table below.

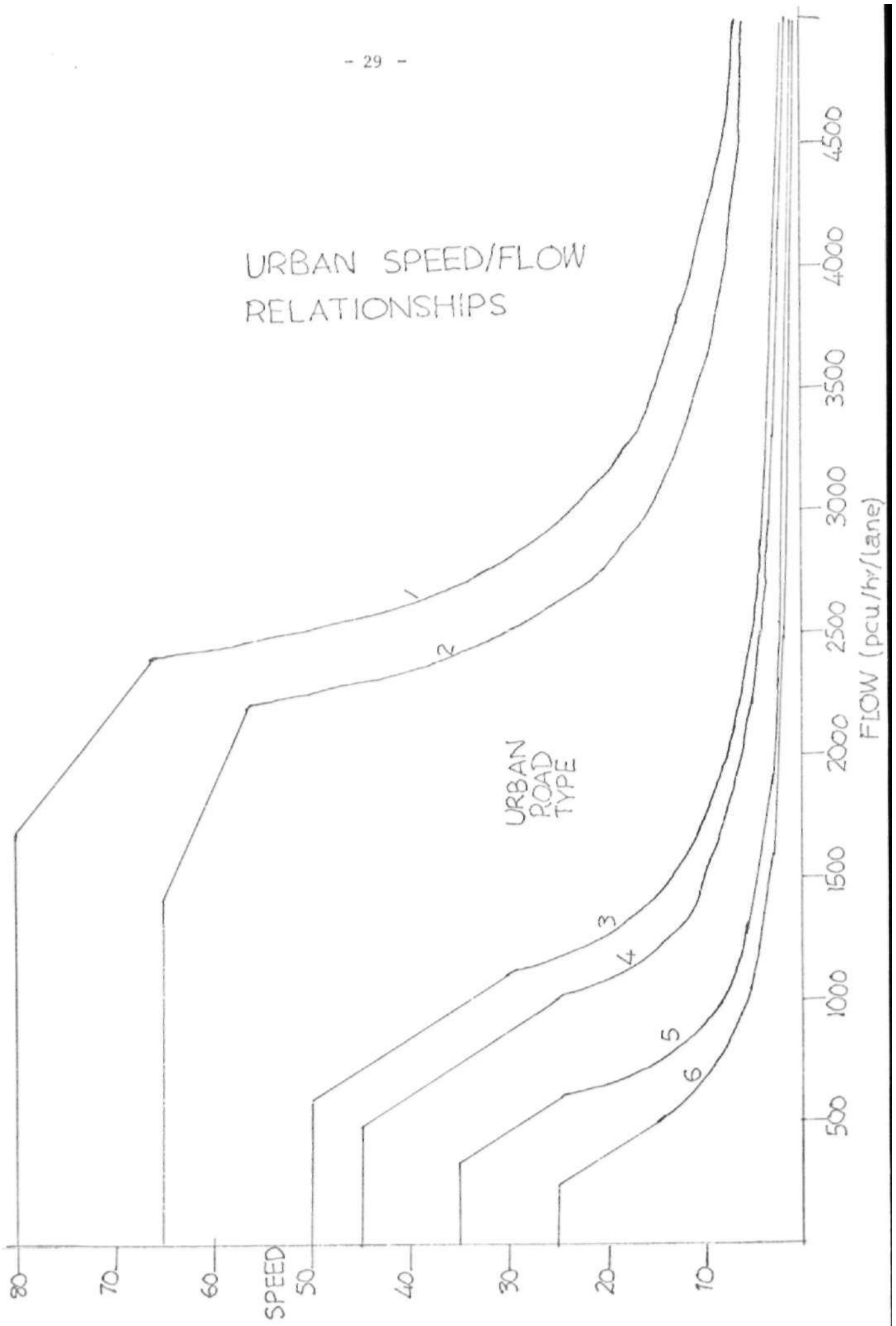

URBAN SPEED/FLOW
RELATIONSHIPS
URBAN
ROAD
TYPE
1
2
3
4
5
6
SPEED
80
70
60
50
40
30
20
10
500
1000
1500
2000
2500
3000
3500
4000
4500
FLOW (pcu/hr/lane)

FIG. 2.2.C.

Curve No.	Road type	Free Flow		Limiting	Capacity
		Speed	Flow	Speed	Flow
1	Dual 2/3 lane motorway	80	1700	66	2400
2	Dual 2/3 lane A P road - limited access	65	1400	56	2200
3	Dual 2/3 lane A P road - restricted capacity	50	600	30	1100
4	Single 2/3 lane A P road - Outer area	45	500	25	1000
5	Single 2/3 lane A P road - Intermediate area	35	350	25	600
6	Single 2/3 lane A P road - Inner area	25	250	15	500

TABLE 2.A

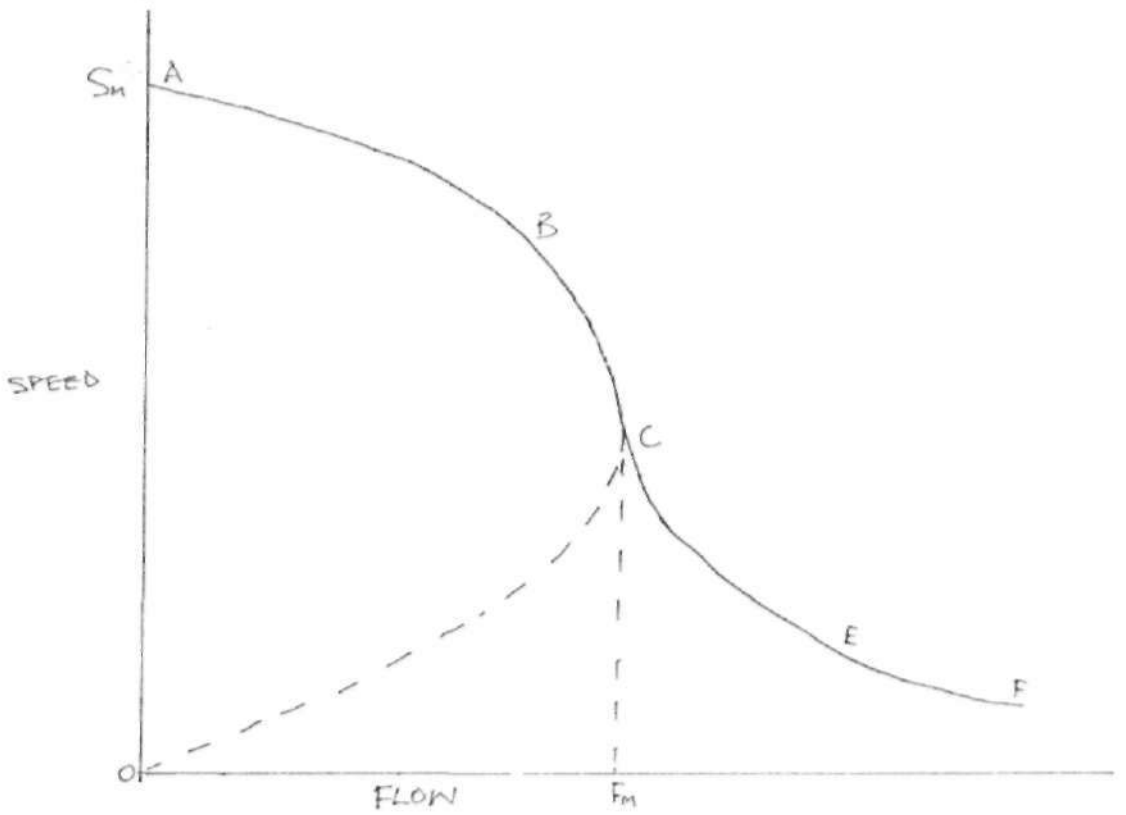


FIG. 2.2.D SELNEC SPEED/FLOW CURVE

2.2.5 THE SELNEC MODEL SPEED/FLOW CURVES

In the SELNEC assignment model the speed/flow curves were of the general form (223);

$$S^2 = aS - bF \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.i)$$

where S was the speed on the link

F was the corresponding flow

and 'a' and 'b' were constants which were characteristic of the type of link involved, that is, they allowed variation in speed/flow curve for different road types, road width, and link lengths.

The relationship is shown diagramatically in fig.2.2.D by the curve ABCDO. The realistic portion of the curve was ABC which represented the situation in which speed fell from a maximum of SM (at minimum flow) to a lower limit SM/2 where flow was an optimum FM (= capacity). Under these conditions 'a' and 'b' have the following values

$$a = S_M \qquad \text{and } b = \frac{S_m\ 2}{4\ F_M}$$

In reference 223 Oucram reported that the survey data was analysed by J. Smith (V_R P_C) and speed/flow relationships produced for each of the seven types of road classifications (see table 2.4) employed in the study. In these relationships 'a' was assumed to be a linear function of the road width and road length, so that equation(2.i)became

$$S^2 = S(a_1W + a_2L + a_3) - bF \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.ii)$$

where W is the width of road, L is the length of road and a_1, a_2, a_3 are constants. The values of these constants are given as shown below in table (2.2).

So far non-congested road conditions have been assumed. In order to assign a speed under flows which exceeded capacity, it was assumed that

the average link time would be the sum of the time under optimum condition and a waiting time to represent the time spent queueing at link ends. Queue length is proportional to the difference between the assigned flow and the optimum flow ($F - F_M$) and since vehicles would clear the junction at the maximum flow rate F_M, the waiting time was assumed to be proportional to $(F - F_M)/F_M$, i.e. $F/F_M - 1$. This gave rise to an implici speed correction proportional to $1/(F - F_M)$ where $F > F_M$. Thus the final part of the curve was hyperbolic in shape. The waiting t_w is represented by

$$t_w = t_o (F - F_M)$$

where F is the assigned flow and, t_o a waiting time constant.

It would be unrealistic to add a large waiting time to the trip at every stage of a journey because congestion at one point would relieve congestion at a subsequent point. Consequently t_o was made of a level so that the individual link waiting times added to a realistic overall trip waiting time.

Since the calibration of the above model further improvement has been made in other versions. Particularly significant is that carried out by Outram (208) on queueing assignment.

The values of the constants employed in the speed/flow relationsh are as follows

TABLE 2.B

Route type	a_1	a_2	a_3	b	Description
1	2.0	3.0	25	0.12	Motorway
2	2.0	3.0	25	0.12	Limited access roads
3	2.0	3.0	25	0.12)	Access roads to and
4	2.0	3.0	25	0.12)	from Motorways
5	0.75	1.0	15	0.055	Two way streets
6	1.0	2.0	20	0.09	Dual carriageway
7	2.0	1.0	15	0.055	One-way street

2.2.6 SPEED/FLOW RELATIONSHIP AS USED ON THE MALTS STUDY

A preliminary inspection of the journey times collected in the survey, to investigate the effect of congestion on route choice, indicated that the free flow speed of traffic varied throughout the study area and differed depending on whether the road was radial or circumferential. On the strength of this analysis, the following free flow speeds (idealised travel times) were adopted for the purposes of analysing trips (225).

(i)	down town links	12 m.p.h.
(ii)	intermediate radial links	25 "
(iii)	intermediate ring links	20 "
(iv)	intermediate dual carriageway links	30 "
(v)	outer radial links	35 "
(vi)	outer ring links	30 "
(vii)	outer dual carriageway links	40 "

The variation of speed with flow was examined for each of these categories using the device of speed density curves to provide a clearer definition of the limiting points in the speed flow curves. This analysis was limited to links on which the proportion of heavy vehicles and buses was less than forty percent and for which density values could be calculated from at least welve observations.

Attempts were also made to account for the loss of road space due to kerbside parking. In this case an allowance of seven feet was deducted from the half width of roads where parked vehicles existed in the peak hour. For each category of road, speeds were then plotted against density measured in vehicle/mile/foot width of carriageway available in the direction of movement.

In the case of dual carriageways, the speeds on isolated sections

of limited length were seen to conform with speeds on the adjacent two-way links. This implies that the widening of short, isolated length of roads does not increase the traffic speed but merely reduces traffic density. Discounting these links it was then apparent that radial and ring dual carriageways could be grouped together. Also no sufficient difference could be detected between one-way and two-way streets in the city centre.

Accordingly, regression analysis was made of the relationship of speed and density for four groups of links.

(i) Down town links

(ii) two-way radial links

(iii) two-way ring links

(iv) dual carriageway radial and ring links

The limiting density equivalent to a stationary queue of traffic was assumed for this analysis. The resulting speed/density relationships were used together with data on the performance of motorways presented in Highway Capacity Manual, to develop a family of speed/flow curves.

Mathematically, the form of these curves can be approximately represented by the following equations

$$t = \alpha(V - \gamma) + \sqrt{\alpha^2(V - \gamma)^2 + \beta} \quad + \delta$$

where t = travel times in mins/miles

V = volume in p.c. /ft width/hr

and α, β γ and δ = constants

The values for α, β, γ, δ shown below have been calculated for each road type to give the appropriate speed for assignment.

CURVE TYPE	α	β	γ	δ
1	0.10	1.00	240	3.5
2	0.10	2.40	430	2.1
3	0.10	2.25	330	2.3
4 & 6	0.10	3.24	650	1.8
5	0.10	6.76	840	1.3
7	0.10	8.40	1000	1.1
8 MW 50	0.11	6.76	1300	1.0
9 MW 60	0.10	2.56	1300	1.0
10 MW 70	0.10	4.41	1400	0.7

TABLE 2C CONSTANTS USED IN THE MALTS SPEED/FLOW RELATIONSHIPS

LINK TYPES			DESCRIPTION OF THE LINK
MALTS	SELNEC	DOE	
1	7	7	Down town links
2	6	6	Intermediate radial links
3	5	5	Intermediate ring links
4	6	6	Intermediate dual carriageway links and outer ring links
5	3	3	Outer radial links

TABLE 2.D DESCRIPTION OF THE LINK TYPES AS USED IN MALTS AND SELNEC SPEED/FLOW RELATIONSHIPS

LINK TYPE	ROAD WIDTH	FFS Mph	FFL P.c.v/h	LC P.c.v/h	Vc Mph
1	40	12	500	1000	9
2	30	25	550	1100	15
3	24	20	400	750	15
4	40	30	600	1200	19
5	40	35	1100	2000	19

TABLE 2.E LINK CHARACTERISTICS

LINK TYPE		CONSTANTS			
SELNEC	MALTS	A1	A2	A3	A4
7	1	2.0	1.0	15	0.055
6	2	1.0	2.0	20	0.09
5	3	0.75	1.0	15	0.055
6	4	1.0	2.0	20	0.09
3	5	2.0	3.0	25	0.12

TABLE 2.F SELNEC SPEED/FLOW CONSTANTS

3. ROUTE SELECTION CRITERIA

In practice the network offers many routes between one zone and another yet it is unlikely that all available routes will be used. It has been observed also that not all travellers follow the same route between two points. This may be explained by either or both of the following reasons:

(a) Alternative routes are evaluated differently by different persons. (313)

(b) In congested conditions drivers react in such a way that a state of traffic equilibrium is reached. (313)

However, the factors affecting the choice of route are related to the three classical elements of traffic engineering.

(A) The road and its environment.

The major factors are:

(1) the trip distance;

(2) the travel time;

(3) fees e.g. tolls on toll roads;

(4) the type of road;

(5) the traffic flow condition

(B) The Vehicle characteristics e.g. local by-laws often exclude vehicles exceeding a specified weight from certain streets.

(C) The subjective element in the choice route . Drivers place different values on road characteristics depending on their age, sex, temperament, personal status, etc.

3.1 BEHAVIOURAL CHOICE

Most drivers in urban areas are subjected to similar pressures and on average they will react to a traffic situation in much the same way. But it should be remembered that not all drivers are equally familiar with a locality. Commuters who travel between the same origin and destination every day may have developed far more local geographical knowledge than the occasional traveller. In a holiday area visitors are likely to keep on well sign-posted routes whereas local commuters make use of their local knowledge.

Generally it is assumed that drivers attempt in their own minds to minimise journey distance, time or cost. A recent investigation in Newcastle (301) illustrates this well. There the chosen routes for home based work trips by private car were compared with calculated minimum routes. In all, six different route choice criteria were used; they were journey time, journey distance, journey cost (both total cost and perceived cost) and two congestion time factors. The first factor was the ratio of excess actual journey time divided by actual journey time. The second factor differed in that an attempt was made to relate congestion to link characteristics. It has been suggested that traffic flows may increase substantially on a link without causing a large reduction in journey speed and so the first congestion factor criterion was considered a little too sensitive for the route selection process.

Some work by Benesh (307) in the U.S. on the relative accuracy of time and distance criteria led to the conclusion that routes are chosen so as to minimise a function of both time and distance. In four studies he found that a third of travellers attempted to minimise time while two

thirds minimise distance but he further suggested that this approach be investigated more fully to find out whether the formula is universally applicable. Later work conducted in Italy (308) demonstrated that drivers on longer journeys attempt to save time rather than distance.

3.1.1. WARDROP'S PRINCIPLES

When the effect of some future improvements of a road system is to be judged, some estimate must be made of the distribution of traffic on the various roads affected including not only new roads but all existing roads from which traffic may be diverted. This is usually done by making some rather arbitrary assumption about speeds on the new roads, and, given the results of an origin and destination survey, by assuming that every vehicle will travel by the quickest route. However, it has been seen that speed is a function of flow, so that redistribution of traffic upsets the pattern of speeds. The problem is to discover how traffic may be expected to distribute itself over alternative routes, and whether the distribution adopted is the most efficient one. It is therefore, worthwhile to consider the theoretical aspects of this problem as postulated by Wardrop.

Consider the case of a given flow of traffic Q, which has the choice of D alternative routes from a given origin to a given destination, numbered 1, 2 .... D. Suppose that the flow Q is divided amongst them so that a quantity q_i follows route i. Then:-

$$q_i \geq 0, \quad i = 1, 2 \ldots D \text{ and } \sum_{i=1}^{D} q_i = Q.$$

The problem is to determine q_i subject to these conditions.

Suppose that the speed/flow relation is linear on each route in the range of flows considered, and that the flow on route i is q_i' before the addition of q_i. Then if Vi is the speed on route i $Vi = a_i - a_i' (q_i' + q_i)$ where a_i and a_i' are constants for route i, depending on street widths and intersections, etc. If l_i is the length of the route, the journey time is:

$$t_i = \frac{l_i}{a_i - a_i' (q_i' + q_i)}$$

This may be written in simpler form:

$$t_i = \frac{b_i}{1 - \frac{q_i}{p_i}} \qquad \ldots\ldots\ldots (1)$$

where b_i and p_i are new constants depending on l_i, a_i, a_i' and q_i'. It is interesting to note the similarity of this expression to that for average delay at fixed time signals.

Consider two alternative criteria based on these journey times which can be used to determine the distribution on the routes as follows:

(1) The journey time on all routes actually used are equal, and less than those which would be experienced by a single vehicle on any unused route.

(2) The average journey time is a minimum. The first criterion is a likely one in practice, since it might be assumed that traffic will tend to settle down into

an equilibrium situation in which no driver can reduce his journey time by choosing a new route.

On the other hand the second criterion is the most efficient in the sense that it minimises the vehicle-hours spent on the journey. In practice of course, drivers will be influenced by other factors such as the state of the roads and the comfort or discomfort of driving in general. However, it is clearly difficult to allow for these psychological factors. Let's consider each criterion separately.

3.1.1.1. PRINCIPLE OF EQUAL TRAVEL TIME

The problem can be stated as follows. Given Q, b_i, b_2 ..... b_D, P_i, P_2 ..... P_D and the relation (1), which routes must be used so that the journey time is the same on each, equal to t_i say, and t is less than the journey time which would be experienced by a single vehicle on any other route used? Also what is the value of t? Suppose that $b_1 < b_2 < \ldots\ldots < b_D$. Any one of these quantities b_i is the journey time on route i when additional flow $q_i = 0$. Suppose that $b_j < t \geqslant b_{j+1}$ for route number j. Then clearly only the first j routes must be in use, for equation (1) shows that the journey time on any route i cannot be less than bi. On the other hand, all of the first j routes must be used. It follows that:

$$q_i = p_i \left(1 - \frac{b_i}{t}\right) \quad \text{where } i = 1, 2 \ldots\ldots j) \qquad (2)$$

these equations being obtained by re-writing equation (1). Summing over the first j routes gives:

$$Q = \sum_{i=1}^{j} p_i - \frac{1}{t} \sum_{i=1}^{j} p_i b_i \quad \ldots\ldots\ldots (3)$$

This equation gives the value of Q for which t is the appropriate journey time. If Q is calculated for each value of t, it is possible to find the solution to the problem by picking out the value of t which corresponds to the given Q.

3.1.1.2. PRINCIPLE OF MINIMUM AVERAGE TIME

In this case the problem is as follows. Given Q, b_1, b_2 ..... b_D, P_1, P_2 ..... P_D as before, find q_1, q_2 ..... q_D satisfying the conditions such that the average journey time T is a minimum.

Now $$T = \sum_{i=1}^{D} \frac{qi\ ti}{Q} \quad \ldots\ldots\ldots (4)$$

Note that if Z_i is the average number of additional vehicles on route i at an instant then $Z_i = q_i\ t_i$. Let $Z = \sum_{i=1}^{D} zi$ be the total number of additional vehicles on the routes.

then $$T = \frac{Z}{Q} \quad \ldots\ldots\ldots (5)$$

Now the criterion considers that T should be a minimum. Since Q is constant, this is equivalent to Z - the total number of additional vehicles en route being a minimum.

Suppose that the solution has an additional flow q_i on route i, i = 1, 2 ..... D. Then if i and j are any two routes in use, the value of Z must not be altered by the transfer of an infinitesimal of flow δ_1 from route i to route j. This means that:

$$\frac{d\,(q_i t_i)}{dq_i} = \frac{d\,(q_j t_j)}{d(q_j)} \qquad \ldots\ldots\ldots \quad (6)$$

Hence $$\frac{d\,(q_i t_i)}{dq_i} = \epsilon \qquad \ldots\ldots\ldots \quad (7)$$

for all the routes in use, where ϵ is a constant indpendent of the route number. A route j will not be used if $\left\{ \frac{d\, q_i t_j}{dq_i} \right\} \geq \epsilon$, for in that case, transfer to it if an increment Sq from any route in use will increase the value of Z.

Now $$\frac{d(q_i t_i)}{dq_i} = \frac{bi}{\left\{1 - \frac{qi}{Pi}\right\}^2}$$

and so $$\left\{ -\frac{d\,(q_i t_i\ 1}{dq_i} \right\}_{q = 0} = bi$$

Thus if $b_j < \epsilon < b_{j+1}$ only the first j routes will be used.

Hence $$\frac{1 - qi}{P_i} = \sqrt{\frac{bi}{\epsilon}}$$

and so $P_i - q_i = P_i \sqrt{\frac{bi}{\epsilon}}$ where i = 1, 2, ... j.

Summing all over j routes gives:

$$\sum_{i=1}^{j} P_i - Q = \sum_{i=1}^{j} P_i \sqrt{\frac{bi}{\epsilon}}$$

There it can be shown that:

$$T = \frac{1}{Q}\left\{ \frac{\left\{ \sum_{i=1}^{j} P_i \sqrt{bi} \right\}^2}{\sum_{i=1}^{1} P_i - Q} - \sum_{i=1}^{j} P_i b_i \right\}$$

And the distribution of flows is given by:

$$q_n = P_n \left\{ 1 - \frac{\left\{ \sum_{i=1}^{j} P_i - Q \right\} \sqrt{b_h}}{\sum_{i=1}^{j} P_i \, b_i} \right\} \qquad h = 1, 2 \ldots\ldots j$$

$$q_n = 0 \qquad h = (j+1), \ldots\ldots D$$

The result of using the two methods in calculating the average journey time is illustrated in Fig. 3.1 The plot is on inverse scale. It could be seen that the advantage given by the minimum average method is not very great in this case.

3.2. MEASURES OF NETWORK RESISTANCE

The important point considered here is what measure of network resistance should be used in assessing the way in which zones should be ranked away from a zone of origin. In most transportation studies distribution models have used travel time. However, a better measure, the total journey cost to the traveller, behavioural cost or perceived cost, may include both the monetary cost of travel and more subjective factors such as comfort, convenience, and the value placed on the passenger time. Although perceived costs should ideally be used as the measure of travel resistance on a link, they are difficult to use in practice because of the problem of associating values to some elements of total perceived costs, such as the value placed on different standards of comfort and convenience. Most earlier transportation studies have, therefore, developed route choice procedures simply using travel time as the measure of travel resistance on each link and at each intersection.

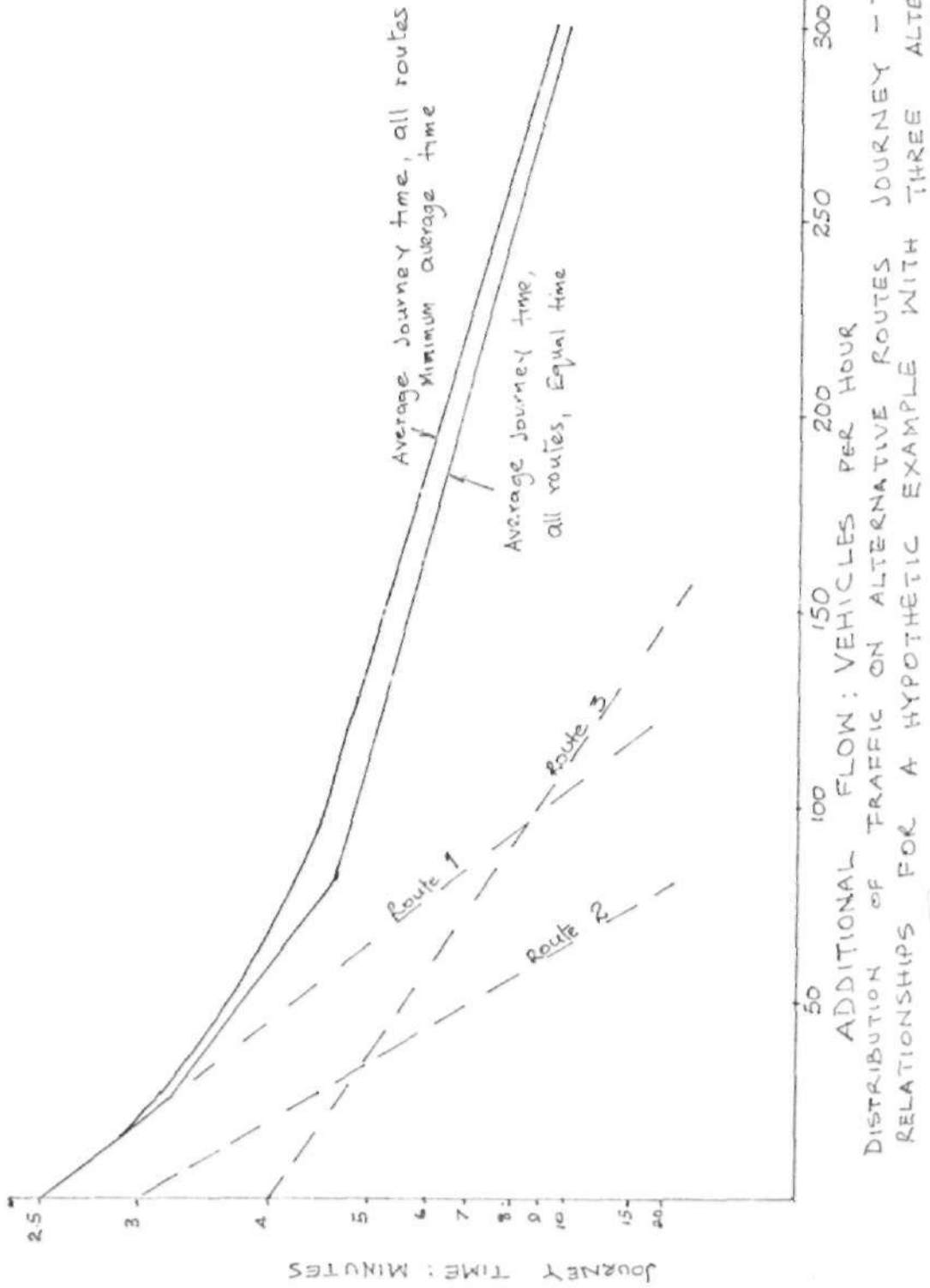


FIG. 3.1 DISTRIBUTION OF TRAFFIC ON ALTERNATIVE ROUTES JOURNEY - TIME/FLOW RELATIONSHIPS FOR A HYPOTHETIC EXAMPLE WITH THREE ALTERNATIVES

This has the advantage of being relatively simple to measure and also appears to be one of the more important variables determining route choice. However, in this country nowadays behavioural cost is the measure of separation most frequently used.

In diversion curve assignment (section 4.3) measures of network resistance have been chosen from travel time, distance saved, travel time ratio, distance ratio, travel time and distance saved, distance and speed ratio, or cost ratio. It must be noted that these variables used in diversion curve assignment apply only to two alternative routes for each zone pair.

3.2.1. EVALUATION OF COSTS

Much work has been done in this field. Burrell (310) suggested that car drivers attempt to minimise their cost of travel, but owing to their lack of knowledge of the state of the road network and variations placed on values of time, distance and other factors, routes other than the minimum cost paths are used. Multiple routing techniques which try to express this variability mathematically have been and are being developed (305). An expression for travel cost will generally contain both time and distance. Overgaard (303) has combined them to form the cost function (in time units) as given below.

$$C = t + 2 * L$$

Where t is the travel time in minutes and L is the distance in kilometers. Here the factor '2' means that one kilometer corresponds to two minutes;

it may of course take any relative value. Expressed in cost units the overall cost function becomes:

$$C = Cd * D + Ct * T + Ck$$

where C is the cost of using a given route

Cd is the travel time in cost/mile

D is the distance travelled in miles

Ct is the cost/minute

T is the journey time (minutes)

Ck is the lump sum to cover fixed charges (e.g. road tolls)

This is the basis of the generalised cost function as used in the SELNEC Study (302). There, allowances were made for travel by different modes and the generalised cost can be represented as follows:

$$C_{ij}^{k} = a_1 t_{ij}^{k} + a_2 C_{ij}^{k} + a_3^{k} d_{ij}^{k} + P_j^{k} + \delta^{k}$$

where k is the mode of travel between i and j

t_{ij}^{k} is the time taken to make the trip

d_{ij}^{k} is the distance travelled to make the trip

P_j^{k} is the terminal cost at j (e.g. parking)

δ^{k} is the modal handicap (or penalty).

The values of time, a_1 and a_2 are assumed to be proportional to income and will, therefore, rise at the same rate as the growth in incomes (about 3% per annum). The other weighting component, a_3^{k}, the perceived cost of travel per mile is assumed to stay constant at 1966 prices provided that petrol costs increase at the normal growth rate. This

is certainly reasonable for car operating costs but is doubtful for public transport fares. The SELNEC value of time is based on Quarmby's (312) paper on work at Leeds.

If these constants are introduced directly in the measurement of impedance defined above, the effect will be to increase the impedance with the increase in the value of time. This is thought to be an unreasonable hypothesis as it would imply that people travelled shorter distances. Hence a more reasonable hypothesis will seem to be that as income increases the relative importance of the direct cost component decreases; this is thought to be best expressed by measuring impedance in 'time-like' units. The cost function for forecasting purposes is expressed as:

$$C_{ij}^{k} = t_{ij}^{k} + \frac{a_2}{a_1} c_{ij}^{k} + \frac{a_3}{a_1} d_{ij}^{k} + \frac{P_j}{a_1} + \frac{\delta^{k}}{a_1}$$

where the values of time, a_1 and a_2, are assumed to grow at the same rate as real incomes (3% per annum).

3.2.2. THE VALUE OF TIME

Transport planning is concerned with the future. It is, therefore, important that modelling techniques have built in flexibility to allow for changes in socio-economic factors. One of these factors, the value of time, is of extreme importance in the assignment process.

The generalised cost function used in the SELNEC study has been mentioned above. On observation it will be seen that an increase in real

income and subsequent rise in the value of time will tend to depress the distance component (Cd * D) if fixed costs of operation are assumed. Conversely, a fall in the real value of time will elevate the distance comfort's importance in the overall generalised cost function. In a stagnant economy where incomes retain the same real value but operating costs increase in time, the distance component will again gradually assume greater importance.

Although experience has shown (304) that in urban areas diversity of activities results in relationships between peak and average daily volumes, which are relatively stable, it is nevertheless to be expected that differing categories of trips and land use will have differing peak-hour characteristics. Lane, Powell and Prestwood Smith (304) have argued th in peak-period when travel demands are greatest, the effect of congestion is critical and assessments of its effects on modal split, distribution and generation as well as assignment are essential. Therefore, in order to synthesise correct conditions of considerable congestion the whole transport model is run for peak and off-peak conditions. This procedure encounters model difficulties besides additional computation. For example, travellers in the peak periods are prepared to suffer greater discomfort and travel costs than in off-peak conditions. Whilst these effects may be synthesised with particular speed/flow relationships, distribution functions and assignment algorithms, actual conditions are not simply divided into peak and off-peak categories. There is a continous change throughout the day. For the present until new forms of synthesis can be achieved, perhaps using some incremental procedures, examination of traffic variations are usually restricted to two or at most three peak and off-peak periods. In many studies (304) the practice is to divide traffic into three components, peak-time traffic, average

daily traffic between the peaks and off-peak (evening, night and early morning) traffic.

For these assignments time-cost indices reflecting both working and non-working time values are used. In conputing vehicle operating costs, Dawson (308) assumed that 17% of car travel is in working time. Most commercial vehicles may be assumed to be travelling for reward but public service vehicle passengers are not generally assumed to be at work. For a traffic composition of 80% private cars, 10% P.S.V's and 10% commercial vehicles approximately 23% journeys may be assumed to be occuring in working time.

From Quarmby's (312) work and the DoE's recommendation it is assumed that the value of time is related to the rate of renumeration for that time. Since most transportation studies obtain and use information about households, it is usually convenient to express working time as a percentage of household income. Current value of average working time is about 90 p/hr. The non-working time is normally taken as between 25-33% of the value of working time. The DoE assumes that the real value of non-working time will grow that 3% per annum while the working time values are expected to rise at 3¼% per annum. These forecasts may not however, hold in the light of the present inflation and world economic depression.

3.2.3. VEHICLE OPERATING COSTS

A meaningful relationship for evaluating the vehicle operating costs can again be attributed to Dawson (308). He concluded that for an average traffic composition of 80% cars, 9% vans and light commercial vehicles, 9% heavy commercial vehicles and 2% P.S.V's the cost per vehicle

mile was, in 1970:

$$1.82 + \frac{76}{Vc} + 0.00087Vc^2 \text{ pence}$$

where Vc is the speed in m.p.h. The relation was derived from studies of fuel consumption which showed that it could be expressed by a formula of the form:

$$\text{Cost per vehicle mile} = a + \frac{b}{Vc} + C\,Vc^2$$

where a, b and c are constants.

In addition account was taken of depreciation, lubrication, tyre costs and maintenance.

This relatively complex relationship between speed and cost introduces further complications to the iterative assignment process. However, transportation studies have normally assumed an average vehicle speed. In the urban area for example, the average speed usually assumed is about 20 m.p.h. and the single cost per vehicle mile is used throughout the study. For the work therein the author intends to use the cost per vehicle mile of 5.5 pence.

3.3 COST VERSUS TIME FUNCTIONS

The traveller is assumed to choose his route of travel by his own perception of minimum 'cost'. However, the perception of travel cost rarely matches the real cost of travel. Often the perceived cost of travel may include such intangible items such as comfort, frequency and convenience. This problem is particularly significant in consideration of choice between modes. This consideration is becoming increasingly important in urban transportation. As a matter of fact, Lane, Powell and Prestwood Smith (314) record that travel time is as good a measure of travel resistance

as any. An additional advantage is that travel time is easy to measure and does seem to be the predominant element in route choice at the same time.

Warner (315) in his modal split model used among other independent variables the cost ration and time ratio. On the other hand Lave's (314) behavioural model which has an equation in the form of Linear Probability function uses cost differences, time differences, comfort etc., as the independent variables. This means that cost and time differences, and cost and time ratios are good criteria for route selection by Quarmby (312) who used a similar method to Lave's admitted that the best method of describing cost and time factors is in terms of differences rather than ratios (316).

4. TRAFFIC ASSIGNMENT

4.1 HISTORICAL DEVELOPMENT OF THE TRAFFIC ASSIGNMENT PROCESS

The subject of traffic assignment process can be traced to earlier traffic engineers who illustrated trip interchanges by some form of desire lines showing the magnitude of the trips on the shortest airline distance between the origin and destination of the trips. The problem of the transportation planner is the routing of those trips over the existing and proposed networks.

In the early 1950's route choice decisions were often based on personal 'guess work' of travel time, distance and user cost. In the U.S. AASHO developed a standard traffic diversion curve as recommended policy for predicting usage of new urban freeways. This was based on empirical considerations of percentage use of the freeway to a travel time ratio. This travel time ratio was expressed as the travel time through the express way divided by the travel time via the existing street system. Other variables used are discussed in Chapter 4. In fact the method was designed to answer the question: Given an existing flow of traffic on a road between two points in a transportation network, what will be the flow on a new road constructed between these two points?

Studies using diversion curves dealt in general with a free-

way and parallel existing routes. As the urban problem became more complex it became necessary to develop for a technique of analysis for the entire road system. However the manpower and time requirements needed to perform the calculations manually prohibited such extensive approaches to highway planning. A major breakthrough in the field of traffic assignment came in 1957, when two papers were presented on the problem of finding minimum time or distance path through a network. One of them was by Moore (412) entitled 'The Shortest Path Through a Maze' and the otherby Dantzig (416) called 'The Shortest Route Problem'. About this time work was being carried out on assignment problem for the Chicago Area Transportation Study. The Armour Research Corporation performed a research investigating andelectronic computer program for an intermediate size computer was soon produced. This was further refined by the Chicago study team into a program for a large high speed computer that could assign traffic to the existing and proposed street system for the entire Chicago area. Concurrently work was being done independently in Washington and Detroit on other versions of a minimum path program. Today this minimum path technique is the basis for the all-or-nothing assignment procedure. Further research work led, in 1960, to the development by the General Electrical Department in Co-operation with the District of Columbia, of an assignment program capable of prohibiting selected turns from the minimum path. This modification led to the capacity restrained technique of traffic assignment. Capacity restraint has become the most widely used technique. This technique is used to match the supply and demand for capacity in the whole or part of the network in an iterative manner until some balance of overall time or cost of

travel in the system is achieved. This balance is detected by Convergence indicators, and it is believed by the author that thebehaviour of the convergence indicators varies according to the Congestion experienced in the network. Capacity restrained assignment is the main subject of this disseration.

4.2 ASSUMPTIONS AFFECTING TRAFFIC ASSIGNMENT TECHNIQUES

In examining the results of the assignments of both existing and future traffic, it is important to understand the *assumptions on which the assignments themselves were based to* know how well the processes have performed.

The principal assumption is that every driver will select that single route giving the lowest travel time (minimum distance or minimum cost) between the origin and destination of any trip. In using this assumption in the West Midlands Transportation Study (102), the flows obtained were considered to be subject to some qualifications. These qualifications were that, since the minimum-path method could assign large volumes of traffic to routes, or parts of routes, which had been allocated fast travel times, without regard to the capacity or congestion of these routes, it could cause some roads to be unduly over-loaded with a resultant reduction of traffic volumes on adjacent and parallel routes. As a result of above, traffic flows predicted on individual links could in some cases be over-estimated, with a corresponding underestimate on adjacent links. In spite of this,

however, the estimated flows in corridors or across Cordons and screen lines could be correctin so far as the trip matrix is correct. The third case is that where two or more routes run parallel to one another the fastest of these could attract the majority of the traffic following in that direction even though it was fractionally faster than others.

The second major assumption is that all trips to a traffic zone are directed to the zone centroid and conversely trips leaving the zone originate from the same point. A corollary to the assumption is that the intrazonal trips, being short trips wholly contained in each zone, are not assigned to raods in the main network. Thus the assignment results imply that intra-zonal trips are wholly constructed on local roads not included in the main road network. Such small discrespancies as arise on this score are, however, off-set to some extent by the compulsory assignment to roads in the designated network of all interzonal trips, which in practice are sometimes run on local roads only.

Other assumptions worth taking note of are:-

1) that traffic of all types (e.g. motor cycles and heavy goods vehicles) would use the same route between any pair of zones

2) that all traffic between a pair of zones travels along the same selected route, irrespective of the time of day or other special factors.

3) that zones providing equal attractions for a certain class of trips, and linked with another zone by roads with equal travel times, will attract from the other zones equal number of trips.

4.3 ASSIGNMENT TECHNIQUES

As stated in section 1.3.6 traffic assignment is the process of allocating a given set of trip interchanges to a specific transportation system. The process may be considered in two main stages:

first the determination of individual routes through the network; and secondly loading these trips onto the paths selected.

The discussion in this chapter is concerned principally with these two stages. The basic assumption in the discussion of techniques is that all trips have their origins and destinations at zone centroids and that unless otherwise stated individuals choose a particular route so as to minimise the travel cost for the journey.

Recent advances in computer technology have permitted traffic assignment to become an iterative mathematical process. The object here is to obtain a stable solution to a very complex problem. A capacity restrained model is presently used to obtain a solution satisfying two basic requirements. These requirements are that:

a) routes are chosen so as to satisfy the real desire of all trip makers to reach destination at minimum cost to themselves,

b) the network loading used and the speeds assumed on the links are in accord with the speed/flow relationships for the links.

Various techniques have been developed based on these requirements all of which are claimed to perform satisfactorily in the circumstances under which they have been used. Two aspects which significantly improve the simulative performance of the models are currently under review. These are the time dynamic nature of travel (travel decisions in particular) and the variability of driver choice (multipath assignment).

The remainder of the chapter contains a discussion of minimum path algorithms followed by a review of assignment procedures.

4.4 MINIMUM PATH ALGORITHMS

In any sizeable network there may be several origins and destinations all of which are accessible by many competing routes. Many different algorithms (mathematical methods) exist for the determination of 'quickest routes', sometimes called minimum paths or trees, through a network. One of the early workers in finding the minimum paths was a German, Pradel. He developed an electro-

mechanical instrument in which each link of the network was represented by an electrical resistance corresponding to the length of the link. Each link was also assigned a counter device. To determine the travel time over a given route an electric current was passed through the links of the route. The travel time required to be measured could be read as resistance from a bridge arrangement. In this way different routes were examined. When the fastest route was found an electric impulse led through the route caused the counting devices to record any increases in flow on each link corresponding to the flow of the route. At the same time Moore (408) and Dantzig (413) were both working on methods of application of electronic computer. Since then many other algorithms have been developed to serve the same basic function, but in some cases in a refined way for specific expediency. Three of these algorithms have been explained in detail as seen below.

4.4.1 MOORE'S ALGORITHMS

Moore's algorithms (408) is applicable to any measure of link and intersection travel resistance. For the purposes of this discussion it is assumed that the problem is to build the minimum cost trees for zone centroid A. In essence the method involves scanning a network, comparing current and past cumulative costs to all routes in turn and then storing information on the minimum cost paths initially to adjoining network nodes and eventually to distant zone centroids. In detail the procedure is as follows:

a) let 't' be a matrix of costs associated with the graph of the network, so that t(m,n) is the cost of the link from node 'm' to node 'n'. If no such link exists, t(m,n) = infinity.

b) let there be 'p' nodes and let node 'i' be the origin. Set up two arrays A (k) and B (k) where K = 1, 2 ... P.

c) Set all the A(k) equal to infinity, and all the B(k) equal to zero, and then set A(i) equal to zero.

d) For all m = 1,2 ....., P and n = 1, 2, ... P see if t (M,n) + A (m) is less than A (n). If so set A(n) = t(m,n) + A(m) and B(n) = m.

e) Repeat (d) until no further alterations can be made. The arrays A and B now hold the minimum cost tree for the origin node 'i' to 'k', this is the sequence of nodes i, ...B (B(k)), B(k), K.

This is a commonly used technique that requires a minimum of computer working space.

4.4.2 THE DANTZIG ALGORITHM

This method usually uses additional store in the form of look-up tables, and as a result can be computationally very fast. The main steps are

i) let C be the associated matrix of the network's graph set up as in Moore's algorithm, and also reserve the same two arrays A ahd B. Node i is again the origin

ii) Set B (i) not equal to zero, all the remaining B(k) equal to zero.

Set A(k) equal to zero for all K

iii) Let $X = \underset{m}{\text{Min}}\,(A(m) + \underset{n}{\text{Min}}\,(C(m,n)))$

for all m and n such that

B (m) is not zero (i.e. m is in the tree) and

C (m,n) is not infinite (i.e. there is a link from m to n).

Then when m and n are the values of the minimum case, set

A (n) = X and B (n) = m

iv) Repeat step (iii) until B(k) is not zero for all K = 1, 2, ... p

The minimum tree is now complete.

Initially the origin is the only node in the tree, and at each step one further node (and one link) is added until all nodes are included. To select the node to be added, a search is made for

all the nodes that are not in the tree and which are connected by one link to a node in the tree. The cost of the path to each of these nodes (which is the cost to the node in the tree plus the cost of the single link) is also found for this set of nodes. The node with the minimum path cost is selected.

4.4.3 CASCADE ALGORITHMS

These methods involve holding the network as two full n x n matrices, A and B, where n is the number of nodes. Initially the elements A(i,j) will be the cost of a single link from node i to node j or infinity if there is no such arc. The method consists of two'passes'. In the first pass the matrix is multiplied by itself using Boolean Matrix multiplication. Intermediate results are inserted immediately.

In the second pass, the process is repeated in the reverse direction, i.e. working from a(n,n) towards a(1,1). The matrix now holds all the minimum trees for all origins, i.e. a (i,j) holds the costs of the shortest routes from i to j. This is the fastest computational process, but requires extensive amounts of store. An example of this method is the Shimbel Algorithm (419). This can be seen in reference 418 where Martin showed a diagram which indicates which algorithm is quickest for differing numbers of nodes, links and link/node ratio).

Martin in the above reference came to the conclusion that Moore's algorithm is generally superior in both speed of computation

computer storage requirements but it is widely held that more recent developments of the cascade algorithms are faster, for example, shortest distance by a Fixed Matrix Method - by, J.D. Muickland - L BS - TNT - 64, 1968.

4.4.4 IMPORTANCE OF MINIMUM PATH ALGORITHM

The relative importance of the minimum path algorithm in the assignment process is demonstrated in the working paper issued by Washington D.C. Metroplitan area transportation planning state (as mentioned by Head (107)). They found that 3 hours of the total computer run time of 6 hours 35 minutes for a complete assignment was devoted to building the minimum paths. (Since then run times have shortened considerably but the proportion of total time occupied by tree building has not altered significantly). The residual time included assimulation of the network data, loading of the network and computation of the total vehicle-hours in the system as well as some setting, control and contingency time.

Although the computation of minimum paths is an important element in the assignment process, it is only significant in the economy of the process. The adoption of a different algorithm should not affect the end result. In modern researches much time is being spent investigating capacity restraint methods, and the

behavioural accuracy. However, all-or-nothing assignment (4.2) is still used at some stages in large transportation studies, and exclusively on some smaller ones. In all-or-nothing assignment the selection of trees for loading occupies the major part of computer time.

4.5 ALL-OR-NOTHING ASSIGNMENT

This is the simplest of all assignment methods. It assigns all of the trips between each origin - destination pair to the single shortest route between them. Most capacity restrained assignments (4.4) effectively use combinations of all-or-nothing assignment method. The modelling for the SELNEC Transportation Study, for example, employed the method to make a trial estimate of link loads, the link travel times, and costs were then adjusted to take account of the flow that resulted.

4.5.1 THE METHOD

As stated in (4.5) the method loads all of the trips from a particular origin-destination pair onto thesingle shortest route between them. Times on all the links are fixed before the traffic is assigned. Peak are fixed before the traffic is assigned for peak period assignments and off-peak velocities for 24 hour assignments. Even if there are two routes exactly the same time all of the

traffic is assigned to one of these routes only.

The basic procedure in all-or-nothing assignments involves:

1) The description and coding of the network into links and nodes

2) The determination of minimum cost from each zone with originating traffic to all other zones. (This stage is often referred to as 'build trees')

3) The assignment of all the flows from each zone to every other zone by the appropriate minimum paths, and the aggregation of total flows on each link in the defined network.

4.5.2. DEFICIENCIES AND ADVANTAGES OF THE METHOD

A major failing of all-or-nothing assignment is a disregard of the capability of links to perform under the applied loads. After assignment the hitherto quickest routes, now fully loaded may well be conjested and hence slower than other competing routes that have been assigned a lesser amount of traffic. Because all of the traffic between an origin and a destination is allocated to

a single shortest route between them the flows in the network are very sensitive to the values on individual links of the measure of network impedance used in determining the choice of routes. If time is used then even the smallest changes in times on some links may result in completely different selections of routes and hence gross changes in volumes of traffic in the various parts of the network. If cost is used as in the SELNEC model, changes in any of the variables or parameters used to determine cost produce the same result. Links may quite easily change from being very heavily loaded to having hardly any load at all as a result of seemingly insignificant changes in variables or parameters. Considering the difficulty of making precise estimates of link impedances this is clearly a serious failing in the model.

Despite its obvious failings the method is still fairly widely used at some stages of analysis. Its major advantages are its simplicity and its requirement of far less computertime than other methods. Generally it gives a clear indication of where the traffic would like to go if it were able to and the experienced transportation planner is able to re-allocate excessive flows to lightly used parallel routes.

4.6 PATH DIVERSION METHODS

This class of assignment techniques diverts trips to alternative paths in a manner which does not depend explicitly on

network speed/flow relationships. The models belonging to this class can be subdivided into three groups;

1) Diversion curve method

2) Path enumerating methods

3) Markov methods

These methods may of course be used in conjunction with some of the capacity restrained techniques already discussed to obtain solutions in accord with specified speed/flow relationships. It is considered by many e.g. Burrell (410) , Dial (411) that because path diversion techniques load more links in each assignment the use of these methods to furnish loadings on the network, speeds up the convergence of a capacity restrained process.

4.6.1 DIVERSION CURVE METHOD

These methods were widely used in the early days of traffic assignment to answer the question: Given an existing flow of traffic on a road between two points in a transportation network what will be the flow on a new road constructed between these points. For any trip from one zone to another there are usually several alternative routes, which can be chosen by the person making the trip. Each route has its own 'travel resistance' derived from its charactersitics of distance, travel time, speed

and level of service. Basically the methods considered only two routes though California Method (422) based on time and distance differences, has been adapted for network assignment problem Path Diversion Curves are usually empirical relationships constructed from data collected in surveys of the usage of alternative routes, e.g. a study may be made of the travel time saved by using route A as compared with route B and also of the proportions using A and B.

Diversion curves have been developed using the following variables

1) Travel time saved (432)
2) Distance saved (432, 425)
3) Travel time ratio (433 and 434)
4) Travel time and distance saved (432, 425)
5) Distance and speed ratio (432)
6) Cost ratio (405)
7) Distance ratio (432)

A further development is to introduce two variables into the model of travel resistance, as for example in the Claifornia diversion curves (422). These are based on a measure of travel time and distance saved, and as such provide a better explanation of how drivers choose a route. The principles stated in the California method are as follows:

1) Factors other than time and distances are ignored

2) The method to be produced should be one which can be expressed mathematically

3) The greater the travel time saved the greater the use

4) The greater the distance saved the greater the use

5) When travel time and distance savings are small some drivers will use the freeway (motorway) and some will not

6) A few drivers will travel any amount of distance to save time, and some drivers will select the shortest route in terms of distance, however much travel time is consumed.

The model developed was as follows:

$$P = \frac{50 + 50\ (D + \frac{1}{2}t)}{(d - \frac{1}{2}t)^2 + 4.5}$$

where

P = percentage using freeway

d = distance saved in mile via the freeway

t = time saved in minutes via the freeway

If diversion curves are used it is usually necessary to consider separate networks, one with and one without the proposed modification and calculate all-or-nothing costs or times on both networks, as input to the diversion. Reference is then made to the diversion curve to obtain the proportion of trips to be allocated to each route. Each proportion is then loaded by an all-or-nothing assignment to its appropriate network and two loadings added to obtain the final assignment incorporating the results of the diversion analysis.

Diversion curve assignment have normally only generated two alternative routes for each zone pair , but clearly in a complex urban network and particularly for longer trips, there are likely to be more than two alternative routes available.

4.6.2 PATH ENUMERATING METHODS

These methods explicitly find two or more paths between a given origin and destination and separtely assign trips to them. There are two broad subdivisions under this heading:

a) Second and third shortest routes

b) Models involving modification of link times.

4.6.2.1 SECOND AND THIRD SHORTEST ROUTES

The second and third shortest routes between origin and destination pairs are fairly easily retained provided that computer storage space is available. The trip distribution matrix can then be loaded on to the stored routes on a chosen proportional basis. There is nothing new in the methodology of the approach so no particular methods are discussed in this dissertation.

4.6.2.2 MODELS INVOLVING MODIFICATION OF LINK TIMES

Typical of these models is the fact that a shortest path algorithm is used iteratively by modifying the times of certain links. Once an acceptable set of alternative paths is determined stored trips are shared out amongst them according to a 'diversion curve' assumptions (425).

An example of the use of the technique of modifying link times without recourse to flow/velocity relationships, is that due to Burrell (410). This method generally known as 'Multiple Route Assignment' determines alternative paths between nodes rather than zones. This is discussed below.

4.6.2.3 BURRELL'S METHOD

The basic assumption in this approach is that the traveller does not know the actual link 'time' but each link is associated with it and distribution of 'supposed' link time for which he selects a 'supposed' time at random. The traveller, uses the route which minimises the sum of his 'supposed' link times.

Ideally each traveller would make his own selection of 'supposed' link times, but, to reduce computer time, in practice it has been assumed that all journeys starting in the same zone have the same set of 'supposed' times. In fact this assumption means that the method differs from the usual concept of 'multiple

routes' assignment, that traffic between a given origin and destination is assigned to several alternative paths. However the fact that a different set of 'supposed' link times is associated with each origin zone allows many different 'quickest' routes between pairs of nodes having many reasonable routes between them, so that the trips between pairs of nodes may be shared between many routes. This is the fundamental feature in this method of 'path enumeration', that is, a method which explicitly finds two or more paths between origin and destination and separately assigns trips to them. Clearly the method could be brought into line with the usual concept of 'path enumeration' or 'multiple routing' by dividing the trips generated in each zone into groups and selecting a set of 'supposed' link times for each group, but these would be at a considerable cost in computer time.

The main object in most assignment procedures is usually to find the total number of trips loaded on each link. In large networks, the maximum proportion of trips on a link generated from any one zone is usually less than 10%, (404). Thus although the method selects the quickest route from each generation zone on the arbitrary basis of randomly chosen 'supposed' link times, the total traffic on each link is relatively insensitive to the random number used to select the 'supposed' link times for any particular zone of generation.

The link costs C used for route selection are permitted to vary according to

$$C = \bar{c} + KV\sqrt{C}$$

where

$\overline{C}$ is the average link cost

V is the variance

K is a random number such that

$(-1 \leq K \leq 1)$

In the study of drivers route choice in Hull for the D.O.E., Burrel found the variance to be 0.91 when C is in cost minutes. Burrell's models runs showed that the level of instability of the model improved considerably compared with the minimum routing case, but the average level of user benefits is considerably lower.

4.6.3 MARKOV METHODS

These assign trips implicitly to alternative paths by applying transition probabilities which reflect the likelihood of moving from one node to another, i.e. of choosing to exit (or enter) a given node by a particular link. These models have the important computational advantage of assigning trips to all alternative paths simultaneously. One Markov model has been described by Gunnarson (in 1969) which, while seemingly close in intent to Dial's (411) is vastly different in both strategy and tactics. Another Markov model was proposed by Bevis (426), together with Dial who designed all the implementing

algorithms which relates through ancestry to the probabilistic assignment model discussed below.

4.6.3.1 DIAL'S PROBABILISTIC MULTIPATH MODEL

This is an example of Markov's model. At each node encountered on a path, trips are shared out amongst the competing links entering the node, on a probabilistic basis. The proportion of the trips assigned to a particular link depends upon the comparative length and number of acceptable paths through the link. The approach is based on the definition of reasonable paths, called 'efficient paths' by Dial. The hypotheses are that:

1. There should be a non-zero probability of use for all reasonable (i.e. efficient) paths between a given origin and destination and zero probability for all unreasonable paths.
2. When there are two or more reasonable paths the probability of the use of the shorter should be greater than that of the longer; paths of equal length should have the same probability of use.
3. The user should have some control over the probabilities of use of reasonable paths.
4. Paths should not be enumerated explicitly.

Dial professes that there is an obvious simple solution but this in unrealistic in computer time. His solution consists of the following three steps:

a) Relate path choice to path characteristics

b) Find all paths between a given origin and destination

c) Using information gathered in step a), apportion trips to the path on the basis of their characteristics.

The probabilistic model attempts to avoid the path enumeration problem that causes computer time to be wasted by assigning only to efficient routes. Efficient routes may be defined operationally as those on which every link has its initial node closer to the origin than its final node. The procedure may be called a 2-pass Markov model. Nodes/links transition probabilities are calculated during the first pass and trips are loaded onto all reasonable links in the second pass. In this way, trips are simultaneously assigned to a complete set of reasonable paths.

Unlike other methods discussed so far, paths are never explicitly examined. The algorithm may be summarised in the following four steps.

1. Determine the following items for each node 'i'

a) Ti = number of trips from origin terminating at 'i'

b) P_i = shortest path length from origin to 'i'

c) I_i = the set of all links with initial node 'i'

d) F_j = the set of all links with final node 'i'

2. Estimate the likelihood, a(N) for all links 'N' as follows

If link 'N' has initial node 'i' and final node 'j' and length Sij then

$$a(N) = f(P(j) - (P(i) + Sij))$$

if $P(i) < p(j)$, otherwise $a(N) = 0$ (i.e. these links need not be considered in the following two steps).

3. Starting with the origin node, arrange all nodes 'i' in in order of increasing p(i) and calculate for each link N the link weight (i.e. effective probability).

4. Starting with the destination node furthest from the origin arrange all nodes 'j' in the order of decreasing p(i).

Now for each link j and F_j assign a volume V(N) in accordance with the link probabilities and record the accumulation of trips from the origin terminating at the initial node of the link. When the origin node is reached the algorithm has completed the assignment of trips from that node. Steps (3) and (4) sometimes known as the forward pass and the backward pass respect-

ively correspond to the two passes of the Markov model mentioned earlier. This model is theoretically attractive when compared with other multipath techniques and perhaps very efficient in computation too.

4.6.3.2 GUNARRSON'S MODEL

This model is similar to Dial's. The route selection is considered to be a Markov Chain, i.e. at each node the traveller makes a choice independent of any previous decisions. The algorithm, however, corresponds to a different definition of efficient paths. Here, they are considered to have every link final node closer to the destination than the initial node. In fact this reverses the third and fourth steps of the Dial algorithm.

Another major difference is in the transition probability that is, the probability that a traveller at node X_i with final destination X_m will select a path (i, j, m) via adjacent node X_j.

A_{ij}^{m} = attractivity for path (i, j, m) expressed as $\frac{1}{C_{ij}^{z}}$ where C_{ij} is the cost of using route ij and z is a parameter which expresses the sensitivity of the travellers.

Gunnarrson estimates a figure of 6. The transition probability Pij is expressed in terms of an attractivity model

$$P_{ij} = A_{ij}^{m} \Big/ \sum_{K=1}^{n} A_{ik}^{m}$$

(n is the number of acceptable paths from Xi)

The attractivity expression is similar to that used by AASHO for diversion curve assignment. Steerwald, Scholz and Hampt developed a model which was mathematical similar to that of Gunnarrson. Other models used primarily in diversion curve assignment may be grouped under multipath assignment technique provided they are applicable to network assignment.

4.7 CAPACITY RESTRAINED METHODS

A capacity restrained assignment procedure may be taken as a process of determining a pattern of traffic flow for a known set of interzonal movements on a network of roads with stipulated speed/flow relationships.

The process is iterative and generally involves loading a predetermined matrix of trips onto a set of minimum cost paths. The cost of travel on each link is then amended to accord with the link speed/flow relationship. New minimum paths are found and trips are again loaded. The process is continued until a

stable state is reached. When the solution is reached, the relationship between journey time and flow on every link in the network should be in accordance with that specified for the link. On the basis of these 'equilibrium' link times all costs on utilised routes between a given pair of zones should be the same and should be less than those on any unused routes available. The rate of convergence to the stable state may be increased by several techniques, such as the cost averaging procedures, successive loading techniques and the incremental loading procedures.

The most common approach to the capacity restrained assignment problem can be summarised as:-

1) The steady building up to the total distribution to be assigned, in small stages, the speeds on each link being adjusted after each increment of loading to take into account the latest assigned flow.
2) Assigning the total distribution at each stage, adjusting link costs after each assignment (usually assuming them to be a function of costs used previously and costs in accordance with the latest assignment) and sometimes, taking a weighted combination of successive assignments.
3) the combination of approaches (1) and (2) first building up in stages to the total distribution to be assigned and then carrying out a series of iterations using weighted combinations of successive complete assignments.

4.7.1 SIMPLE CAPACITY RESTRAINT

This simple approach involves building minimum time (or cost) trees, loading all trips, adjusting link times and costs finding new trees successively until a state of equilibrium has been reached. This method is, however, very slow in converging to a reasonable solution and is therefore rarely used.

The chief problem is that trips tend to alternate between two competing routes (107). After the first pass a set of original minimum paths are heavily loaded, the speed/flow adjustments render these routes uncompetetive and a new set of routes is selected for loading at the second pass. Now, on the third pass, the minimum path trees will revert to the original route since loading will have slowed the second set to an uneconomical level.

4.7.2 CAPACITY RESTRAINT USING COST AVERAGING

A simple method which has been found to stabilise the assignment significantly involves averaging the two previous link times (407). It is worth noting that this is a mathematical manipulation with no sound reasoning behind it. Infact at any iteration after the first link times (or costs) and loads will not be compatible. The value of the cost averaging technique may be increased by using the suitable speed/flow relationships

(the non linear relationships

in particular). Currently the Do E's recommended speed/flow (209) relationships are linear up to the limiting capacity.

4.7.3 BUREAU OF PUBLIC ROADS (BPR) METHOD

This is a cost averaging assignment procedure. After the total distribution is loaded on the first set of cheapest routes, link times are adjusted according to the equation

$$T = T_o \left(1 + 0.15 \left(q/Q\right)^4\right)$$

where T is the journey time assuming assigned flow on the link.

T_o is the journey time on the link with zero flow (o.87) journey time on link at capacity)

q is the assigned flow

Q is the practical capacity.

In network testing it was found that the new link time caused alternation of link loads similar to that experienced in simple capacity restraint. This effect was however reduced by using a new link tim T_1 where $T_1 = T_Q + (T - T_Q)$ /4 (T_1 is the new link journey time at the end of the first iteration and for use in the second iteration, T_Q is the journey time on the link at capacity). The same technique is employed at each of the subsequent iterations until the link times reach a stable value.

4.7.4 THE DETROIT METHOD

The all-or-nothing assignment initially made is based on minimum paths with capacity loaded link times. After loading the links travel times are adjusted according to the formula

$$T = e^{\left(\frac{q}{Q}-1\right) x} \; T_Q$$

where T, q, Q and T_Q are defined as in BPR model above. This adjustment has been incorporated into a flow iteration method developed by Smock (430).

4.8 PARTIAL LOADING PROCEDURES

In these procedures the trips are loaded in stages. After each loading the link times are adjusted and new paths found. The process in continued until all the trips are loaded. The result is that trips from one zone to any other may be split between several routes corresponding to minimum paths at the various stages. The accuracy of the method used depends critically on the loading sequence. Four different approaches will be discussed here.

4.8.1 SIMPLE PARTIAL LOADING METHOD

Link times are first given appropriate values and minimum trees are found. A predetermined portion of the trips are loaded onto these trees, links are given new times corresponding to current flows and the procedure is repeated until all trips are loaded.

Logically this is the most straight forward of the methods, except that the simplicity of the approach may not in some cases describe adequately the distribution of real route choices. The main disadvantage of the method is the slow rate of convergence but this can be ameliorated by the more sophisticated partial loading procedures. All the same, none of these methods pay strict attention to the dynamic nature of the traffic pattern except the queueing assignment method which is discussed in sections 4.8.

4.8.2 CAPACITY FACTOR LOADING METHOD

Link times and hence initial minimum paths are found as above (section 4.4.1). An all-or-nothing assignment is attempted. On each link a ratio, F, of assigned flow to capacity is found. If the largest of these factors is greater than unity then at least one link is overloaded. A reduced trip matrix $\frac{1}{F}(T_{ij})$ is substituted so that overloading does not occur. The link loads are recorded. Links are then given new times and a second sequence is commenced to assign the portion of trips unassigned in previous iterations. The procedure is completed when all trips have been loaded. Convergence of the method may be enhanced by using suitable speed/flow relationships. These must have a sufficiently severe cost/time element at capacity in order to reduce the risk of repetitive assignment.

4.8.3 THE TNET MODEL

Effectively this model (403) is the same as the capacity factor loading method.

The function relating the travel time on arterial links to the $V/_C$ ratio (one for intersection delay and another for link delay) have been selected arbitrary. These functions are-

1. Intersection Delay: $T_a = T_b + \frac{V/C}{10\ (1 - {}^{V}/_{CQ})}$

where the symbols are as shown below.

2. Link Delay: $T_a = T_o\ (0.75 + {}^{0.25}/_{(1-{}^{V}/_{CQ})})$

where Ta = adjusted travel time on links

T_o = Original travel time on links ('normal free flow conditions')

V = volume on the link

Q = the multiple of capacity at which travel time becomes infinitc

It should be noted that the T_2 in both expressions become infinite when V = CQ. It is therefore considered important that values used and the value of Q shouldbe related to each other. (In this work a value of 1.10 for Q was chosen).

4.8.4 THE I.B.M. INCREMENTAL LOADING PROCEDURE

This method represents the result of a series of tests on the effectiveness of the part loading methods. In order to speed convergence it was found desirable to remove part of the load already applied at each iteration. The load removal phase also attempts to prevent the program assigning so much traffic to a road in one step that it becomes irrecoverably overloaded. Generally it was found that the loading increments should reduce at each stage of the assignment, and one third of the trips loaded should be removed after link times have been adjusted. The number

of iterations fixed initially depends on the degree of congestion and the size of the system; the optimum values of the Pi can be decided upon from experience of other runs. For four iterations the loading increments shown below are suggested.

TABLE 4.4

I.B.N. LOADING INCREMENTS

INCREMENT	1	2	3	4
P (%)	67	42	25	10
S (%)	22	14	8	0

As the number of increments increases the assignment approaches a model of individual behaviour. This aim is impracticable in all but the simplest of cases. The form of the speed/flow relationship used is as shown in Fig. 4.4

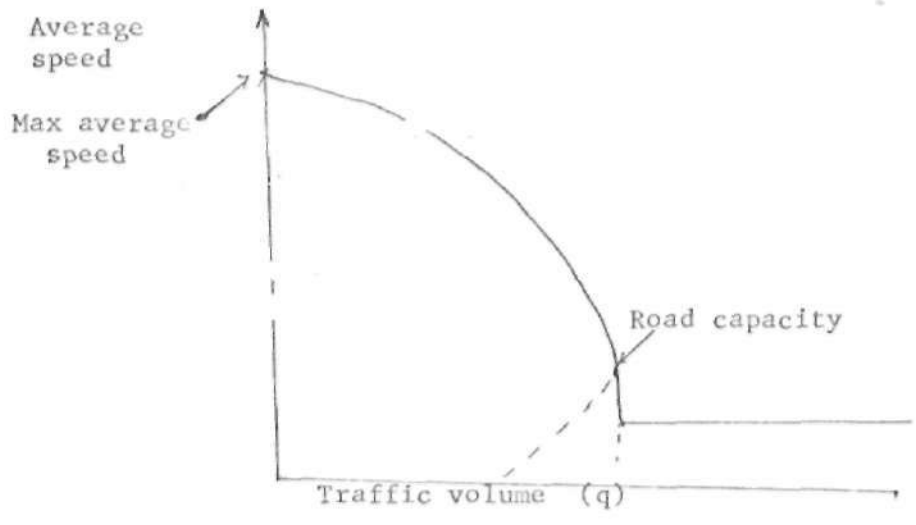


Fig. 4.4 The speed/fow relationship

It is assumed that the loading on any link never exceeds its capacity so that forced flow conditions are not realised.

4.9 SUCCESSIVE LOADING TECHNIQUES

4.9.1 THE CHICAGO METHOD

The Chicago study (432, 428) presented the first assignment method based on link speed/flow relationships. In addition it employed an incremental loading procedure in which all trips from selected zones are applied at each iteration. The full procedure is as follows:

a) The fastest routes from zone A to all other zones is determined using link travel times at zero flows.

b) The traffic from zone A is loaded onto the quickest routes to all other zones.

c) Travel times are adjusted according to the flows assigned so far.

d) Next, a tree is found for zone B using the new travel times and traffic from this zone is loaded onto the network.

e) The traffic loads on each link are summed and new travel times found.

f) Iterations follow until all traffic from all zones has been assigned.

In the Chicago study to avoid unrealistic distributions due to the successive handling of zones, origin zones were taken in a certain but unfortunately unrecorded order. Generally an order is

taken to achieve a fairly uniform increase in travel times over the network.

The method was later used in Pittsburgh (432) in which study it was considered that link flows were practically independent of the zone order. This being so, zones were selected at random. A problem largely ignored in both Chicago and Pittbourgh is the difference in network condition for paths between zones in opposite directions. For example, if the trips from zone A to zone Z are assigned in the first iteration, and those from zone Z to zone A at a later stage, the paths are unlikely to be the same. Practically, if two way flows are required then this makes little odds but philosophically it demonstrates yet another flaw in the assignment process.

4.9.2 THE TIME DYNAMIC MODEL

This is an incremental loading procedure in which the loads applied correspond to a subdivision of the time period. The procedure starts with emission of a portion of trips from all zones at the beginning of the time period. Traffic is assigned along minimum paths until the end of the first time sub-period. At this stage new routes are found and a second time sub-period may start. The traffic already on the network is released to progress along the new paths towards its destination and in addition a second portion of the overall trip matrix is fed on to the network. The procedure terminates when all trips have reached their destinations.

Although the method appears to be a step towards 'correct' traffic assignment, it has the disadvantage of greater computer time and storage space. Choice of the time period and sub-time period depends on network configuration and travel times. While there is no evidence that the method is long winded the absence of recorded practical application may suggest that the method is impracticable.

4.10 FLOW ITERATION TECHNIQUE

This method loads the total distribution matrix on to the network at each iteration. Following each loading link 'times' are adjusted new minimum paths determined, the total distribution loaded onto these paths and the assigned link flows estimated by a weighted average of the flows obtained when the total distribution is loaded on to each of the sets of 'quickest routes' determined to date.

With this approach there are slight variations in the basic method arising from different methods of weighting the individual assignments and adjusting link 'times'. A popular method is one in which, at the end of each iteration, flows are adjusted to an average value of the link flows in all iterations to date. Using these flows link travel times are adjusted and the routing repeated until link loads, costs or times have some stable value. This particular model was first described by Smock (430). In the model travel times are adjusted according to the Detroit formula

$$T = e^{(q/Q - 1)} \times T_Q$$

Beckman, was referred to by Overgaard (405) as having considered

that the model converges to a solution corresponding to the principle of equal travel times. Recent models based on the flow iteration technique include that used by T.R.C. in Toronto (432) and by the SELNEC transportation study. A satisfactory level of convergence was thought to have been achieved at the fourth and third iterations respectively of the above mentioned models.

4.11 PROJECTED DEMAND TECHNIQUE

Projected demand is a relatively recent development due to Outram (435). A prediction of the total link loads is made on the accumulation of link load during the first iteration Outram claims that the proportion of the final load assigned to a link at any stage in loading is nearly independent of the coded costs used. Thus when the network has been loaded once, it is possible during any subsequent loading operation, to estimate the proportion of the final load assigned at any stage in the loading sequence. Knowing the magnitude of the currently assigned load, an estimate can be made of the magnitude of the final load. Thus, in the first iteration of his model he compiles a matrix of the proportion of final link load accumulated at the end of the assignment of trips from each origin zone. During the second iteration the same loading sequence may be used. At the assignment of trips from each origin he estimates the final link load using the matrix. Link costs are then altered in accord with this estimation of final link load. Trips from the next origin are loaded onto minimum paths thus found. He further recommends that subsequent alterations be carried out in the usual way with link costs being adjusted to accord with the completed assignment. Effectively the method is an iterative procedure with the second iteration using some form of Chicago successive loading technique.

4.12 ASSIGNMENT IN CONGESTED CONDITIONS

When all the loads assigned to roads are less than or equal to their capacities most of the procedures described above prove satisfactory because the network is not restricting the demand for trip making in that time period and consequently all trips may be completed. This can result in meaningful economic and operational evaluation of the model run. We would run into difficulties however if some of the loads assigned to the roads exceed their capacities. In this case the loads cannot be interpreted as flows because that number of vehicles could not possibly traverse the roads in the time period under consideration. In practice queues will develop very quickly and flows of vehicles exiting from the overcrowded roads would approximate to their flows at capacity. This restriction to movement of the vehicles on a few of the roads means that the loads on the remaining roads may not be interpreted as flows either, since some of the vehicles wishing to use these roads may be forced to queue on the over-crowded roads and not complete their journeys until after the time period under consideration. Hence some of the flows on the non-overloaded roads could be lower than the assigned loads.

It can then be seen why the overloaded roads present problems in capacity restrained assignment, the loads being vehicle demand not vehicle flow. Many methods have been used for this type of situation which either partially solve the problem or ignore it all together. They include extending the speed/flow relationship (DOE Note 1A, SELNEC) so that it corresponds to the average waiting time vehicles would encounter in queueing, projecting the relation-

ship and incorporating a minimum speed along the road, and using mysterious techniques which are usually described as 'the analyst using his professional experties'.

However, none of these techniques alone adequately reflects either how the traffic would filter through the network or the time that would be spent travelling. Thus an operational evaluation of a model run incorporating congestion is very difficult, if not impossible. Additionally, the economic benefits derived from road improvements in congested regions would be highly suspect because the time savings acquired from relieving the congestion would be questionable.

4.12.1 QUEUEING ASSIGNMENT

Capacity restraint assumptions give rise to some doubt, especially as regards the position of traffic within a network over a period of time. Queueing assignment technique is therefore seen as an extension of capacity restraint. The flow of traffic along any road is regulated by the restrictions imposed by the rest of the road network as well as the speed of the traffic using the road being regulated by the road characteristics. The normal procedure hitherto has been to consider trip loadings onto a network independent of the time period in which they occur. The time-dynamic model is an exception in this respect but even this approach makes no serious attempt to consider what happens to traffic once the link capacity has been exceeded. In an over-congested network, and planners are often concerned with overcongested areas, much of the journey time will be spent queueing. While

queueing makes no progress at all traffic on less congested routes may be moving freely. If the assignment is to be truly time-dynamic then the network flow patterns must represent traffic situations at real points in the time period.

Before the queueing assignment can commence it is necessary to ascribe a maximum flow to every road, or capacity as it is usually termed. This is usually estimated from the characteristics of the road, the intersection at its exit and the traffic movement at the intersection.

During loading sequence the above information is used to determine whether the interzonal traffic can complete its journey, or if it will have to queue, due to part of the route operating above capacity, and complete the journey in a later time period. That is, in simulation, queueing or slow moving traffic released at an earlier stage from their origins must be considered alongside traffic that was already in the system or is just being loaded.

About twenty years ago, Wardrop compiled a theoretical explanation of the time spent queueing. However assignment models have in the main ignored the problem until quite recently. The SELNEC model, the I.B.M. Capre Model and the London Transportation Study team have given the problem a very casual attention. The first two models provide an extended speed/flow curve past capacity, speeds are reduced to allow for time spent queueing. In the London approach excess demand was removed using linear programming techniques. Unfortunately these approaches ignore the basic

problem of the relative position of traffic within the network at different times and rely heavily on the simple capacity restraint approach.

The major developments in queueing assignment techniques can accredited to Stephen (414) and Outram (406).

4.12.1.1 OUTRAM'S QUEUEING ASSIGNMENT MODEL

In capacity restraint, loads which are less than road capacities may be taken as flows since traffic that cannot reach the road will be held up elsewhere. However when the load exceeds capacity the time spent queueing must be taken into account in computing travel time. In Outram's model (435) estimate of the queueing time can be made as follows:

Consider a load 'L' assigned to a link with working capacity 'C' in a time period 'T'. Now assuming that vehicles arrive at a constant rate, the time period 'dt' which passes before all the vehicles that can traverse the road in time period 'T' have reached the link is given by

$$dt = C\ T/L \quad \text{where } L > C$$

The number of vehicles 'N' which would still be queueing at the end of dt is given by

$$N = C - C^2/L$$

and the total time spent queueing by the vehicles which will traverse the road is given by

$$\frac{N.T}{2} = \frac{T.C}{2}\left(1 - \frac{C}{L}\right)$$

Hence the average time spent queueing by those vehicles to traverse the road in the time period 'T' is given by

$$\frac{T}{2} \quad (1 - \frac{C}{L})$$

The model itself is based upon a postulation by Wilson (416) that the destination of vehicles travelling a link is independent of the origins. From this the size and order of loading sequence do not make any difference so that an incremental loading procedure may be confidently used within the time period under consideration.

A simple application of the model is derived using a double loading sequence. The first pass is designed to find the demand for travel along each link from current origin. A second pass is intended to indicate the number of vehicles queueing on any of the links and where these occur to suppress loadingson following links of a route. In this way the valuable information listed below is extracted.

a) Total demand for travel along roads

b) Number of vehicles queueing along any of the roads

c) The flow of vehicles along any of the roads

4.12.1.2 THE HAMMERSMITH MODEL

The model (414) is an iterative process with the total number of trips loaded in several stages. It may be regarded as a time dynamic model specially designed to cope with the queueing problem.

Travel demand is assumed constant throughout a peak hour and loadings are staged corresponding to divisions of the peak hour. In

Hammersmith's model it has been the practice to carry out five loadings i.e. four of 22.2% and one of 11.2%. The program first calculates the capacity, assigned demand and degree of saturation of each link. The model is based on the time-dependence of delays and incorporates suitable delay functions. From the degree of overload and the time elapsed, the delay to be expected by the next vehicle to travel along a link can be calculated. New minimum path trees are found at the end of each iteration and these take account of accumulating queueing delays. Naturally queueing delays may be reduced at a later fraction of the time period.

The program is said to work well in a compact urban area. Of course in a near central area of London the problem of queueing delays at peak hours is very great.

4.13 LINEAR PROGRAMMING TECHNIQUE USED IN THE LONDON TRANSPORTATION STUDY

The assignment technique used in this study (436) is an example of an approach which assumes that travellers interact optimally in some way. Following the peak period trip distribution and modal split phase of the London Study it was found that the initial all-or-nothing assignment to the network of private vehicles produced a considerable overloading of the system. This overload was removed in two stages which are summarised in general terms below.

Stage 1 was the reduction of the assumed design speeds on certain overload parts of the motorways in such a way the volumes

assigned to them exceeded their capacity by similar amounts to that by which the volumes assigned to the adjacent base roads exceeded their capacity. A new distribution and modal split is determined on the basis of the latest journey times and the private vehicle trips re-assigned.

In stage 2 the remaining excess demand was removed by the application of a linear programming technique to a set of over-loaded motorway links chosen to that a reduction of capacity of the selected links reduce the whole network to capacity. The study area was divided into 33 groups of traffic districts and a solution was obtained which maximised the total number of trips attracted to the groups subject to the constraints imposed by the capacities of the chosen links and there being a minimum percentage of desired private attractions fulfilled in each group.

Although generally sound the method as applied included a number of inconsistencies, for example, only a portion of the links were used to set up the L.P. However, in essence the linear program can be expressed in the following form

$$\text{Maximise} \quad \sum_{x=1}^{n} R_x$$

$$\text{subject to} \quad \sum_{x=1}^{n} K_x \cdot R_x \leq Z_x \qquad r = 1, \ldots\ldots n$$

$$\text{and} \quad R_x \geq K.B_x \qquad x = 1, \ldots\ldots n$$

where R_x = number of allowed trip attractions to zone x

K_{rx} = proportion of trips attracted to zone x

Zr = capacity of link 'r'

B_x = desired attractions to zone x

K = constant

4.14 A PERTURBATION MODEL

This is a technique for producing assignments over congested routes and for assessing the accuracy of the result. When the flow assignment is produced by network simulation models, some roads in the network may be overloaded to a point far above their capacity.

A problem that usually arises in transportation planning is the matching of a network of limited capacity to future travel demand that exceeded the capacity of the network at certain points. A perturbation procedure enables this matching process to be carried out, and simultaneously provides an approximate solution to a traffic assignment pattern that lies within the network capacity together with a matrix of travel demand that corresponds to this reduced level of travel. This is illustrated below by the detailed discussion of the model.

The model is not restricted to the case of excess demands for network capacity, but can be applied to many other network flow and demand problems such as finding of traffic flow pattern that is both in equilibrium with the speed/flow relationship of every road in the network and made up from flows of travellers seeking to make their trips and routes of minimum cost to them. Assignment by most othermodels discussed above, can only give approximate solutions to the flow assignment problems, but by using a perturbation model for the travel demand between every pair of origins and destination these solutions can be reduced to a known level of accuracy and measures of the quality of the solution can be obtained.

This model is described fully by Wigan and Bamford (409) but it is still in its early stages of development. It makes use of the concept of trip demand and perturbation cost.

Perturbation costs are small elements of link cost introduced into an assignment to hasten convergence towards the equilibrium solution. This is reached only when all possible alternatives are more costly or time consuming. In the model, the trip demand qij is expressed by the relationship

$$q_{ij} = K_{ij} C_{ij}$$

where K_{ij} is a calibrated constant linking demand and cost

C_{ij} is the total generated cost of travel from i to j over a route of minimum cost

and e is the elasticity of demand i.e. fractional change in demand divided by the fractional change in cost at a given point.

This seems to give an acceptable mathematical solution to the problem of convergence without the inconsistencies inherent in other approaches. First, two other quantities are defined: (M^{o}_{ij}) a matrix of known fixed link travel demands obtained from one of the assignment approaches above and (M^{1}_{ij}) which is a matrix of new travel demands corresponding to costs (C_{ij}). The procedure is iterative but initially an elasticity 'e' must be defined so that K_{ij}, which equals $q_{ij} C_{ij}^{-e}$ for all ij, may be found.

A set of perturbation costs is applied to part or all of the network and minimum costs of travel between all ij pairs over the network are found. These costs and the demand function $q^{1}_{ij} = K_{ij} C_{ij}$

are used to determine the current variation in demand for travel on each of the links from the original demands M^{o}_{ij}. Hence a new matrix M^{1}_{ij} is found. The assignment may be 'smoothed' by one or two total 'flow interactions' without altering the travel demand q_{ij}. The procedure is repeated several times.

The additional perturbation costs are then removed and the iterative procedure repeated without them. The costs used (C^{1}_{ij}) are those of the new minimum path costs minus the perturbation costs. The variation of the assigned trips (q^{1}_{ij}) from the original demand (q_{ij}) is found and applied to the new minimum paths. The resulting link loads are added to the flows already assigned and a final convergence may be obtained by another series of flow iterations.

In the network in which the link speed/flow relationship continues past the link capacity, the approach may be used to handle the situation where the network is heavily loaded. Wigan and Bamford are of the opinion that this model could be used in conjunction with linear transport programming technique or the method used in the London Transportation Study. They also contend that the perturbed equilibrium approach gives a framework within which the Linear Programming restraint technique could be used more efficiently. The deficiencies of Linear Programming as used in London Transportation Study could be alliviated by its use with a perturbation model in a wider iterative framework.

4.15 DEFICIENCIES OF ASSIGNMENT TECHNIQUES

The deficiencies peculiar to all-or-nothing assignment procedure were discussed in section 4.5.2. but it will be useful to mention some of the deficiencies of assignment procedures in general (including all-or-nothing assignment procedure). Factors that contribute to poor results of assignment process can come out of the following deficiencies.

1. Network Considerations:

Assignment procedures assume that the network consists of links which are uniform along their lengths and the assumed speed/flow relationship applies equally along the lengths at all times to all travellers. This assumption ignores the changes in physical characteristics of the road, the presence of other traffic (stationary and dynamic), differences in driver behaviour and the variations in the composition of the traffic stream all of which affect the assumed speed/flow relationship. The behaviour at junctions is equally variable.

2. Cost Consideration:

The assumption is made that all trips originate and have destination at zone centroids. Clearly trips have their ends at points spread over the whole area of the zone and an assumption of this type produces a poor simulation of the real situation (especially on local streets within the zone). A further factor coupled with the above assumption is that all travel takes place on the designated networks. Errors due to the omission of the less important roads, some of which may carry significant volumes of traffic may often be important.

It has been mentioned earlier that it is usually assumed that the individual seeks to minimise his travel time or his perceived cost when selecting his route. Whichever behavioural criterion is used, errors in the

evaluation of assigned flows will be found because a driver may also have considered factors such as the number of turning movements and the number of traffic signals he has to pass through, or, for a public transport journey maker, he may have considered the waiting, comfort and the number of boardings in addition to travel cost. Perceived cost usually includes a modal penalty in addition to the time and out of the pocket costs but it is next to impossible to account for the variation in an individual's evaluations of the factors influencing him in his choice of route or mode.

Not only do individuals weigh each of the elements within the total perceived costs differently, they also estimate the value of each element to various levels of accuracy. For example, a regular comuter may be able to assess the travel time or cost on a route with a higher degree of accuracy than an individual making such journey for the first time.

There is a lot of difficulty in accurate measurement of values and determination of parameters in cost relationship. Inaccuracies made in journey time measurements will tend to accentuate the problem of assigning trips to competing routes with small time differences. As far as the behavioural accuracy is concerned, there are two points to note. Firstly, small differences in journey times (or costs) by different routes between the same origin and destination can bring about unrealistic journey paths especially when the all-or-nothing assignment technique is used. Secondly, the saving of the time (or money) may not be significant incentive to attract drivers from a fast comfortable motorways to tortuous but shorter town roads.

Assignment techniques use overall averages assumed to be the same for all persons at all times while in actual fact such elements of cost as comfort and convenience vary from person to person. Burrell (4.6.2.3.) attempts in his model to overcome some of defects mentioned above by the

use of randomisation of link costs while Dial (4.6.3.1.) attempts this by choice on probabilistic basis which is based on costs.

3. Effect of Congestion:

Though some assignment techniques have taken account of queueing problem (e.g. Outrams's (4.12.1) queueing assignment technique and the SELNEC model) most techniques ignore this important phenomenon, and assume that all journeys start and finish in the time interval under consideration.

4. Termination of the Iteration Process:

Most assignment techniques are terminated when appropriate convergence criteria are satisfied. It is implicitly implied that any solution obtained obeys Wardrop's (3.1.1.1.) principle of equal travel time but few have actually tried to test for this or to test the stability of the solution as a whole. However, application of the perturbation approach ensures that the solution obtained is the stable one.

5. ACCURACY AND CONVERGENCE OF CAPACITY RESTRAINED TECHNIQUES

In the discussion so far, not much has been said about the assignment end conditions. In all assignment techniques it is of course most desirable that the procedures be both accurate and economic. In practice models are used to simulate existing travel patterns and later as predicting planning tools. They should however, be capable of maintaining a realistic approach if sensible assignment results are to be obtained. The problem in hand, therefore, is to make a mathematical model as accurate and efficient as possible; and the successful completion of modelling is reached when an end condition is satisfied. One of the most popular end conditions is that in the final stable pattern of flow, no one should be able to make his desired journey at a lower total cost (or time) than he is then incurring. Clearly the application of this principle, due to Wardrop (311) now allows many different routes to be used between any pair of points and the process of determining the pattern of flow that satisfies the principle and the speed flow relationships at the same time will require successive iterations of the supply and demand.

The two theories of Wardrop on the final equilibrium of traffic (the principle of equal travel time and principle of minimum average time) have been discussed in Section 3.1.1. The principle of equal travel time (3.1.1.1.) is particularly suitable for a mathematical programming solution but is difficult to apply in the usual capacity restraint methods. The principle of minimum average time (3.1.1.2.) assumes that travellers behave in such a way that they consider the overall situation. Unfortunately this does not correspond to what actually happens and so its application to the assignment problem should be viewed with suspicion.

Tillman (504) has noticed that a constant link travel time is not reaslistic since it does not reflect travel times when additional vehicles are added to the link. To overcome this he proposed a linear travel time function. From this linear travel time function he produced a non-linear total travel time function which he applied to the problem of traffic assignment by an iterative, technique based on the 'principle of optimality' (Bellman and Dreyfus) from dynamic programming. Although the Tillman method gives a satisfactory result for square grid systems, its application outside this is limited. Various workers have found that different network assignments converge to a quasi-stable solution, either in terms of flow stability, total vehicle miles, time or cost. However, none of these parameters give an absolute final solution, and the stability may well depend on the time of restraint, loading or iterative techniques used.

5.1 ACCURACY

In transportation work, the accuracy of the results obtained is usually sufficient for the job in hand. The accuracy desired depends on whether the assignment is used in system design or facility design.

System design entails determination of the best form of improvement for an existing transport system often within the framework of a transport or development plan. These plans are long term and forecasts will only be very approximate. However, they should be sufficiently accurate to show major deficiencies in the system. The time span between the base year and design year normally falls between 15 and 30 years.

Facility design concerns the determination of the form of a transport system element. This element may be a road improvement, road junction, transport interchange, etc, and is conducted when an overall picture of the transport system has been obtained. The period between design and installation will generally be quite short but rarely greater than 10-15 years. To obtain the best use of the facility it is often desirable to consider its use at a later date when the transportation system required has been improved as a whole. Transport elements normally operate under the most testing conditions at peak hours but not necessarily so for some other elements. For example, multistorey car-parks in shopping or business areas may be under heaviest load at periods other than the general system peaks. As the information may not be readily available from system assignment it is necessary to carry out estimates at a finer scale. Forecasts may be left to the designer's own judgement. Generally facility design requires results in absolute terms whereas system design may be satisfactorily carried out as a comparison of alternatives.

5.2. TYPES OF ACCURACY

A good reference on this topic is Parker and Johnson (505). They say that inaccuracies can arise from traffic data assigned, the assignment technique and testing procedures. These types of accuracies (or inaccuracies) they call the statistical, methodological and procedural aspects respectively.

5.2.1. STATISTICAL ACCURACY

At the base year there may be inaccuracy in the travel data sample derived from census. It is estimated that with 1 in 50 sampling factor flows of 1,000 units incur a 95% confidence limit of 550 and 1,450, but a 1 in 10 sampling ratio these limits are reduced to 800 and 1,200. At greater flows the range of confidence limits reduces even further.

At design year the uncertainity of population land use and car ownership predictions must be added to the inaccuracies at the base year. The reliability of these parameters depends on local conditions. Statistical accuracy is extremely important in facility design where precise estimates are required but in system design the effects may be small enough to be ignored.

5.2.2. METHODOLOGICAL ACCURACY

This is an extremely important subject critical to model performance that requires full consideration. Errors may arise at each stage of the assignment process, hence it is proposed to take a more critical look at the inaccuracy throughout the various stages of assignment.

Now network building is a 'fine art' that has to provide a realistic framework for assignment at reasonable cost. In West Midlands Transportation Study, traffic flows on some links were overestimated while others were underestimated. But as a general rule estimated

flows in corridors and over screen lines were correct as far as the trip matrix were concerned. In addition to the conscious errors of network assignment, care must be taken to avoid random human errors in network definition. When data is being stored on computer stationary mis-coding, mis-punching or ommission may not be easily detected.

Although tree-building itself is a simple mechanical process, the wa in which it is used may expose fundamental errors of the assignment. Inaccuracy often results from the tree building criteria, whether time distance or cost. The difinition of cost functions requires much thought particularly in relation to individual link resistances. Suppose, for example, that a cost function is simply expressed as:

TIME + A * DISTANCE

and that link attractiveness is to be compared with 'A' set at 0 and 2. On the first link of length 3 miles, at 60 m.p.h. the link cost becomes respectively 3 and 9 units. On a second link of length 2.5 miles, at 40 m.p.h. the costs of travel are respectively 3.75 and 8.75 units. Hence the longer route appears more attractive with 'A' set at 0 while the shorter route is cheaper with 'A' set at 2. In addition the starting speeds of an iterative capacity restraint procedure may seriously affect results throughout the assignment. These errors may be made even worse by incorrect speed/flow specifications in which the minimum speed at high flows is critical. If this is set too low it is equivalent to deleting the link from the network and traffic may be sent through very inferior routes, or, if set too high, may prevent traffic from being assigned to reasonable alternative routes. Some researchers have found turn penalties useful in directing traffic to

realistic routes particularly in close mesh urban networks where junction delays are proportionally much greater. However, others (212) have found that they make little difference to the overall assignment.

In general more realistic assignments are obtained after a greater number of iterations. This corresponds eventually to a situation in which each trip is individually assigned but the cost of such an approach would be prohibitive. Weaver, (511) however, feels that the same level of convergence could be obtained if total loading technique is used and terminated earlier than would have been the case if partial loading technique were used.

5.2.3. PROCEDURAL ACCURACY

This is particularly important in system design. At this level there are many alternatives and care must be taken to include all likely contenders for implementation. In comparison of schemes some gross errors are inevitable. However, their extent should be limited if possible by careful testing of models at the base year stage. Streeter (514) has presented a method for testing adequacy at the base year using established statistical procedures.

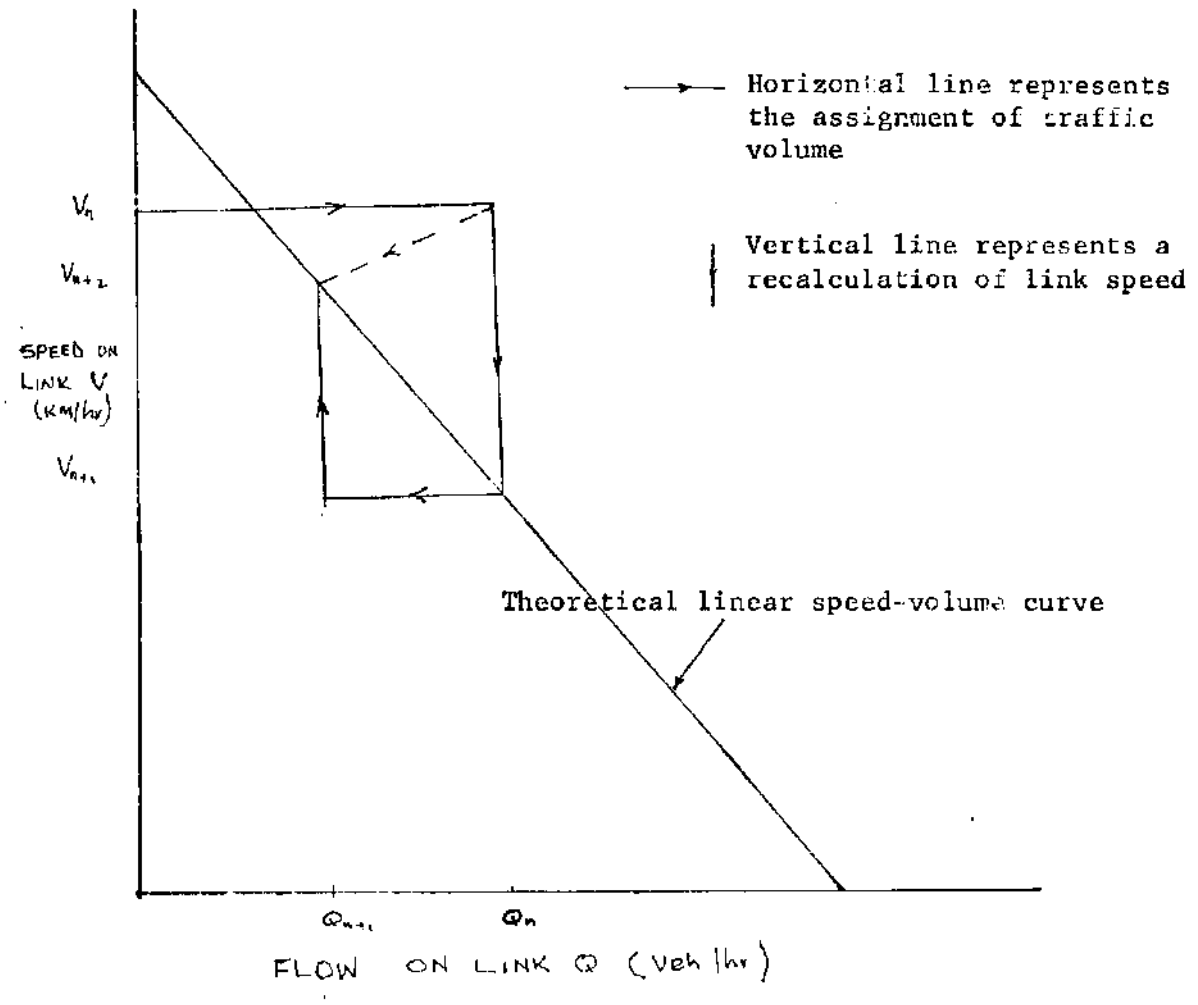
5.3. CONVERGENCE OF ASSIGNMENT AND METHODS OF ASSESSING IT

Most assignment procedures have two main mechanisms that may or may not guide them to a satisfactory final solution. These are the loading - load adjustment procedures and link resistance function - link

resistance adjustment procedures. In the normal capacity restraint operation these mechanisms are used alternatively to assign trips and then to adjust the balanced speed/flow relationships. Ideally we are searching for a solution where all link values of speed and flow lie on the respective speed/flow curves and the travel times on alternative used routes are equal. The convergence process can be illustrated as shown in Fig. 5A (511) in which, the simplicity, on linear speed-flow relationship has been assumed. Vn is the speed on a particular link at the start of the nth iteration. The assignment process then assigns a volume, say Qn, to this link which usually causes the speed on the link to fall to a lower value, say Vn + 1. The $(n + 1)^{th}$ assignment will generally restrain the traffic on this link, producing a lower assigned volume, say Qn + 1. This reduction in traffic loading will cause the speed on the link to increase to, say, Vn + 2. This process is repeated until convergence occurs, i.e. at some iteration i the values of Vi and Qi will represent a point on the speed flow curve depending upon the accuracy of convergence required. The convergence process may be improved, in terms of the number of iterations required, if the speed on the link for the $(n + 2)^{th}$ iteration could be predicted at the n^{th} iteration. This prediction is shown by the dotted line in Fig. 5A.

Certain techniques have been developed which attempt to speed up the convergence process. These methods either reduce the assign volume after calculation of link times or alternatively do not amend the travel to the full extent after the assignment. In practice this will be a very lengthy computation, and obviously we do not require this degree of accuracy in assignment processes. The problem then is when do we consider the assignment process to be completed? A straight

FIG. 5.3A CONVERGENCE PROCESS



forward measure of convergence appears to be a simple comparison of link flows before and after loading. However, there is a danger when links are viewed totally in isolation that the behavioural criteria of minimising cost is ignored. In addition to link convergence the setting of the network as a whole must be taken into account. Even with multiple routing methods of allocating traffic (4.3.2.3), Outram (504) found that the rate of convergence was lower than is desirable. He found that the large number of iterations necessary to produce a near stable model

would be prohibitive on cost grounds, particularly when large networks are being evaluated. From the analysis of the multiple routing model mentioned above, Outram concluded that the slow rate of convergence was mainly attributed to the route choice and capacity restrained models. The situation in these two sections of the model he said could be likened to the dog chasing its tail. With the load chasing the cost in route choice and the costs chasing the load in capacity restraints. The two meeting by chance, because one of the quantities does not know how the other responds.

In fact, there is very little in the literature concerning the rate of convergence of the various assignment techniques. Most of the published work admits to being based on one network only, though the effect of marginally different sets of link costs may have been investigated, and hence it is possible that the results quoted may be to some extent network dependent. Most planners have been content to use a technique for a predetermined number of iterations without much control over convergence. Overgaad (525) presents some work on convergence carried out in Denmark. This is concerned with both the link flow convergence and total network convergence aspects. One of the most interesting features of this is a plot of link flows after each iteration. Each of the links experienced some fluctuation of load during the first five iteration but settled to a steady load from the fifth to the twentieth iteration. Wardrop's criteria of equal travel times was also examined in Denmark. For the study 66 pairs of zones between which more than one route seemed likely to be used, were selected. Of these 45 used two different routes only, but in 26 of those cases the travel times were not the same. On the average, one twentieth of the traffic used the route while the rest used the other

route. Overgaad, therefore, suggests that given an infinite number of iterations it is possible that all traffic may be assigned to one route and yet the principle of equal travel times still be observed. He contends that in the limiting case, traffic on the single route will be subject to exactly the same travel time.

Weaver and Riley (511) have shown that the form of speed/flow relationship used influences the rate of convergence whichever technique is under review, though it is usually claimed that the technique are all affected in a similar way so that comparisons made using the same speed/flow relationships are valid over a rage of such relationships. The sensitivity of the method used to determine when an acceptable solution has been achieved is another factor which influences the rate of convergence. The following sections have been devoted to looking more closely at the methods of assessing the rate of convergence of an assignment technique. Some of these methods are listed below.

(a) The number of links changing costs or flows by more than a fixed amount in successive iterations (509).

(b) The number of links changing costs or flows by more than a fixed proportion in successive iterations (511).

(c) The difference for each link between the assigned flow and the capacity of the link at the speed used when building the trees for the assignment. Error for the whole system is:

$$\frac{\sum \left| \frac{\text{Flow-capacity}}{\text{capacity}} \right|}{\text{No. of links}}$$

ref. (516).

(d) The number of links for which the speed/flow points lie on opposite side of the speed/flow curve in successive iteration (516).

(e) The variation in user benefits relative to a standard solution

$$\text{User Benefit} = \sum_{ij} \tfrac{1}{2} \left(Tij^{o} + Tij^{1}\right)\left(Cij^{1} - Cij^{o}\right)$$

where subscript 1 and o relate to the current and standard solution values respectively and Tij and Cij denote the number of trips and the cost of travel between zones i and j respectively (509).

(f) Variation in the average trip cost (524).

(g) Lane, Powell and Prestwood Smith (501) suggest three measures of link convergence.

(i) A ratio of assigned flow to capacity at assigned speed summed over all links in the system. The flows may be conveniently expressed in vehicle mile units. Unfortunately it is possible that an average value of unity which suggests convergence may in fact be composed of a series of links some with too high and some with too low speed values.

(ii) The above indicator may be improved by an absolute measure as:

$\sum_{\text{all links}}$ Capacity at assigned speed + Mod (assigned flow - capacity at assigned speed)/ $\sum_{\text{all links}}$ capacity at assigned speed (501).

This may be used to study convergence in a particular part of the network, or, on specific types of link.

(iii) This is similar or the same as (d) above.

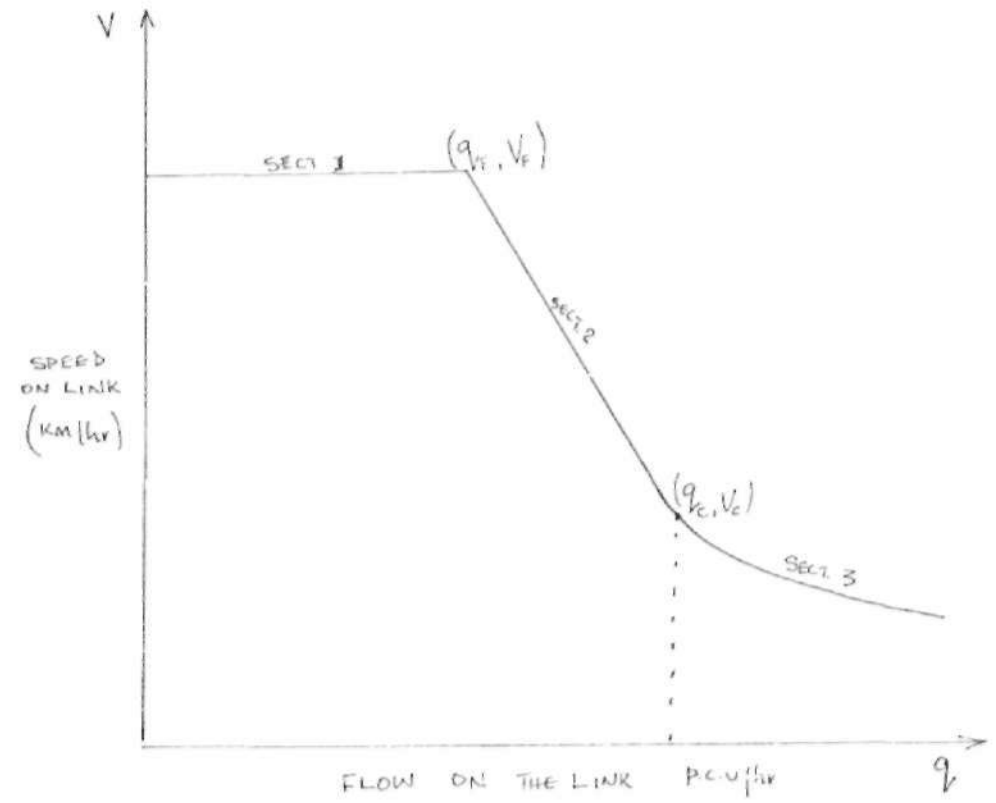
5.3.1. SENSITIVENESS OF THE MEASURES USED TO ASSESS CONVERGENCE (526)

All of the measures listed above indicate that a solution has been achieved only when successive estimates of link flows and/or link costs agree satisfactorily. Apart from the first iteration, all link costs are determined using the speeds obtained when the assigned flows are substituted in the appropriate speed/flow relationships. The following discussion (526) relates to the flows and the corresponding speeds, times or costs derived from speed/flow relationships of the outline in Fig. 5.3B which is taken from The Department of the Environment Urban Project Appraisal Directorate of Transportation Studies - Advice Note 1A - speed/flow relationships for use in transportation studies (209).

5.3.1.1. FLOWS OR COSTS CHANGING BY MORE THAN A FIXED AMOUNT

The change in link cost is synonymous with the change in travel time on the link. Most computer programmes store costs in units of 0,1 cost minutes and flows in units of pcu/hr. Thus if integer (as distinct from real) flows and costs are used the smallest changes that can be detected are 0.1 cost minutes and 1 pcu/hr for link cost (0.1 min for time) and flow respectively.

FIG. 5.3B ASSUMED SPEED/FLOW RELATIONSHIP (Taken from ref 209)



Section 1:- $0 \leq q \leq q_f$

$V = V_f$

Section 2:- $q_f < q \leq q_c$

$V = V_f - K(q - q_f)$ where $K = \frac{V_f - V_c}{q_c - q_f}$

Section 3:- $q > q_c$

$$V = Vc \left(1 + \frac{Vc}{8L}\left(\frac{q}{q_c} - 1\right)\right)^{-1}$$

where L = link length in KM

On section 1 of the speed/flow curve

$$V = Constant$$

$$\text{therefore } t = \text{Constant}$$

i.e. the link flow may change from 0 to q_f without producing a change in link time (or cost).

On section 2 of the curve

$$V = V_f - K\ (q - q_f)$$

$$t = \frac{6000L}{V} = \frac{6000L}{V_f - K\ (q - q_f)} \qquad \text{in (0.1 mins).}$$

$$\frac{dt}{dq} = K * \frac{600L}{(V_f - K\ (q - q_f))^2} > 0$$

$$\frac{d^2t}{dq^2} > 0 \qquad \text{hence } \frac{dt}{dq} \text{ has its maximum value at } q = q_c$$

i.e. $$\frac{dt}{dq} \leq K.\ \frac{600L}{(V_f - K\ (q_c - q_f))^2}$$

$$\leq \frac{Vf - Vc}{q_c - q_f} \cdot \frac{600L}{V_c^2} \leq \frac{1}{q_c - q_f} \cdot \frac{600L}{Vc \cdot \frac{Vc}{V_f}} \leq \frac{1200L}{(q_c - q_f)} \frac{Vc}{}$$

since $\frac{V_c}{V_f} \geq \frac{1}{2}$ for all urban roads

Referring to urban roads in ref. 209 $(q_c - q_f) \geq 250 \times 15$

hence $$\frac{dt}{dq} \leq \frac{1200L}{3,750} < \frac{L}{3}$$

It may be assuemd that $L < 3$ kms

hence $\frac{dt}{dq} < 1$ i.e. flow in pcu/hr changes more rapidly

and hence is a more sensitive measure than time 0.1 mins (or cost in 0.1 cost mins).

On section 3 of the curve

$$V = Vc \left\{1 + \frac{Vc}{8L} \left(\frac{q}{qc} - 1\right)\right\}^{-1}$$

hence $$t = \frac{600L}{Vc} \left\{1 + \frac{Vc}{8L} \left(\frac{q}{qc} - 1\right)\right\} \quad \text{in 0.1 mins}$$

$$\frac{dt}{dq} = \frac{600L}{Vc} \cdot \frac{Vc}{8Lq_c} = \frac{600}{8q_c} \leqslant 1$$

on all urban roads except types 5 and 6 since q_c = 500 and 600 on types 5 and 6 respectively and $q_c > 1000$ on other urban roads. If it is possible to consider changes of q_c by 0.5 pcu/hr then on this section, change in flow in 0.5 pcu/hr is a more sensitive indicator than change in link cost in 0.1 cost mins. Hence with the type of speed/flow relationships assumed a change in link flow of 0.5 pcu/hr is a more sensitive indicator of instability in the convergence process than is a change of 0.1 cost mins in the link costs. That is the number of links changing costs by 0.1 cost mins or more is more likely to indicate that convergence has been attained when it has not than is the number of links changing flow by 0.5 pcu/hr.

5.3.1.2. FLOWS OR COSTS CHANGING BY MORE THAN A FIXED PROPORTION

It must first be borne in mind that if the assignment programme uses integer flows and costs it has been shown above that a change in cost is less likely to be observed than the flow except on section 3 of urban roads 5 and 6 and hence, near the solution particularly, a change in flow by a fixed proportion is a more sensitive indicator than a change in cost by a fixed proportion. With this qualification we may now consider the comparison of $\frac{dq}{q}$ v $\frac{dt}{t}$ as indicating the relative sensitivities of the proportional changes concerned.

On section 1 of the speed/flow curve since dt = 0 no changes in link time can be observed so that changes in costs whether proportional or absolute cannot reflect instability in a solution and hence the use of link flows is preferable. In comparing $\frac{dt}{t}$ with $\frac{dq}{q}$ we note that

$$\frac{dt}{t} \gtrless \frac{dq}{q} \qquad \text{according as} \quad \frac{dt}{dq} \gtrless \frac{t}{q}$$

On section of the speed/flow curve

$$\frac{dt}{dq} = \frac{K.600L}{(V_f - K(q - q_f))^2} > 0 \quad \text{for } q_f < q \leq q_c \qquad \ldots\ldots (1)$$

$$\frac{d^2t}{dq^2} > 0 \quad \text{hence} \left[\frac{dt}{dq}\right]_q = q_f < \frac{dt}{dq} \leq \left[\frac{dt}{dq}\right]_q = q_c$$

$$\text{for } q_f < q \leq q_c \qquad \ldots\ldots (2)$$

We have $\frac{dt}{t} \gtrless \frac{dq}{q}$ according as

$$K.\frac{600L}{(V_f - K(q - q_f))^2} \gtrless \frac{t}{q} \qquad \left(= \frac{600L}{Vq}\right)$$

i.e. according as $\frac{K}{(V_f - K(q - q_f))^2} \gtrless \frac{L}{Vq} \quad \left\{= \frac{L}{q(V_f - K(q - q_f)}\right\}$

i.e. according as $Kq \gtrless V_f - K(q - q_f)$

i.e. according as $2q - q_f \gtrless \frac{V_f}{K}$

Values of $\frac{V_f}{K}$ on urban roads types 1 - 6 are estimated in Table 5.3 below.

For all road types $\frac{V_f}{K} > 2q - q_f$ at $q = q_f$

i.e. $\frac{dt}{t} > \frac{dq}{q}$ at flows near q_f

For road types 1, 2, 5 we have $\frac{V_f}{K} > 2q_c - q_f$ so that $\frac{dt}{t} > \frac{dq}{q}$

throughout the range of flows q_f q q_c.

For road types 3, 4, 6 we have $\frac{V_f}{K} < 2q_c - q_f$ hence on these roads

TABLE 5.3

ASSUMED VALUES OF $\frac{V_f}{K}$ ON URBAN ROAD TYPES 1 - 6

ROAD TYPE	V_f (Km/Hr)	Vc (Km/Hr)	q_f (pcu/Hr)	q_c (pcu/Hr)	$K = \frac{V_f - V_c}{q_c - q_f}$	$\frac{V_f}{K}$	VALUE OF $2q - q_f$ AT	
							$q = q_f$	$q = q_c$
1	80	66	1700	2400	0.02	4000	1700	3100
2	65	56	1400	2200	0.011	5778	1400	3000
3	50	30	600	1100	0.04	1250	600	1600
4	45	25	500	1000	0.04	1125	500	1500
5	35	25	350	600	0.04	875	350	850
6	25	15	250	500	0.04	625	250	750

$\frac{dt}{t} > \frac{dq}{q}$ at flows near q_c and thus proportional change in time is a more sensitive indicator than proportional change in flow at flows near q_c. However, it must be borne in mind that cost = time + const., hence proportional changes in time. It is true that as the flow increases time becomes more and more dominant in the cost relationship but it can be seen that on long links of types 3, 4, 6 we have $\frac{dt}{t} < \frac{dq}{q}$ throughout the range $q_f < q \leq q_c$.

We can briefly say that although proportional change in cost may be a more sensitive indicator than proportional change in flow over a range of flow near q_c, taken over all it appears that proportional change in flow is likely to be the more sensitive measure.

On section 3 of the speed/flow curve we have $\frac{dt}{dq} = \frac{600}{8q_c}$ for $q > q_c$

hence $\frac{dt}{t} \gtrless \frac{dq}{q}$ according as $\frac{75}{q_c} \gtrless \frac{t}{q}$

i.e. according as $\frac{75}{} \gtrless \frac{q_c}{q}$

Throughout tnis section $q > q_c$ hence $\frac{dt}{t} > \frac{dq}{q}$ if $75 > t$. It is unlikely that there will be many sections on which it is not less than 75 even with flows $q > q_c$ hence it appears that at high flows proportional change in flow. At flows in the region $q > q_c$, cost is very largely attributable to time and hence it seems likely that proportional change in cost is also a more sensitive measure than proportional change in flow.

It should be noted that the above discussion shows that proportional changes in time are greater than proportional changes in flow on heavily loaded networks but it doesn't take account of the situation that arises when all flows and costs are rounded to integer values.

This means that, a proportional change cannot be detected if the

corresponding absolute difference cannot be detected. Hence, assuming integer flows cand costs the minimum proportional change that can be detected on a link with flow q pcu/hr is $\frac{1}{q}$. Since the minimum flow of any real interest is likely to be not less than 100 pcu/h. the implication is that we can detect changes in flow of 1%. But this is more than adequate for any convergence investigation. Burrell (5;6) feels that an 'error' of 10% on the most important links is acceptable; and if we agree with him then the permitted proportional change in flow corresponds to an absolute difference of at least 10 pcu/h.

When $q > q_c$, we have $\frac{dt}{t} > \frac{dq}{q}$ showing that proportion of changes in link time and hence cost are greater than proportional changes in flow. However, as mentioned earlier on, the proportional change in cost may be decteded only when the absolute change is greater than 1 cost unit, that is, 0.1 cost mins. For flows in this region, $dt = \frac{75}{q_c} \times dq$. Thus the maximum change in t occurring for the minimum detectable change in q, that is, $dq = 1$ pcu/h, is given by putting $q_c = 500$, the minimum value quoted for urban roads. Hence $dt < 0.15 dq \left(d_q\right)$. The change in flow corresponding to the minimum detectable change in time, or cost, is $dq = \frac{1}{0.15}$, i.e. $d_q = \frac{20}{3}$ pcu/h. For $q > q_c$ the minimum proportional change in flow which can be detected is $\frac{1}{500} = 0.002$. This, even for heavily loaded networks, if integer flows and costs are used then proportional changes in flow are more sensitive measures than proportional changes in cost or time.

From the above discussion Thomas (526) came to the following general conclusion for networks not loaded beyond capacity proportional change in flow is a more sensitive indicator of instability in the convergence process than change in cost except perhaps for link types 5 and 6 at flows near q_c if integer flows are used or to a lesser extent in time.

For networks loaded beyond capacity, proportional changes in cost or time are to be preferred unless flows and costs are measured in integer values of 1 pcu/h. and 0.1 cost mins. respectively in which case proportional change in flow is a more sensitive measure.

5.3.1.3 THE ERROR $\dfrac{\sum \left| \text{FLOW-CAPACITY AT TIME USED} \right|}{\text{NO. OF LINKS}}$

If the speed used following each assignment are read directly, from the speed/flow curves then the value of the measure under discusssion can be taken as being the same as the proportional change in link flow in successive iterations. If this is not the case then this measure is not directly comparable with (5.3.1.1. and 5.3.1.2.). However, in those techniques in which the speeds read from the curves are not used directly it is usual to use a value of speed nearer to that used in the previous assignment. In this case suppose q_1 and q_2 are the successive assigned flows and that Q^2 is the link capacity corresponding to the time used when q_2 is obtained. The present method is more sensitive than (b) if

$$\left| \frac{q_2 - Q}{Q} \right| > \left| \frac{q_2 - q_1}{q_1} \right|$$

As a rule it may be assumed that in successive iterations if q_1 is too high then q_2 is lower and $q_1 > Q > q_2$. Thus $0 < \frac{q_2}{q_1} < 1$ and $\frac{q_2}{q_1} - 1 < 0$

and hence $1 - \frac{q_2}{Q} < 1 - \frac{q_2}{q_1}$ which implies that the current method is

less sensitive than (b).

Similarly, if q_1 is too low then $q_1 < Q < q_2$, $1 < \frac{q_2}{Q} < \frac{q_2}{q_1}$ and $\frac{q_2}{Q} - 1 < \frac{q_2}{q_1} - 1$

and the current method is less sensitive than (b). Hence the current method is less sensitive than (b).

5.3.1.4. NUMBER OF LINKS FOR WHICH SPEED/FLOW POINT LIES ON OPPOSITE SIDES OF THE SPEED/FLOW CURVE IN SUCCESSIVE ITERATIONS

Burrell (516) regards this as a valuable indicator of the convergence process though houses the 'error' defined in (5.3.1.3) to determine when a satisfactory solution is obtained. Clearly in the early stages the number of links changing sides is high, particularly if the network is heavily loaded, and thus if the measure menas anything it implies that the number of links crossing the curve becomes smaller as convergence is approached. To detect a point crossing the line we must be able to detect either a change in flow or a change in cost (i.e. an implied change in velocity) or both and, therefore, this measure is no more sensitive than the method of observing numbers of links changing cost or changing time. Additionally since even near convergence some points will continue to change sides it is unlikely that this method is as sensitive as (5.3.1.1.) above.

5.3.1.5. THE VARIATION IN USER BENEFITS RELATIVE TO A STANDARD SOLUTION

We have 'user benefits' = $U = \sum \frac{1}{2} (Tij^1 + Tij^0)(Cij^1 - Cij^0)$.

Assuming fixed trip matrixes this becomes $U = \sum T_{ij} (Cij^1 - Cij^0)$ thus if we compare the user benefits Ur, Ur + 1 in the r^{th} and $(r + 1)^{th}$ iterations:

$$Ur - Ur+1 = \sum Tij \left(Cij^r - Cij^0 - (Cij^{r+1} - Cij^0)\right)$$

$$= \sum Tij \, (Cij^r - Cij^{r+1})$$

This difference between estimates of user benefits is essentially the same as difference between total trip costs.

The total trip cost is given by $C = \sum_{i=1}^{N} q_i C_i$ when N is the number of links in the network and q_i and C_i are the flow and cost on link i respectivel

For any link i the 'total link cost' is $Ci = q_2 C_2$.

Since $\frac{dC_i}{dq_i} = C_i + q_2 \frac{d_{c2}}{d_{qi}}$ and $\frac{dCi}{dC_i} = q_i + C_i \frac{d_{qi}}{dC}$

and hence $\frac{dC_i}{d_{qi}} > 0$ and both C_i and q_i (except perhaps in the early loading cycles) are greater than 1, it is apparent that change in 'total link cost' is more readily observed than either change in link cost or change in link flow and thus it may be assumed that the present measure is more sensitive than either of the measures in (5.3.1.1.) above. Certainly the number of links changing 'total cost' by more than a fixed amount is a more sensitive measure than either of those in (5.3.1.1.) above. It must be noted however, that the discussion here assumes flows and costs corresponding to points on the v - q curve.

5.3.1.6. VARIATION IN THE AVERAGE TRIP COSTS

Basically this measure is the same as (5.3.1.5) above with the difference between average trip costs being equal to the difference between the sum of 'total link costs', i.e. between user benefits, averaged over the network links.

5.4 COMPARISONS OF THE SENSITIVITIES OF THE MEASURES USED TO ACCESS CONVERGENCE

In 5.3.1.1. it has been shown that except for links of types 5 and 6 (209) loaded beyond capacity change in link flow by more than 1 pcu/hr is a more sensitive measure than change in link cost by more than 0.1

cost mins. Since most programmes use integer flows and costs measured in these units, these are the smallest differences which can be detected.

It was shown in 5.3.1.2., however, that for networks not loaded beyond capacity proportional change in flow is a better indicator of instability in the convergence process than is the proportional change in cost but for networks with many links loaded beyond capacity the order of preference is reversed. However, if integer flows (in pcu/hr.) and costs (0.1 cost min.) are used this situation does not hold; in this case changes in flow, either proportional or absolute, are more sensitive measures than changes in cost.

The discussion in 5.3.1.3. shows that the measure:

$$\left| \frac{\text{Flow - Capacity}}{\text{Capacity}} \right|$$ is as sensitive as the proportional change in flow only when the speeds assumed following an assignment are read directly from the speed flow curve. It is suggested in reference 516 that the quantity:

$$\frac{1}{N} \sum_{i=1}^{N} \left| \frac{\text{Flow - Capacity}}{\text{Capacity}} \right| \quad \text{where } i = 1 \text{ to } N$$

are the network links, is a good indicator of the process of convergence over the whole network. Whereas this is true, if an overall assessment of the network from the convergence point is required, the above measure is clearly no more sensitive than the average value of the proportional changes in link flows or the number of links changing flows by more than a fixed amount, etc.

It has been pointed out in 5.3.1.4. that the number of links for which the speed/flow point lies on opposite sides of the speed/flow curve in successive iterations is not likely to be as sensitive a measure

of convergence as the number of links on which the flow changes by more than a fixed amount or a fixed proportion. However Burrell (516) finds this to be an 'especially valuable indicator of the working of the convergence process' as distinct as a measure of the attainment of speed/flow equilibrium for which he uses:

$$\frac{1}{N} \sum_{i=1}^{N} \left| \frac{\text{flow - capacity}}{\text{capacity}} \right|$$

In 5.3.1.5. it has been shown that if costs are determined using the assigned link flows and corresponding speeds derived from the speed/flow curves then the change in user benefits, or more strictly in 'total link cost' is a more sensitive measure than any heretofore discussed. It integer costs and flows are used this statement is modified to the extent that it is at least as sensitive as any of the other measures. Other people have used user benefits without making it clear whether the link costs used are those defined above or those from which the trees producing the assigned link flows are built. It seems more likely that the latter is the case in which event, because flows which are too high will tend to be associated with costs that are too low, the variation of the measure and hence its sensitivity will not be as great as that of the indicator proposed. Basically the proposed measure assumes that which ever trees are built, the actual link costs are in accordance with the link flows, which after all is the object of the exercise, in which case high flows will produce corresponding high costs. It is appreciated that the costs produced may well result in the former cheapest routes no longer remaining so, though of course if equilibrium has been attained the costs should not change in the final assignment.

If the cheapest route costs are required we can:

(a) use the cost on which the latest trees, the current practice

(b) use an average between these costs and the costs produced by

the assigned flows, or

(c) determine new trees using the new costs and assume the costs on these trees to be the costs required.

This latest approach would of course involve most of the work, all apart from the loading, in a new flow iteration and hence would be ideal either for assigning flows to the last two trees or for the standard flow iteration assignment.

As stated in 5.3.1.6. if the definition of link costs is the same, the difference between successive estimates of average link cost is basicall the difference between the successive estimates of the network sum of the 'total link costs' averaged over the network links.

In conclusion, therefore, the author concurs with Thomas's suggestion (526), that the variation in the number of links changing 'total link costs' by more than a fixed proportion if non integer flows and costs are used, is probably the most sensitive measure of the convergence of the iterative process to a network equilibrium solution. If this measure is use then all information is available for the evaluation of such quantities as the change in user benefits or the change in average link cost in successive iterations, the total cost of all trips made, etc. If integer flows and costs are used, the relative insensitivity to changes in costs near the equilibrium condition implies that the proportional change in 'total link cost' is effectively the same as the proportional change in link flow in which case, since it involves less calculation, this latter measure may be preferable.

6. FACTORS INFLUENCING SOLUTION OF CAPACITY RESTRAINED ASSIGNMENT PROCEDURES - EARLIER INVESITGATION

An acceptable capacity restrained assignment is a pattern of traffic flows such that for every link in the network the assumed speed and the assigned flow satisfy the appropriate speed/flow relationship and the cost on all coterminous paths is the same. Most capacity restrained assignment methods claim convergence to a solution provided enough iterations are carried out. In view of the high cost of the iterative procedures involved and bearing in mind the errors arising from other sources (e.g. trip generation predictions, the distribution and modal split procedures) as well as those involved in the assignment model (e.g. definition of the highway network, the assumed speed flow relationships and the assumption that all trips start and finish in the same interval under consideration) it is usually considered that an exact solution is inappropriate (606).

Most studies in traffic flow have assumed that there is a definite relationship between the volume of traffic which can pass along a given length of road and the speed of movement on the road. They have then set out to determine this speed/flow relationship. However whatever the speed/flow relationship adopted, it is conceptual that the solution obtained from the capacity restrained assignment depends very much on the assumed relationship, provided that other factors like the road conditions do not change. Hence it can be seen that the solution obtained in general depends on the type of inputs. Some of these factors are discusssed below.

6.1. CRITERION USED

The route choice criterion used in the capacity restrained assignments should relate to nature of decision rule and method of estimating value of

chosen criterion. It was mentioned in Chapter 3 that not all travellers in the urban area follow the same route between two points because:

(a) alternative routes are evaluated differently by different persons.

(b) in congested conditions drivers react in such a way that a state of equilibrium is reached.

This means that any route selection criterion chosen which does not incorporate these behavioural characteristics of the road user may produce a solution which is not representative of what happens in practice.

The author feels that a meaningful criterion should be one which enables people to choose routes so as to minimise the cost of travels, whilst allowing drivers on long journeys to attempt to save time rather than distance as reported in reference 308. The cost function, used if it does not reflect the right traffic composition could give a less reliable solution.

6.2. VOLUME OF TRAFFIC TO BE ASSIGNED - DEGREE OF CONGESTION

Experience (601) has shown that the density of flow or degree of congestion must have some affect on the solution obtained. This fact was briefly mentioned in Chapter 4 where Outram was quoted as having said that if some of the loads assigned to the roads exceed the capacities these loads cannot be interpreted as flows because that number of vehicles could not traverse the roads in the time period under consideration. What actually happens then is that queues quickly form and the flows of vehicles exiting from the overloaded routes will approximate to their capacity. Thus some of the flows on the links further from the trip origins could be lower than the assigned loads as some of the vehicles wishing to

use them may be forced to queue on the overloaded roads near the origins and hence will not complete their journeys until after the time period under consideration.

The use of any capacity restrained model of the congested network without an incorporated element to deal with any queues that might develop would give a less reliable solution. Outram (604) has developed a queueing assignment model (604) which regulates the flow of traffic along any road by using restrictions imposed by all the road network) in addition to the speed of the traffic using the road being regulated by the road characteristics.

Another set of models, the Factor Loading Methods discussed in Chapter 4, (particularly the TNET model) try to find a reasonable method of dealing with the congested network by effectivcly removing any link loaded to capacity. Whatever method used to deal with the problem of high traffic volume the solution obtained must reflect what happens in practice.

6.3. DESCRIPTION AND SIZE OF NETWORK

As mentioned in section 5.2.2, human errors in network description could affect the solution obtained. Any wrong data resulting from mis-coding, mis-punching or omission will affect the solution obtained. This is because it is assumed that intrazonal trips take place on the local street network and they are not usually assigned, but larger zones and particularly heavily trafficked zones this omission might have a serious effect on estimates of flows in the vicinity. If the centroid connectors are not properly defined it could affect the way trips from the zone are distributed to other zones. Representation of the intersections and turning

penalities is also very important. The greater the number of intersections the network has the denser the network becomes and the larger the number of turning penalties required to be computed and incorporated. After all not all junctions are equally important. At first sight it might look reasonable to argue for the reduction of network size in order to reduce storage requirements but the fundamental characteristics of the assignment procedure which supposes that all flows take place on the represented links could affect the solution obtained. Drivers who have a good knowledge of the locality may not use the links represented hence if many would-be-used links are omitted from the network the solution obtained may not be representative of what happens in practice.

6.4. SPEED/FLOW RELATIONSHIP

Speed/flow specification is a very important factor which influences the solution obtained in a capacity restrained assignment. The fact that the iterative procedure always makes reference to speed/flow relations when adjusting the link resistances implies that an erroneous specification of the speed/flow relationship would give an entirely unrealistic solution. For example, if the minimum speed at high flows is set too low, it would be equivalent to deleting the link from the network and traffic could be sent through very inferior routes. If set too high, it may prevent traffic from being assigned to reasonable alternative routes. The influence of the speed/flow relationship can be reduced by using multiple routing assignment techniques.

6.5. METHOD OF LOADING OF NETWORK

The loading procedure is important although it is difficult to say whether similar results are obtained using different methods without testing

many networks. Weaver (6013) observes that a total successive loading technique brings about a faster convergence than incremental loading methods. He claims however, from his tests that both partial and total loading techniques produce similar link loadings for all load values. A feature of the partial loading technique like the capre method is that th number of iterations is fixed and the convergence is not directly taken into account; the assignment would be terminated after a fixed number of loading cycles (iterations) irrespective of the state of convergence reached. Partial and total loading methods have been used in the programme developed in this dissertation.

Other methods that could be considered are, the Chicago method (605), which terminates by the loading from the final origin zone rather than from convergence consideration, projected demand method which estimates final loadings from the proportion of loads on the links at the end of the first iteration though this is flowed by flow iteration, and Outram's queueing assignment method (604) with the assertion that the destination of vehicles travelling along a road may be regarded as being effectively independent of the origins of the trip makers. It can be seen from these different methods of terminating the assignment processes used with various loading techniques that the solution obtained depends very much on the techniques used.

6.6. METHOD OF LINK ADJUSTMENT

Outram (604) and others have stated that the link costs or times at the final solution do not depend on the coded values. But it was noted in the Bureau of Public Roads Method (4.7.3) that the link time *adjusting equation*

$$T = T_o \ (1 + 0.15 \ (q/Q)^4)$$

could cause an alternating of the link loads similar to that experienced in simple capacity restrained techniques and that this could be reduced by using a time averaging procedure such as the new time

$$T_1 = T_Q + (T - T_Q)/4$$

(the variables are as defined in section 4.7.3). This then shows that the link time adjusting procedures affect the final solution of the capacity restrained assignment.

In a situation where queues will develop Outram (604) has suggested that the time spent queueing should be added to the link time. But this does not prevent loading the same link beyond queueing point in the next assignment though it does make the link concerned less attractive.

6.7. METHOD OF DETERMINING AN ACCEPTABLE SOLUTION

Ideally we are searching for a solution where for all links values of speed assumed and curves and the travel times on alternative routes used are equal. In practice this would be a lengthy computation, and obviously we do not need this degree of accuracy because of the magnitude of errors arising from other sources. Hence the answer to the question of when an acceptable solution has been obtained can be obtained from considering the magnitude of the change of the traffic volumes on the links, the traffic speed (and hence the time or cost) or a combination of both or various other methods like the changes in user benefits or total link costs. The solution obtained will depend largely on the sensitivity of the criteria used to monitor the changes (mentioned above). These criteria are the basis of the methods most commonly used to indicate the convergence to a solution of the assignment process. Whichever method is

used to assess convergence of the solution it is important that the stability of the solution should also be considered. The rate of convergence to an acceptable solution and the stability of the solution are the principal qualities considered when comparing acceptable solutions.

The Peturbation technique is probably the best approach to determini a stable solution approximating closely to the equilibrium condition in congested networks (606).

6.8. PREVIOUS WORK IN THE FIELD

There is very little published work on the factors influencing the solution of capacity restrained assignment techniques apart from the papers by Outram (604) and Weaver (603). An unpublished MSc thesis by Head (607) and an unpublished report by Thomas (606) also contain relevant material.

Outram (604) by incorporating simple capacity restraint in a minimum routing model made a model run which produced the results illustrated in Fig. 6.8A. The figure shows how the user benefits (relative to the standard) and number of links changing cost by 0.1 cost minutes or more varies. The results indicate that a good measure of instability of a model is either the variation in the user benefits from one iteration to another, or the number of links changing cost. A major cause of the above instability is the alternate selection of parallel routes from one iteration to the next. This creates excessive loadings on one route and very low loadings on parallel routes resulting in very high costs on the former route and very low costs on the latter routes after capacity restrai

One of the methods he used to dampen the above oscillation involved the

averaging the loads and costs from all iterations. The simplest form of cost averaging he adopted set the new link cost equal to the mean of the cost used to obtain the current load and the cost obtained from simple capacity restraint of the current load. The results obtained using this approach are shown in Figure 6.8B. It is noticeable that the variation in user benefits has diminished considerably, and the number of links changing their cost has approximately halved. The observations from the above discussion could lead one to expect the model has converged closer to the supposed equilibrium state, but this type of model which uses integer cost and trip quantities has many quasi-stable equilibrium states. With the use of integer cost units as in the model tested by Outram it is necessary for the cost obtained in simple capacity restraint to be at least two cost units different from the cost used in the assignment if the new cost is to have a different value.

In using incremental loading, in which the load is set to the mean of the previous and current load, Outram obtained similar results (Fig. 6.8C). In this case however, the magnitude of the user benefits are smaller than before because very few links changed their cost. This occurs because in order for the link cost to be able to change at all, the load has to change drastically.

Burrell (604) in his type of Multiple Routing Assignment technique uses link cost C for route selection. C is permitted to vary according to

$$C = \bar{C} + KV\sqrt{\bar{C}}$$

where $\bar{C}$ = the average link cost

V = half the range of the cost variation

K = a random number such that (-1 K 1)

Burrell obtained the value V = 0.91 (when C is in cost minutes) from the

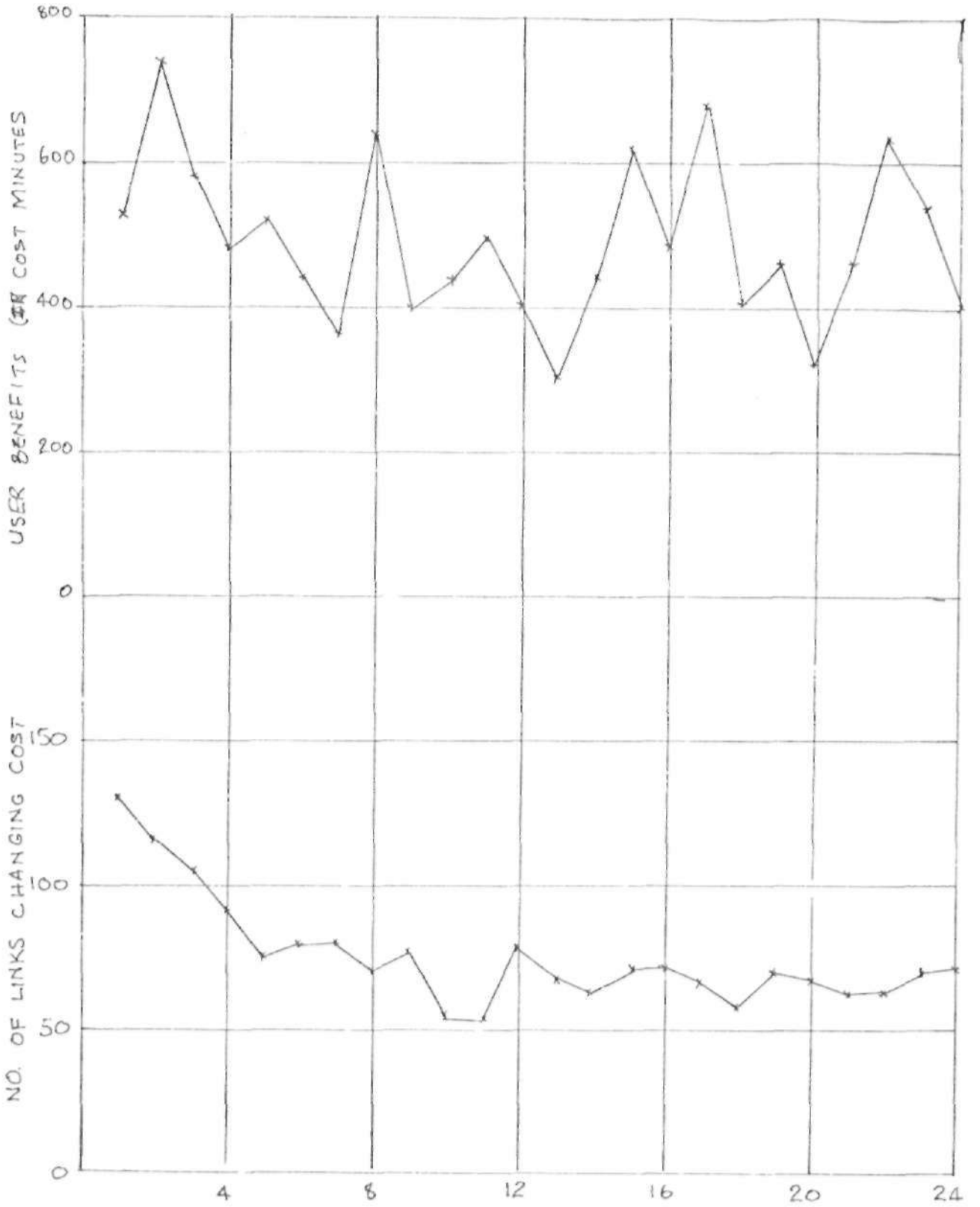


FIG 6.8.A SIMPLE CAPACITY RESTRAINT WITH MINIMUM PATH ROUTING

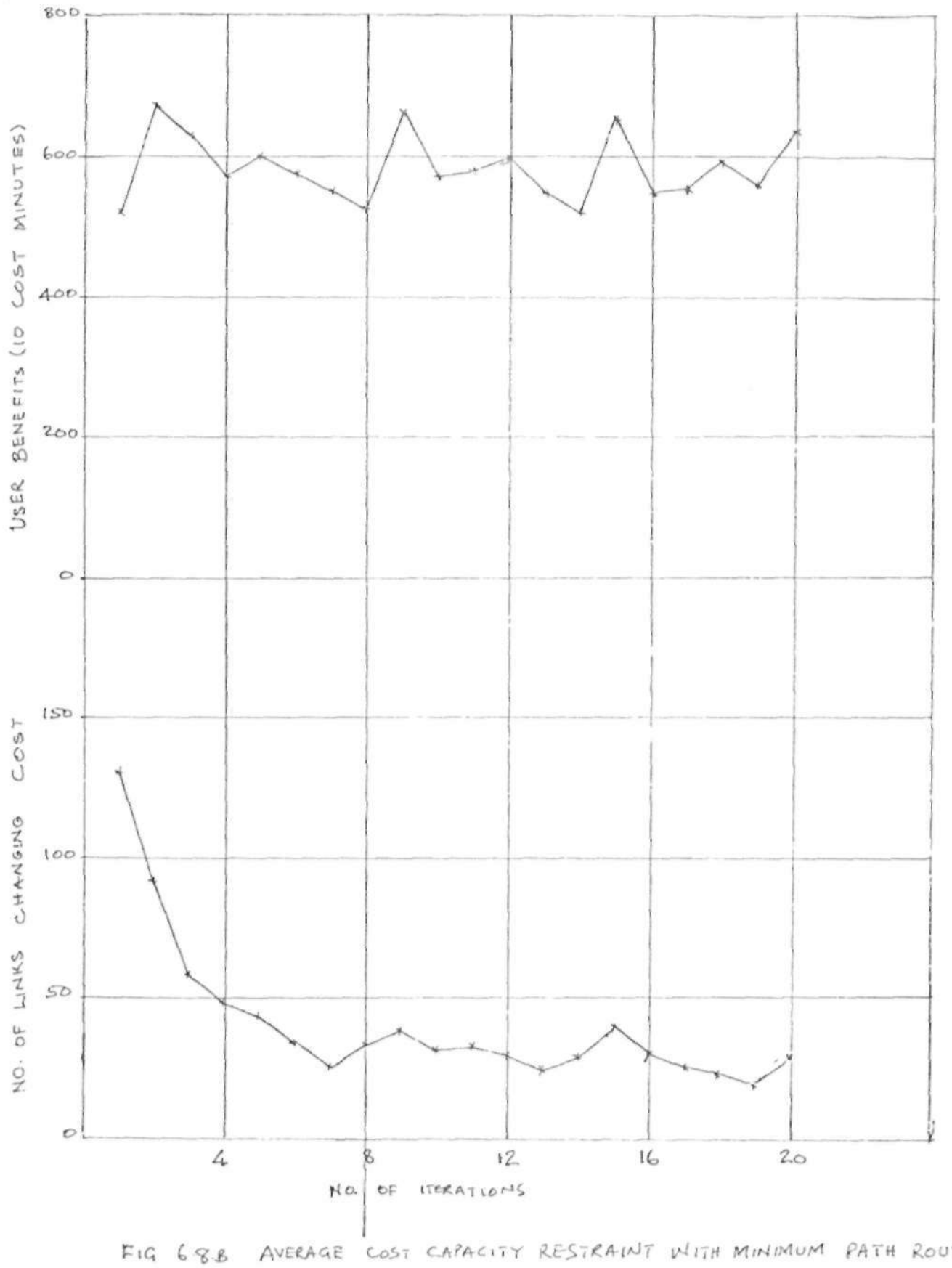


FIG 6.8.B AVERAGE COST CAPACITY RESTRAINT WITH MINIMUM PATH ROUTING

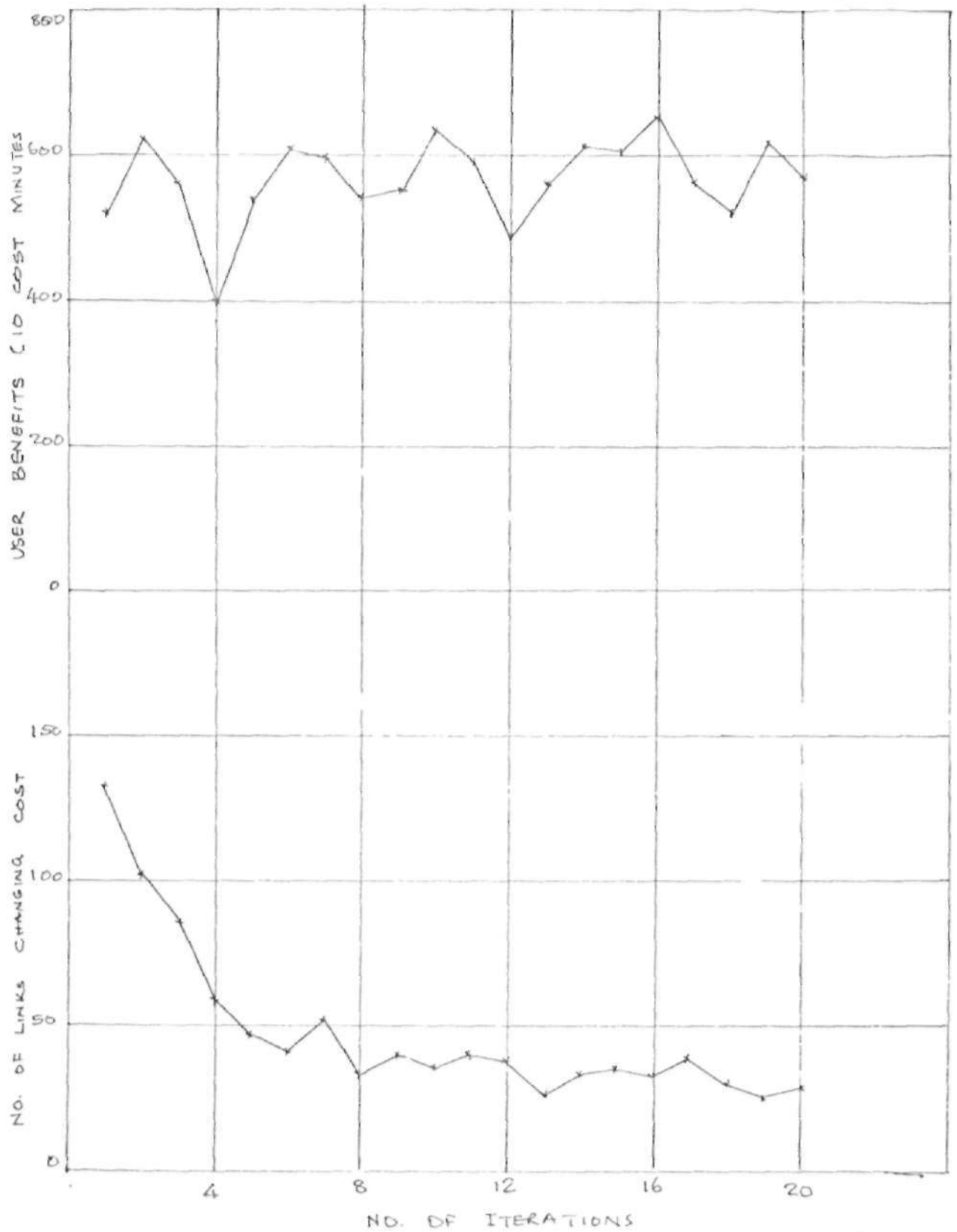


FIG 6.8C SIMPLE CAPACITY RESTRAINT, INCREMENTAL LOADING WITH MINIMUM PATH ROUTING

study he undertook for the DoE in Hull concerning drivers route choice. In using this value with Burrell type multiple routing in a model run Outram found that the instability of the model was improved considerably compared with the minimum routing case, but the average level of user benefits was considerably lower. Several model runs were executed using a range of values of V. The results obtained show that the level of stability of the model improves as the degree of multiple routing increases until a critical level of multiple routing occurrs. At this point, increase in the level of multiple routing so increases the average trip cost that the cost of travel along the minimum cost paths also increase, bringing about a reduction in the level of user benefits. The level of stability of the model as indicated by both the variation in user benefits from one iteration to the next, and the average number of links changing cost during capacity restraint, deteriorates in the process. From the above work Outram concludes that even with multiple routing the rate of convergence of the model used is lower than is desirable and that the large number of iterations necessary to produce a near stable model would be prohibitive on cost grounds.

When Outram ran the Projected Demand model (4.11) in conjunction with Dial type multiple routing (4.6.3.1.) the model was almost stable after four iterations and completely stable after seven iterations.

In order to test whether the rate of convergence of the model he used was dependent upon the original coded state of the network Outram slightly varied the link costs in a random fashion with the link costs as the mean prior to model run. The results he obtained indicate that little difference in rate of convergence or user benefits. The examination of the data lead Outram to say that even using measures of trips of 0.1 of a trip and costs to 0.1 cost minutes is insufficient to produce unique

solutions to his type of model. However, finer measures are unlikely to be used because of computer storage limitations. In the final analysis Outram came to the following conclusions:

1. That there does not exist a unique solution to his type of transportation model which uses integer values of trips and costs;
2. That the residual instability (noise) in a model incorporating minimum path routing is very high. Average costing and incremental loading tending to reduce the model's sensitivity rather than decreasing the noise level.
3. That Burrell's type multiple routing (4.6.2.3.) improves the basic noise level, but the mechanics of the algorithm tend to set up a basic noise level which is dependent upon the level of multiple routing permitted.
4. That projected demand capacity restraint in conjunction with multiple routing permits very rapid rate of convergence of the model.

It should be noted that investigations by Outram are based on the general network details given below:

(a) Generalised cost is stored in units of 0.1 cost mins.

(b) Times are stored in units of 0.1 mins

(c) Distances are stored in units of 0.1 miles

(d) 165 units on user benefit scale represent approximately 1% of total highway travel cost

(e) Maximum number of links able to be adjusted in capacity restraint is 186.

Thomas (606) has shown theoretically that the number of links changing costs by 0.1 cost mins or more is more likely to indicate that convergence has been attained when it has not than is the number of links

changing flow by 0.5 p.c.u./hr. In his (Thomas) work using the curves given in reference 608 he shows that for networks not loaded beyond capacity proportional change in flow is a more sensitive indicator of instability in the convergence process than proportional change in cost except perhaps for link type 5 and 6 (see Fig. 2.2C) at flows near capacity if integer flows are used, or to a lesser extent in time. For networks loaded beyond capacity, proportional changes in cost or time are to proferred unless flows and costs are measured in integer values of 1 p.c.u./h and 0.1 cost mins respectively in which case proportional change in flow is a more sensitive measure. The best measure he found in his work is the user benefit or the 'total link cost'. He shows that if costs are determined using the assigned link flows and corresponding speeds derived from speed/flow curves then the change in 'total link cost' is a more sensitive measure than any discussed above. If integer costs and flows are used this statement is modified to the extent that it is at least as sensitive as any of the other measures.

In his conclusion Thomas suggests that the variation in the number of links changing 'total link cost' by more than a fixed amount or by more than a fixed proportion if non integer flows and costs are used, is probably the most sensitive measure of the convergence of the iterative process to a network equilibrium solution. If this measure is used then all the information will be available for evaluation of such quantities as the change in user benefit or the change in average link cost in successive iterations, the total cost of all trips made, etc. If integer flows and costs are used the relative insensitivity to changes in cost near the equilibrium condition implies that the proportional change in 'total link cost' is effectively the same as proportional change in link flow in which case, since it involves less calculation, this latter measure may be preferable.

Head in his thesis states that the results of his tests demonstrate quite conclusively that an iterative all-or-nothing assignment is a waste of time. That fair results in terms of equilibrium user time are achieved in an initial all-or-nothing assignment but little progress is made subsequently. He claims that after the initial all-or-nothing assignment, the flow iteration model produces gradually decreasing equilibrium user times up to the fifth iteration. Effectively the net decrease between the third and fifth iterations is small and in the network used convergence seems tc have been reached in the third iteration.

On the use of the CAPRE approach before iterative all-or-nothing and flow iteration assignments he states that the former failed to produce a satisfactory convergent situation while in the latter there was not significant improvement over the results of flow iteration used alone after three iterations. Using Burrell's technique (sect. 4.6.2.3) randomisation of the link resistance he obtained a remarkably dampened iterative all-or-nothing assignment.

In his comparison of the end results of runs using time and costs as alternative route selection criteria for the same assignment, Head found that the results were similar. Further inspection shows a major decrease in time spent in the system when route selection dependent on cost. The simple unweighted cost averaging function appeared to stablise iterative all-or-nothing assignment.

Weaver (603) is another researcher who has shown that the form of the speed/flow relationship used influences the rate of convergence whichever loading technique is under review, though he also claims that the techniques are all affected in a similar way, so that comparisons using the same speed/flow relationships are valid over a range of such relationships.

7 FACTORS TO BE INVESTIGATED IN THE PROGRAM AND THE METHODS USED

Apart from a discussion of traffic assignment techniques the other main aim of this dissertation is to write and develop a computer program to investigate the effects of some of the factors influencing the solutions furnished by capacity restrained techniques. No attempt is made to investigate these effects in the dissertation, the aim is to produce a tool that will facilitate the investigation of the influence of such factors as

1) the speed/flow relationship
2) the loading method e.g. total loading procedure, incremental loading procedure and their combination
3) the use of time or cost
4) effect of varying densities of loading
5) the use of integer and real loads and times or costs; (through the present program uses real load and time or cost, it can be readily amended to use integer load and time or cost)
6) the use of weighted (or unweighted) averages of time and cost which can easily be incorporated since the necessary information has been stored on the magnetic for successive iterations in connection with the convergence indicators
7) the convergence indicators. Whilst the above factors are being investigated the program at the same time examines the behaviour of the measures (convergence indicators) used to indicate that a solution has been arrived at. More indicators can be included at the

cost of increased storage requirements which may become so large as to prohibit the use of all but the smallest of networks. The various factors which can be investigated by the program are discussed in detail in the remainder of this chapter.

7.1 NETWORK VARIATION

Naturally any assignment program permits the use of different highway networks though the same method of network definition is used for all networks. For the purpose of this study a test network is coded in a modified version of the format described in the TNET suite (701) of programs adapted for input to theKDF9 computer. The coded network is stored on a magnetic tape, using subroutine NET06, for ease of access by other subroutines in the iterative procedures. The test network used comprises of five centroids, fifteen nodes and thirty-eight one-way links. Since there was no time to vary the network, all testings have been carried out on this network.

7.2 NETWORK DESIGNATION

The network is loaded using one-way links between pairs of nodes or centroids; a sketch plan of the test network is shown in Fig. 7.2.

Nodes are numbered consecutively, the centroids being numbered first and then the intersection nodes numbered successively with no number omitted. The link lengths for the test network are

THE TEST NETWORK

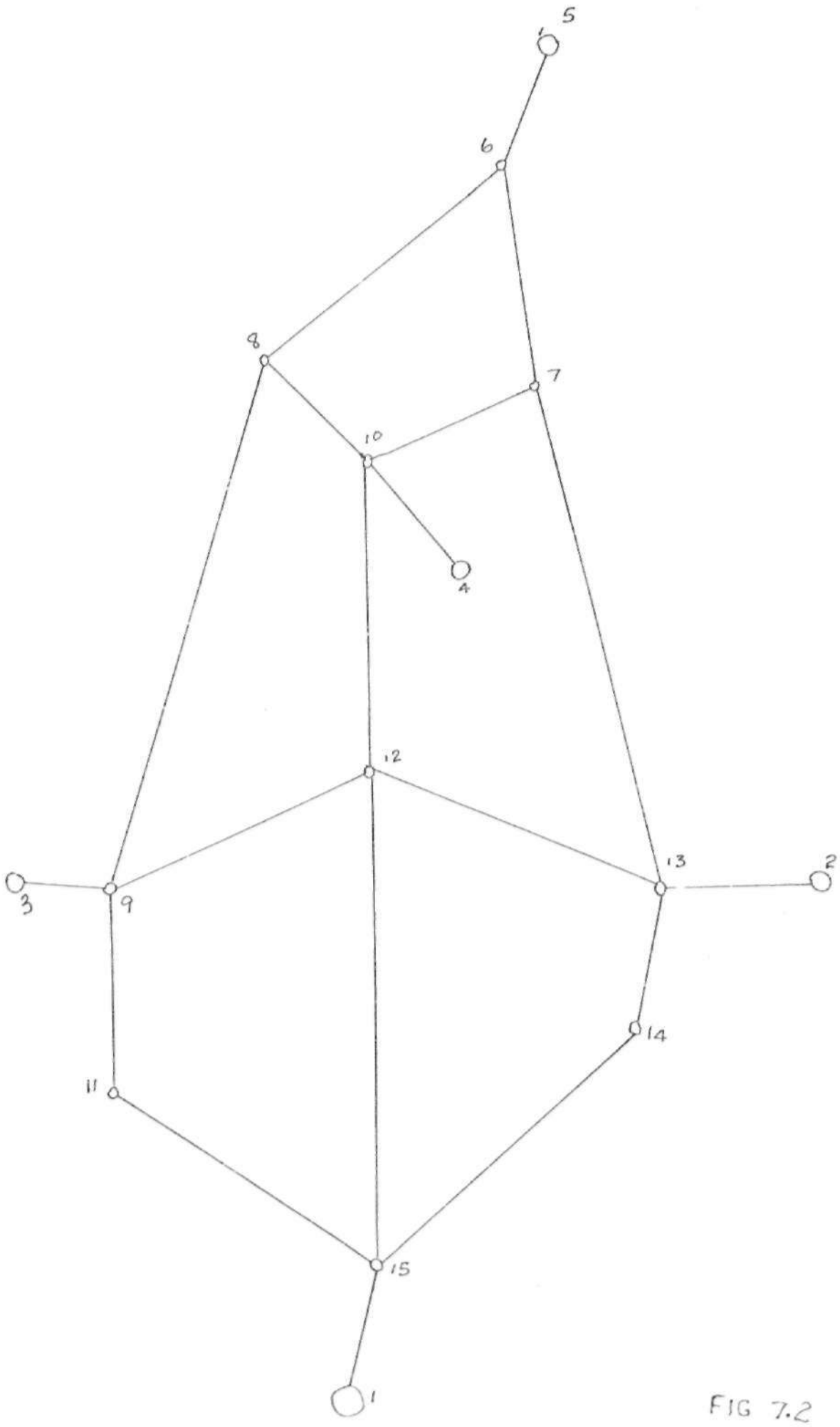


FIG 7.2

arbitrarily specified and the speed/flow index numbers allocated to the links so as to include all possible values. The road widths (and hence link widths) are also allocated arbitrarily. For each link the following items are input:- Origin node, final node, speed/flow curve index number, road with, any two of link length and initial speed and time, capacity, capacity class and the speed/flow characteristics corresponding to the speed/flow curve index number. These characteristics are the free flow speed and limit capacity, the link capacity flow and speed at capacity. The link flows and speeds in each iteration are compared with the above characteristics so that the appropriate sections of the speed/flow relationship could be used. The curve index number is used in SUBROUTINES MALTIM AND SERTIM in selecting the appropriate constants used in the MALTS and SELNEC speed/flow relationships. The road width coded is used in the MALTS time adjustment equation and of course the origin node, destination node and the distance coded define the physical network.

7.3 THE SPEED/FLOW RELATIONSHIPS INCLUDED

In any capacity restrained model updated link speeds to take account of the latest estimates of link flows are required at each stage of the assignment process. Clearly the speed assumed to be appropriate to a particular flow will depend on the form of the speed/flow relationship assumed.

Three speed/flow curves have been incorporated in the program. In this way the effect of different speed/flow relationships may be

investigated. The three speed/flow relationships are those taken from the

SELNEC model (2.2.5)

MARTS model (2.2.6) and

TNET model (4.8.3)

It is not necessary in the speed/flow specification to make the link type index numbers in the MALTS the same as those in SELNEC as steps are taken in the program to make sure that no confusion arises. The difference in index numbers can be observed in table 2.E and 2.F. Because these speed/flow relationships have been discussed at length in chapter two above only a brief discussion of the speed/flow relationships included in the program used is given in the sections below. It must be noted that the SELNEC speed/flow curve is similar to that recommended by the DoE (708) in the relationship between speed and flow assumed at flows greater than capacity. However in advice note 1a the speed is assumed constant up to a limiting free flow and then decreases at a constant rate to a lower speed at limiting capacity. Beyond limiting capacity speed is assumed to decrease at a slower rate as given in section 2.2.4 But in SELNEC speed/flow relationship the part of the curve up to the limiting capacity is represented by a parabolic equation as given in section 7.3.1 below. Beyond the limiting capacity the SELNEC curve takes account of the time spent queueing. In the TNET model reference is made to the coded link times when adjusting the travel times on the links. This implies a dependence of the final results on the link times assumed initially. The relationships used are given in section 7.3.3. The model effectively removes the link when the capacity or a specified critical capacity is reached

by adding to the link time a large penalty of 500 cost minutes. The MALTS speed/flow curve is also similar to the advice note 1a except that it does not have a separate relationship for adjusting flows beyond the limiting capacity. The relationship used in adjusting link times is given in section 7.3.2 below.

7.3.1 THE SELNEC SPEED/FLOW RELATIONSHIP

In the SELNEC speed/flow relationship (708) the part of the curve up to the optimum is represented by the relationship

$$S^2 = S(a_1 w + a_a L + a_3) - bF$$

where s = link speed

F = link flow

l = length of the road

a_1, a_2, a_3, and b are constants whose values are shown in table 2.F.

The curve does not exibit a free flow limit as in the advice note 1a (708). The speed falls from the maximum Sm at zero flow to $^{sm}/2$ at optimum flow F_m

Beyond the optimum flow, a waiting time penalty is added to the time spent queueing on the link. The waiting time t_w is represented by

$$t_w = to\ (F - F_m)$$

where F is the assigned flow, t_o is a waiting time factor and F_m is the optimum flow. The shape of the curve is shown in Fig. 2.2.D. The value for the factor t_o is chosen in such a way that too large a penalty is not added at capacity. It can vary from network to another depending on the degree of congestion. In the program t_w is thought of as being given by the expression

$t_w = t_o F_m (\frac{F}{F_m} - 1)$ so that the value chosen for use in the program is 2.5 represent the value for $t_o F_m$. This means that t_o is a constant only for a particular link.

7.3.2 THE MALTS SPEED/FLOW RELATIONSHIP

The MALTS speed/flow curves can be approximately represented by the equation

$$t = \alpha(V - \delta) + \sqrt{\alpha^2 (V - \gamma)^2 + \beta} + \varepsilon$$

where t = travel time in mins/mile

v = volume in pcu/ft width/hr

$\alpha, \beta, \gamma, \delta$ = constants

The values of α, β, γ and δ are given in table 2.C. It can be seen from the relationship that when $V = \delta$ the time $t = \delta + \sqrt{B}$ or 4.5 mins/mile see table 2.C. This speed/flow relationship does not give the values of the free flow limits and capacities of the road types (not in detail where given). The link free flow limits and capacities used are those obtained from the advice note 1a. The link type capacities obtained from the above source are expressed as capacities per unit foot width of the road in the direction of movement. It is considered that since all transportation work has to comply with the DoE recommendations, the capacities and free flow limits assumed when using MALTS speed/flow relationships should not be far from those assumed in the work.

7.3.3 THE TNET SPEED/FLOW RELATIONSHIP

The functions relating to travel time on arterial links in

TNET (701) speed/flow relationship used in this work take account of intersections explicitly. The possible ways the other speed/flow relationships mentioned could take account of intersection are discussed in section ( ) below. The functions used are

1) for Intersection Delay

$$T_a = T_o + \frac{V/C}{10(1 - V/CQ)}$$

where T_a = adjusted travel time on link

T_o = original travel time on link ('normal free flow conditions')

V = volume on the link

C = the capacity of the link

Q = the multiple of capacity at which travel time becomes infinite

2) For link Delay

$$Ta = To\ (0.5 + 0.25/(1 - V/CQ))$$

where the symbols are as above

The value of Q used in this study is 1.10. This speed/flow relationship is basically the same as the Bureau of Public Roads speed/flow relationship with an in-built bias toward the coded travel time on the link. This dependence on the original travel time could be an important failing on the relationships as an improperly (incorrectly) coded links times could produce an unreliable assignment. It is considered that the separation of the time adjustment equations into link delay and intersection delay does not affect the convergence process and if it does, the effect can be investigated.

7.3.4 COMPARISONS AND CONTRASTS OF SPEED/FLOW RELATIONSIPS INCLUDED

It has been mentioned above that TNET modeltakes account of

intersection by having different function relating travel time on links depending on whether the links experience intersection delay or link delay. There are three possible ways the other speed/flow relationships used (SELNEC and MALTS) can deal with the problem of intersections. One approach is to augument the network by representing each intersection by a sub-network in which a travel time is alotted to each turning movement. The second approach is to index each link with a sign and add a penalty (say 30 secs) to the route everytime a sign changes. The third approach concerns intersections where long delays are experience; in this case the long delay can be represented by insertion of additional links.

Whereas the TNET model has a bias toward the original travel time T_o, the other speed/flow relationships as used in this program have no such time weighting. Depending on the conditions on the network concerned this could be included in the program as an improvement. For example

New time = ½ (last time + time corresponding to corrent loading)

The TNET model effectively removes the link loaded to capacity by adding to the link time a large penalty. The SELNEC model on the other hand adds on to the link time a penalty for flows greater than capacity. The MALTS relationship has been developed for a non-congested network so that there is no explicit expression for dealing with flows greater than the capacity.

7.4 VARIATIONS OF THE LOADING TECHNIQUE

Various methods of loading traffic onto the network and applying a specified speed/flow relationships to the traffic so loaded have been

developed as described in Chapter 4. Although, ideally each of these methods assigns traffic on the principle of equal travel cost or time on alternative routes or minimum paths, this aim is seldom achieved due to the nature of the convergence process involved and the impractability as well as undesirability of exceedingly precise solutions.

The loading techniques most widely used in practice are partial loading (e.g. TNET model (701) and CAPRE (703)) and flow iteration (704). These three loading techniques are included in the program.

CAPRE fixes before hand the number of loading cycles, the proportion of the total distribution to be loaded at each state and to be unloaded after the new costs have been determined.

In any one loading increment, the TNET model adds to the load already assigned the maximum proportion of the as yet unassigned distribution which can be added without thereby loading any link beyond its capacity. The resultant flows are used to estimate new travel times on the links not loaded to capacity. Links loaded to capacity or specified critical capacity are effectively removed from the network by the addition of a travel time penalty.

The flow iteration method loads the total distribution matrix on to the network at each iteration. Following each loading, link times are adjusted, new minimum paths determined, and the loads on the links when the total distribution is loaded on to these paths estimated; the assigned flows are then estimated by the average of the flows obtained when the total distribution is loaded onto each of

the minimum paths determined to data. It is possible to use a weighted average rather than a straight forward average mentioned above.

It is intended that the program be used to investigate

a) the differences between the total and partial methods of loading traffic onto the network as regards the number of iterations to produce an acceptable solution.

b) The effect of using both methods of loading; that is, moving from the partial loading method to the total loading method.

In (b) above it is necessary to label each type of loading (say 1 for TNET, 2 for CAPRE and 3 for the FLOW-ITERATION so that at the end of the partial loading method, the label is changed to 3. The label 3 therefore enables the FLOW ITERATION method to be used. It is hoped in this way to obtain a faster rate of convergence.

The link loads at the end of the partial loading method are stored as LLAST (I) and compared with the link loads in subsequent iterations using the GLOW ITERATION method. The comparison which is output as AUSUMM is calculated thus

$$\text{AUSUMM} = \sum_{i=1}^{N_{LINK}} \left| \frac{(XP(I) - LLAST(I)) \;/\; LLAST(I)}{NLINK} \right|$$

where AVSUMM is the average over the network of the absolute difference between the loading at the end of the partial loading method and the current load from th FLOW ITERATION method expressed as a proportion of the former, XP(I) is the current load from FLOW ITERATION method, LLAST(I) is the load at the end of the partial loading method and NLINK the number of the network links.

7.5 USE OF TIME AND COST

One of the two behavioural assumptions in traffic assignment concerns the criterion used in determining the route of an individual driver. In the UK at present time, cost has replaced time as the basis for assignment. Time is included in the expression for cost as seen from the SELNEC generalised cost model (709). The model makes allowances for different modes and expresses the cost at C_{ij}^{k} given by

$$C_{ij}^{K} = A_i t_{ij}^{k} + A_2 E_{ij}^{k} + A_3^{k} d_{ij} + P_{ij}^{k} + \delta^{k}$$

where k is the mode of travel between i and j t_{ij}^{k} is the time taken to make the trip

E_{ij}^{k} is the excess term on the trip from i to j by node k d_{ij} is the distance travelled to make the trip P_j^{k} is the terminal cost at j (e.g. parking) δ^{k} is the model handicap (or penalty) A_1, A_2 are constants assumed to be proportional to income and A_3^{k} is the cost per kilometer by mode K. The cost as seen from above is dependent of the effects of time and distance primarily but not dependent explicitly on speed. Historically time has been used as the route selection criterion although nowadays in UK generalised cost is the criterion in common use. It is therefore considered worthwhile investigating the differences arising from the use of cost and time criteria. In the programs developed facilities are incorporated to compute link resistance in terms of generalised cost or time. The cost function used can be expressed as follows

$$\text{Link Resistance} = C_d * \text{DIST} + C_t * \text{ULINK}$$

where DIST = thelink length

ULINK = the link time

and the constants C_d and C_t are costs per kilometer and value of time

per minute respectively. Values of C_d and C_t used are 3.5 and 2.0 pence respectively, but these can be varied at will. The coefficients used are taken from reference 702 which, on the basis of operating costs surveyed in 1970 derived the appropriate values in the manner described in the next section.

7.5.1 DERIVATION OF THE COST PARAMETERS C_d and C_t

Dawson (308) gave equations for the net operating cost and gross cost of travel in 1970 in the form

$$A + B/V^2 + C.\ V_c^2 \text{ pence per km}$$

Both this relationship and that in 7.5 above may include allowances for the cost of travel to the community and to the individual user.

If an average composition of traffic is assumed, then knowing the cost of vehicle occupants time in each type of vehicle, the average cost of vehicle occupants time in an average vehicle may be found.

COST OF VEHICLE OCCUPANTS' TIME

Type of vehicle	% age of vehicle type (1)	Cost of occupants' time by vehicle type (pence/hour) (2)	(1) * (2)
Car	80	56	44.80
Van	9	75	6.75
HGV	9	70	6.30
PSV	2	575	11.50
	100		69.35

Table 7.5.A

Gross and net operating (the latter free from allowances for taxation) may be expressed as follows

$$\text{Net operating Cost/Km} = 1.13 + 76/Vc + 0.000021\ Vc^2$$

$$\text{Gross operating cost/Km} = 1.49 + 85/Vc + 0.00041\ Vc^2$$

Using these cost formulae the gross and net cost of travel for an average vehicle and its occupants along urban road links of length 1Km can be found.

URBAN ROAD TYPE	SPEED (KPH)	TIME ON LINK (MIN)	COST OF TIME (pence)	NET COST (pence)		GROSS COST	
				OPERATING	TOTAL	OPERATING	TOTAL
1	80	0.75	0.87	2.21	3.08	5.17	6.04
	66	0.91	1.05	2.37	3.42	5.57	6.62
2	65	0.92	1.06	2.39	3.45	5.52	6.58
	56	1.07	1.24	2.55	3.79	4.30	5.54
3	50	1.20	1.39	2.70	4.09	4.22	5.61
	30	2.00	2.31	3.68	5.99	4.69	7.00
4	45	1.33	1.54	2.85	4.39	4.21	7.75
	25	2.40	2.78	4.18	6.96	5.15	7.93
5	35	1.71	1.98	3.33	5.31	4.42	6.40
	25	2.40	2.78	4.18	6.96	5.15	7.93
6	25	2.40	2.78	4.18	6.96	5.15	7.93
	15	4.00	4.62	6.18	10.80	7.26	11.88

Table 7.5B

COST OF TRAVEL FOR AVERAGE VEHICLE AND ITS OCCUPANTS

It is likely that the average speed of travel in the network will be around 30 km per hr. The net operating cost, which is assumed simular to the perceived cost of route selection is then about 5.5 pence per Km. Of this 2 pence is attributed to vehicle occupants time and 3.5 to the operating cost of the vehicle. Hence the constants C_d and C_t.

7.6 USE OF INTEGER AND REAR LOAD AND TIME OR COST

Outram (706) has stated that the use of integer loads and times or cost in models produce many quasi-stable equilibrium states. The use of integer cost for example, in a program using the averages or costs used in building trees and costs resulting from latest network loading, necessitates that the difference between the two should be at least two units for any change in cost to be indicated.

In the program developed real values have been used but they can readily be adapted to use integer values. This can be done for the time or cost values by including statements

ITLINK (I) = ULINK (I)

where IULINK(I) is the integer value of the link time or cost ULINK (I) on link i. The appropriate places where this statement can be incorporated in the program have been indicated in the listings of the subroutines (in appendix) using single asterisks (*). For the loads NLOAD(I) can be used instead of XP(I) where NLOAD(I) is the integer value of the real load XP(I) on link i. Where this could be incorporated in the program are indicated with double asterisks (**) in the listings of the subroutine (in the appendix).

7.7 USE OF AVERAGES OF TIME OR COST

It has been stated in section 4.7.2 that this method is a mathematical manipulation with no sound reasoning behind it. It has also been pointed out that the use of averages of time or cost can improve convergence at the expense of unstable solution especially if integer costs or times are used. Many methods e.g. Bureau of Public Roads use time or cost averages.

In the program developed all necessary information in connection with convergence indicators is stored on the magnetic tape. Hence, though the program does not use cost or time averages, it can be easily adapted to use weighted (or unweighted) averages of time or cost. For example the new link cost TULINK (I) can be expressed as

TULINK(I) = 0.5 * (ULINK (I) + TLAST (I))

where TULINK (I) is an unweighted average of ULINK(I) the cost on link i at current iteration and TLAST (I) the cost on link i at the previous iteration. The appropriate places on the program where this can be incorporated have been indicated by three asterisks (***) in the listings of the subroutines in the appendix.

7.8 INVESTIGATION OF THE CONVERGENCE PROCESS

As stated in chapter 5, there are many methods proposed to indicate when a traffic assignment process should stop. Whatever methods or indicators are used to determine when an acceptable solution has been achieved, the sensitivity of these indicators is another factor which influences the rate of convergence and the solution deemed acceptable. An insensitive convergence indicator may produce a solution highly dependent on the initial link costs; it may fail to

detect small but significant changes in link flows. The following methods of assessing convergence can be investigated with this program.

1) Number of links changing 'total link cost' (i.e. the product of cost on the link and the flow on it) by more than (1.1) a fixed amount, (1.2) a fixed proportion

with cost a) corresponding to assigned load

b) used to build trees

2) Number of links changing flow by more than a fixed proportion

3) Number of links changing cost or time by more than a fixed proportion

4) The Error $\frac{1}{N}\sum_{i=1}^{N}$ $\frac{\text{assigned flow - flow on the link in accordance with cost used to build trees}}{\text{flow on the link in accordance with cost used to build trees}}$

where N is the number of links in the network.

In order to carry out the above investigation, a number of items are stored on the magnetic tape. These are

a) Link costs used to build trees

b) Corresponding flows from speed/flow relationship

c) Total link cost a) X b)

New trees are then built and load assigned

d) Link flows are estimated which will later be stored

e) Estimates of the total link cost using a) and d) i.e. a) X d) and this is also stored

f) Link costs corresponding to flows in d) which are later stored

g) Total link cost estimated using d) and f) and this is stored so that it is read out later in the program as

step c) above without having to go through a) and b)

From the conclusions drawn up by Thomas (710) in his report based on the use of the speed/flow relationships presented in DoE advice note 1a, is expected that if integer flows and costs are used, the relative insensitivity of changes in cost near the equilibrium condition will indicate that the proportional change in 'total link cost' is effectively the same as the proportional change in link flow. If link costs are defined to be the costs determined using the assigned link flows and corresponding speeds derived from the speed/flow curves then the change in 'total link costs' is a more sensitive measure than the others to be tested, provided that integer costs and flows arcnot used.

In the first method of assessing convergence mentioned above, costs used are those

a) corresponding to assigned load,

b) used to build trees. The two have been used in order to compare their sensitivites. In fact it is held by Thomas (710) that if (b) above is used, then because flows which are too high will tend to be associated with costs that are too low the variation of the measure and hence its sensitivity will not be as great as that of the indicator proposed. Basically the indicator proposed (in 1) above) assumes that whichever trees are built the actual link costs are in accordance with the link flows in which case high flows will produce correspondingly high costs. It is appreciated that the costs produced may well result in the former cheapest routes no longer remaining so, though of course if equilibrium has been attained the costs should not

change in the final assignment. In the case of the indicators for links changing flows by a fixed proportion or changing cost or time by a fixed proportion, Thomas has said that for networks not loaded beyond capacity proportional change in flow is a more sensitive indicator of instability in the convergence process than change in cost except perhaps for link types 5 and 6 (707) at flows near capacity if integer flows are used. For networks loaded beyond capacity, proportional changes in costs or time are better indicators unless flows and costs are measured in integer values of 1 pcu/hr and 0.1 cost mins respectively in which case proportional changes in flows are more sensitive measures.

The 'Error' used as a convergence indicator can be taken to be the same as proportional change in link flow in successive iteration if the speeds used following each assignment are read directly from the speed/flow curves. The validity of these claims when different speed/flow relationships are used can be investigated at the same time as the detailed comparison of the functioning of the convergence indicators is examined.

The convergence process is also investigated by setting up a frequency table to record for each iteration the number of links for which the calculated values of DEL (see below) are less than or equal to 0.05, 0.1, 0.3, 0.5 and 1.0 and for DEL greater than 1.0. DEL values are obtained using the flows on the link and then using the link costs. The frequency tables are set up separately. DEL values are obtained as follows

DEL = ABS (XP (I)) - LLOAD (I) / LLOAD (I)

and

DEL = ABS (ULINK(I)) - TLAST (I) / TLAST (I)

where DEL is the absolute difference between the link load (or cost) in the last iteration and that in the current iteration expressed as a proportion of the former.

XP (I) = load on link i in the current iteration

LLOAD (I) = load on link i in the last iteration

ULINK (I) = cost on link i in the present iteration

TLAST (I) = cost on link i in the last iteration

Given a common degree of congestion and other prevailing conditions on the network the program facilitates a comparison of methods of assessing convergence in order that the method deemed most appropriate may be determined. Limitations as to the number of methods that can be investigated are seen clearly to be the requirements to store link time or costs, loadings and other link information for a large number of iterations.

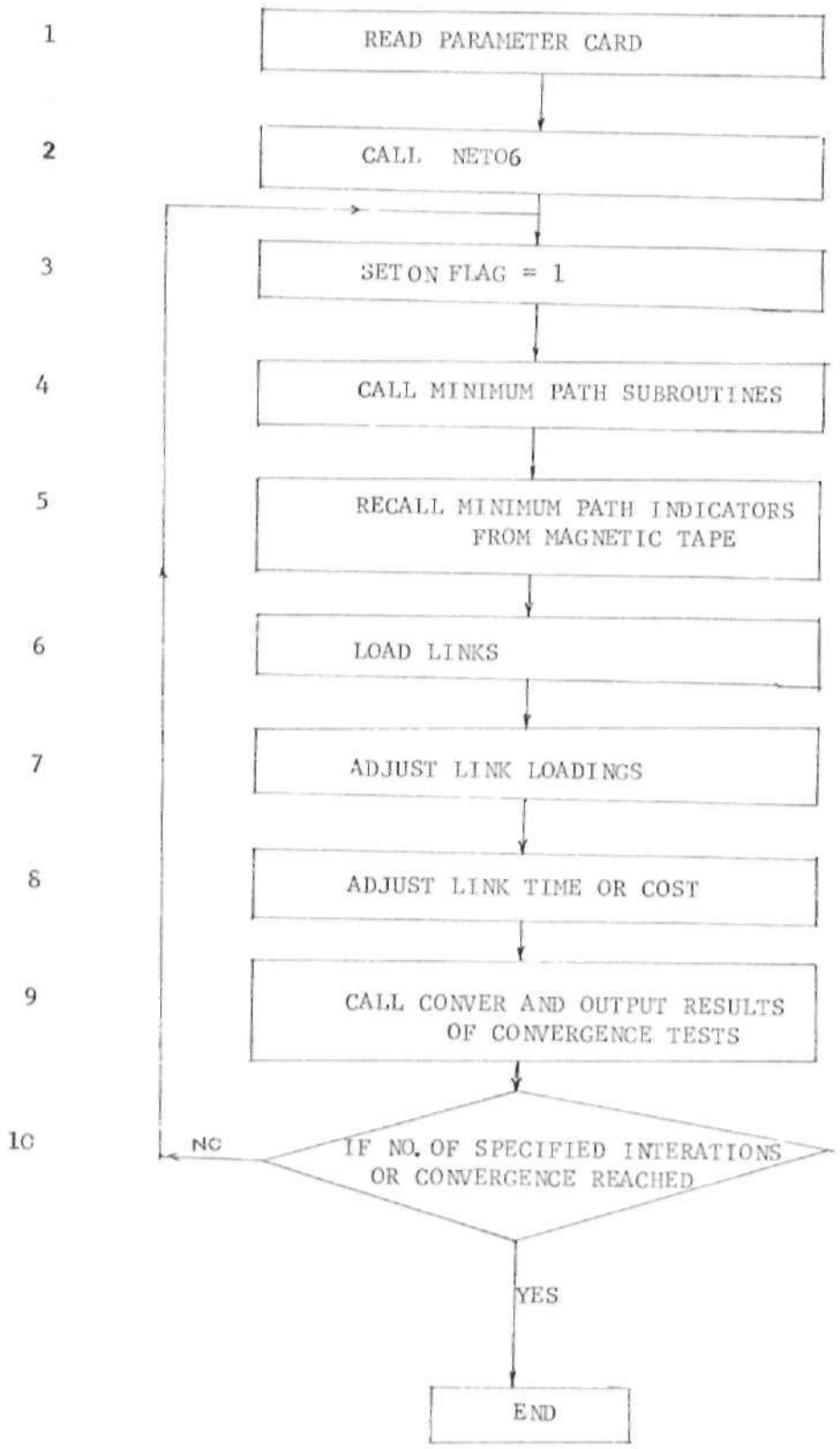
THE COMPUTER PROGRAM

This forms the kernel of the second aspect of the dissertation.

The programs are written in Egtran the local dialect of Fortran and run on the KDF9 computer at the University of Salford programs. All data are input on standard 80 column punch cards. Certain common arrays stored on magnetic tapes and called by the main programs or the subroutines are required. Three main programs which are very similar, differing only in the load and time adjusting subroutines have been written. The common subroutines are NET06 NETIOI, NETIC2 NETI03, NET20I, NET202 (I, J) FLOITR and CONVER. The three main programs are FLOWNET, CAPRE and FLOWSEL. The general flowchart is given below.

The nomenclature used in the program variables is given to aid the reader in understanding the listings of the subroutines given in the appendix.

GENERAL FLOWCHART FOR PROGRAMS



8.1 NOMENCLATURE OF PROGRAM VARIABLES

(variables common to two or more subroutines are underlined)

SUBROUTINE NET06

NLINK - The total number of links in the network

ND(I) - The destination node of link (I). It varies from 1 to NLINK

ND(I) - The origin node number for any link

DIST - The length (in miles) of any link

FFS - The free flow speed on link I (mph)

SPD - Initially coded speed on link I (mps)

FFL - The free flow capacity on link I pcu/hr/lane

CAP - The limiting capacity on link I

VC - Speed at limiting capacity

USPD - The speed at which a link may be traversed assuming speed/flow characteristics to be obeyed

TLINK(I) - The time taken to traverse link (I) at free flow condition (i.e. the coded time)

J - An indicator for which of the missing link characteristics (time, length or speed) is to be calculated

JJ - No of the items (speed, length or time for each link) present. Two items must be present otherwise 'DATA MISSING OR WRONG' message is printed out.

KAPCL - The capacity of link (I)

NCURV - The speed/flow curve index number associated with link number I.

ERROR - Originally set equal to zero but set to 1 where one or more links have JJ values of 1

WL - The width of the road

SUBROUTINES NET101, NET102 AND NET103

NHOME - Initially the number of the first zone centroid in the network, subsequently it becomes the origin of the minimum path seeking process.

NSTOP - The node number corresponding to the final centroid

NNODE - The total number of links in the network

NCENT - The total number of zone centroids in the network

LI - An index of originating node

NSKIP(I) - An array of zone centroid numbers which are to be excluded from the minimum path process, all elements have values between NHOME and NSTOP

KAPCL - See subroutine NET06

K1(I) - An index used in the minimum path algorithm of the links emanating from zone centroids. For zone I, K1 (I) is the number of the 1st link from the zone.

TSUM(I) - The sum of link resistance to node I

TLINK(I) - See subroutine NET06

TCUM(I) - Time to reach the final node of the link on the path from the origin node passing through the link's initial node

NCUM(I) - The link number

NTREE - A counter of nodes investigated in thepath seeking process

NN(I) - The origin node on a link for which the destination is I

TMIN - When links from any node are being studied TMIN takes the value of TSUM (NODE) + TLINK (LINK)

L2 - The upper limit derived from K1(I) values of link number

for investigation from any node

K - The destination node number of the link from any node

TREE(I) - A node number on the minimum path. The may be up to 70 elements in the array.

NM - Initially equals NHOME but then equals the number of the highest zone plus one

NI - A record of the node reached inprevious passes of the algorithm. but not yet used while NI holds the value I, links from I are investigated

SUBROUTINES NET301 and NET302 (I,J)

TR(J) - The number of trips attracted to zone IJ from a single origin zone I, derived from the relative attractions of all destination zones J

VOL(I) - Expected load on link (I) if all the distributions were loaded on to thenetwork (i.e. load 100% loading)

SUBROUTINE FLOITR

VCUM(I) -Actual load on link (7) except in SUBROUTINE CAPRE

XP(I) - This the same as VCUM(I) except in SUBROUTINE CAPRE

SUBROUTINE NET401

XMAX - Proportion of trips that can be loaded in the corrent interation

LCRIT - The critical link

A - Percentage of trips loaded in previous iteration (= 0 in 1st iteration)

Q - Multiple of volume capacity ratio at which travel time is infinite

QQ - Percentage of Q which defines almost critical links

X - Proportion of trips that each link can take in the current iteration. Zmax is assumes the value of the minimum x

I LOAD - Load adjusting method indicator

SUBROUTINE CAPRE

P(ITER) - Percentage of total distribution to be loaded at the current iteration

S(ITER) - Percentage of total distribution to be removed from load on the link at the current iteration

PP - An algebraic sum of P(ITER) and S(ITER) where P(ITER) is positive and S(ITER) negative in sign

SUBROUTINE TNETIM

JWIST- Determines the type of links the program output relates

NUM - Sequential number (starts from 1 and ends at NLINK)

SUBROUTINE MALTIM

M-Link type indicator set equal to NCURV

NCURV - see subroutine NET06

ALPHA - A constant in MALTS speed/flow relationship

BETA - " " " " " "

GAMMA - " " " " " "

DELTA - " " " " " "

ICOST - An indicator for the type of resistance to use for example ICOST = 1 implies the use of cost as measure of resistance

IC2 - A parameter which can take values up to 3 to enable LIAST to be stored on themagnetic take when changing from partial to total loading technique.

T - Time in minutes/mile of the link

SUBROUTINE SELTIM

A1, A2 The constants used in the SELNEC speed/flow relationship.

A3, A4 -

C, BD, B - These are equal to terms in the general expression for the solution of quadratic equation. They are used to solve the quadratic equation in the SELNEC speed/flow relationship.

SPDI - The speed at optimum capacity. A waiting time penalty is added to this to estimate the time for the link when flow is more than capacity.

SUBROUTINE CONVER

TCOST1 (I) - Total link cost on the link corresponding to the cost used in assignment and the current load.

TCOST2 (I) - Total link cost on the link corresponding to the current and/or modified cost and the current load.

DEL - The proportion ABS (XP(I) - LLOAD(I))/LLDAD(I) or ABS (ULINK(I) - TLAST(I))/TLAST(I) for each link (I).

IFR (I) - The number of links for which the values of DEL are each less than a fixed proportion.

ICRIT - The value of ICRIT enable the programme to calculate the value of DEL in terms of the load or resistance.

DIFF - Absolution difference between the load at the end the partial loading method (TNET or CAPRE) and the current from the total loading method expressed as a proportion of the former.

NDIFF - Number of links for which DIFF is greater than 0.1

SVMM - Sums the DIFF of one link to the other for the whole network links.

DELPR 1 Absolute difference of LCOST1 and TCOST2 expressed as a proportion of TCOST1 for each link.

DELPR2 - Absolute difference of LCOST2 and TCOST2 expressed as a proportion of TCOST2 for each link.

NCASS - Number of links for which DELPR1 is greater than 0.1.

NCOLO - Number of links for which DELPR2 is greater than 0.1.

COSDII - Sums up all the DELPRI over the network.

DELINK - Absolute difference between previous link load and current link load expressed as a proportion of the current link load.

NCHLI - Number of links for which DELINK is greater than 0.1.

CHFLOW - Sums up all the DELINK over the network.

DELTIM - Absolute difference between the last link resistance and the present link resistance expressed as a proportion of the present link resistant.

ITIMCH - Number of links for which DELTIM is greater than 0.1

TIMEX - Sums up all the DELTIM over the network.

EFE - Absolute difference between the present loading and the capacity of the link expressed as a proportion of the capacity of the link.

NEFE - Number of links for which EFE is greater than 0.1.

ERVE - Sums up all the EFE over the network.

AVDIFF - Average proportion of the network links with DIFF greater than 0.1.

AVSUMM - Average link value for DIFF.

AVDIF1 - Average link value of DELPR1.

AVDIF2 - Average link value for DELPR2.

AVCFLO - Average link value for DELINK.

TCCH1 - Proportion of the network links for which DELPR1 is greater than 0.1.

TCCH2 - Proportion of the network links for which DELPR2 is greater than 0.1.

TLCH - Proportion of the network links for which DELINK is greater than 0.1.

CCH - Proportion of the network links for which DELTIM is greater than 0.1.

DRPTIM - Average link value of DELTIM.

CAPCH - Average link value for EFE.

PCCAP - Proportion of the network link for which EFE is greater than 0.1.

IPREND - This is set equal to 1 when all the convergence conditions are satisfied otherwise it is set equal to 2.

LCOST1 - The value of TCOST1 in the previous iteration.

LCOST2 - The value of TCOST2 in the previous iteration.

8.2. FLOWNET

This main programme is essentially the TNET set of programmes modified to run as one job. The modification has the provision which allows the load adjusting method to change from the TNET method to FLOW ITERATION method after a specified number of iterations (taken as 6 in the programme but subject to the user's choice) or when the percentage load is equal to 100, i.e. all the loads to be assigned have been assigned to the network. The values of the loads on the links when the loading method is changing from the TNET model to FLOW ITERATION model are stored as LLAST on the magnetic tape and compared with subsequent loads on the links. This is made possible by introducing a variable IC2 which can increase to 3 only in the iteration in which the loading method indicator changes. That is when ILOAD changes from 1 to 3.

The main steps in FLOWNET are as shown in the listing below.

```
      ITER=0
      READ 100,NT6,NNO,ICOST,ILOAD,NLINK,A,Q,QQ,CD,CT
  100 FORMAT (515,2F5.2,F5.1,2F5.2)
      CALL NET06
    4 NFLAG=1
    5 CALL NET101
      CALL NET102
      CALL NET103
      GO TO (1,1,1,1,2), NFLAG
    1 GO TO 5
    2 CALL NET301
      CALL NET302 (I,J)
      GO TO (10,10,20), ILOAD
   10 CALL NET401
      GO TO 21
   20 CALL FLOITR
   21 CALL TNETIM
      CALL CONVER
      IF(ITER-NNO) 17,13,18
   17 GO TO (19.18), IPREND
   19 GO TO 4
   18 CALL EXIT
      END
```

We now discuss briefly the working of the various subroutines in FLOWNET.

8.2.1. SUBROUTINE NET06

Essentially this subroutine prepares the link deck from the original data cards read in, as required for the minimum path programmes. In using the subroutine, the original data for each link is presented on separate cards. Data include origin node, destination node, link type, link length, road width and values for the speed/flow relationship for the curve type. Links are input in descending order of origin node and for each origin node in ascending order of destination node. If these rules are violated the programme outputs the message 'CARD IN LINK DECK OUT OF ORDER' on termination of the job.

The programme calculates for each link the third of the link length, time or speed out of any two of them given on the data card. The deck is prepared with sequential numbers assigned to the level and stored on the magnetic tape.

8.2.2. SUBROUTINES NET101, NET102, NET103

Finding the minimum path is the kernel of the first part of the assignment process. Three subroutines are used to build the minimum paths. The algorithm represented by the three subroutines was developed by the Toad Research Laboratory (431). The essential feature of this procedure is that links from any node are only considered once the routine has been modified to store the minimum path records on magnetic tape. The steps in the tree building procedure can be found in the listing of the subroutines in the Appendix.

8.2.3. SUBROUTINES NET301, and NET302 (I, J)

These two work together to load trips on the transportation network. This is done by locating each link which is part of the path from origin i to destination j and increasing its traffic load by TR(J):

i.e. VOL(I) = VOL(I) + TR(J)

where VOL(I) = load on link if the whole distribution is loaded; and

TR(J) = TRIPS (I, J) - trips from centroid i to all centroids J.

The cumulative total of trips assigned to each link VCUM(1) is however, maintained at this stage. The new value of VOL for each link is then stored in the array XRA on the second tape.

8.2.4. SUBROUTINE NET401

This subroutine uses the partial loading technique. It determines

the proportion of all trips which can be loaded on the network and combined with the flows already assigned with the volume on any arterial link exceeding its capacity. If this proportion is greater than that required to complete the assigned then the assignment is completed, otherwise the proportion of trips determined as above is added to the flows already assigned (see Appendix).

8.2.5. SUBROUTINE FLOITR

This subroutine uses a total loading technique, FLOW ITERATION similar to that developed by Smock (430). It is brought into operation in FLOWNET (as well as HUCAD) after ILOAD assumes the value of 3.

At each iteration the loads are assigned equally to all the routes found so far. For example, during the first iteration all trips will be laoded onto the minimum paths as in the all-or-nothing assignment (5.4.1) but at second iteration trips will be loaded onto two different paths, at three iterations to three different paths and so on. The general operation statement used in the subroutine is to determine the VCUM(I), the load assigned to any link I, at iteration ITER is:

VCUM(I) = VOL(I)/ITER + VCUM(I) * (ITER - 1)/ITER

If required this may readily be modified to incorporate a desired weighting of loads on the latest trees, VOL (I) and those previously assigned.

8.2.6. SUBROUTINE TNETIM

This subroutine has been modified from that in the TNET model. TNETIM calculates new travel times for arterial links to account for either intersection or link delay. However, it does not make such calculations for arterial links with volume/capacity (V/C) of less than 0.5 (increase in trip time considered negligible) or for non-arterial

links. The steps for adjusting the links are:

For intersection delay

ULINR (I) = TLINK (I) + VCUM (1)/CAP/(10.*(1. - VCUM (I)/(CAP*Q)))

and for link delay

ULINK (I) = TLINK (I) * (0.5 + 0.25/(1. - VCUM (I)/(CAP*Q)))

where ULINK (I) = adjusted travel time on link i

TLINK (I) = original travel time on link i

VCUM (I) = load on link i at current iteration

CAP = capacity of the link

Q = The multiple of capacity at which travel time becomes infinite

The travel times of the 'critical link' and of those other arterial links whose V/C ratios are within a specified proximity to 1.0 are increased by an additional 500 minutes to effectively 'remove' them from consideration in the minimum path algorithm of the next iteration. They are further identified by having their capacity class codes changed to 5. When the load adjusting method is changing, however, all the capacity class codes are given their original values. Almost-critical, QQ, has been defined here to be equal to 99.0% of capacity. The multiple of capacity at which travel time becomes infinite, Q has been taken as 1.10.

8.2.7. SUBROUTINE CONVER

CONVER is incorporated in FLOWNET as well as FLOCAP and FLOWSEL to indicate when the desired solution has been obtained and the programme has, therefore, to stop before completion of the maximum number of iterations specified. This happens when all measures of convergence indicators are less than or equal to the specified amount or proportion (proportion specified in this work is 0.1).

It also sets up a frequency table for IFR (I) which is the

number of links for which the calculated values of DEL (see below) are less than or equal to specified amounts (section 7.6). The logical statements for calculating DEL are

IF(ICRIT.EQ.2)DEL = ABS(XP(I) - LLOAD (I))/LLOAD (I)

and

IF(ICRIT.EQ.1)DEL = ABS(ULINK (I) - TLAST (I)/TLAST (I)

where ULINK (I) = the link travel time at the current iteration

TLAST (I) = the link travel time at the last iteration

XP (I) = load on link i at the current iteration

LLOAD (I) = load on link i at the last iteration

DEL = absolute difference between load (or time) at the current iteration and the load (or time) at the last iteration expressed as a proportion of the latter

ICRIT = An indicator which assumes the values of 1 or 2. When ICRIT is 1, DEL is evaluated in terms of time and when ICRIT is 2 DEL is evaluated in terms of load.

The subroutine also writes the current values of the link data onto the tape for use in the next iteration. At this point the programme is ready to build trees for another iteration if the convergence indicators have not shown that the solution has been reached or if the maximum number of iterations specified has not been reached.

8.3. FLOCAP

This programme also uses partial loading technique (capre) followed by a total loading technique (flow iteration). Link time (or cost) is adjusted using MALTS speed/flow relationship. At the termination of the partial loading ILOAD (see 8.3.1.) is assigned the value 3, and the total loading technique is used for subsequent iterations. At this point

the programme stores the link loadings as LLAST to be compared with subsequent link loadings. In this programme the total load distribution matrix is put on the network after four increments of loading using SUBROUTINE CAPRE.

```
      ITER = 0
      READ 100,NT6,NNO,ICOST,ILOAD,NLINK,A,Q,QQ,CD,CT
  100 FORMAT (515,2F5.2,F5.1,2F5.2)
      CALL NET06
    4 NFLAG=1
    5 CALL NET101
      CALL NET102
      CALL NET103
      GO TO (1,1,1,1,2),NFLAG
    1 GO TO 5
    2 CALL NET301
      CALL NET302(I,J)
      GO TO (10,10,20),ILOAD
   10 CALL CAPRE
      GO TO 21
   20 CALL FLOITR
   21 CALL MALTIM
      CALL CONVER
      IF (ITER-NNO)17,18,18
   17 GO TO (19,18),IPREND
   19 GO TO 4
   18 CALL EXIT
      END
```

SUBROUTINES CAPRE and MALTIM will be discussed here as the others have been discussed under FLOWNET.

8.3.1. SUBROUTINE CAPRE

This is an incrementai loading (partial loading) technique which incorporates a facility for applying a fraction of the load P(I) at one time and an option of removing part of the load already assigned. Thr fraction taken off S(I) is expressed as a percentage of the total distribution matrix to be assigned as in P(I).

The loading step is

XP(I) = VOL(I) * P(ITER)/100. + VCUM(I)

where XP(I) = the total cumulative load on i following the addition

of P(ITER).

VOL(I) = the total load on link i if all the trips were loaded on the network.

The off-loading step is

VCUM(I) = XP(ITER) * PP/(PP + S(ITER))

where VCUM(I) = the cumulative link load left after removing the proportion S(ITER) which is the proportion of total load to be removed from XP(I).

and PP = the algebraic sum of P(ITER) and S(ITER) with S(ITER) treated as a negative term.

After all the trips have been put on the network the loading method indicator ILOAD is assigned the value 3. This step enables the programme to used the FLOW ITERATION method of loading.

8.3.2. SUBROUTINE MALTIM

The speed/flow relationship used in the MALTS study is incorporated in CAPRE as MALTIM to adjust the time during each iteration. For each link the subroutine identifies the link type and constants for the link type. The time per mile to traverse the link is then calculated using the expression.

T = ALPHA * 2*XP(I)/WL - GAMMA) + SQRT (ALPHA * ALPHA *)

2*XP(I)/WL - GAMMA) **2 + BETA) + DELTA

where T is the time per mile of the link

XP(I)= the cummulative load or link i at the current iteration.

ALPHA, BETA, GAMMA and DELTA are constants for the links as given in table 2. Hence the total time spent on the link ULINK is given by

ULINK(I) = T * DIST where DIST = link length.

8.4. FLOWSEL

This programme uses only FLOITR for adjusting link loads and the SELNEC speed/flow relationship. Other necessary subroutines are as discussed for FLOWNET and FLOCAP. Only SUBROUTINE SELTIM will be discussed here. Below is the listing of FLOWSEL.

```
      ITER = 0
      READ 100,NT6,NNO,ICOST,ILOAD,NLINK,A,Q,QQ,CD,CT
  100 FORMAT (515,2F5.2,F5.1,2F5.2)
      CALL NETO6
    4 NFLAG=1
    5 CALL NET101
      CALL NET102
      CALL NET103
      GO TO (1,1,1,1,2), NFLAG
    1 GO TO 5
    2 CALL NET301
      CALL NET302 (I,J)
   20 CALL FLOITR
      CALL SELTIM
      CALL CONVER
      IF (ITER-NNO) 17,18,18
   17 GO TO (19,18),IPREND
   19 GO TO 4
   18 CALL EXIT
      END
```

8.4.1. SUBROUTINE SELTIM

This subroutine adjusts the link time using the SELNEC speed/flow relationship as stated above (8.4). It identifies the curve type and selects the constants that go with (which are A_1, A_2, A_3, and b). It then substitutes these constants as well as the road width W, road length l and the load F into the expression

$S^2 = S (A_1W + A_2l + A_3) - bF$ as given in section and solves for S

where S = speed on the link.

For links whose loads exceed capacity, the time at capacity is added to a penalty which takes account of the time spent in queueing, i.e.

ULINK(I) =DIST * 60./SPD1 + 2.5* (VCUM(I)/CAP - 1)

where SPD1 = FFS * FF5/4. * CAP

FFS = free flow speed on the link

ULINK(I) = time on the link

DIST = length of the link

VCUM(I) = cumulative load on the link

and CAP = capacity of the link

The listings are shown in the appendix.

8.5. DESCRIPTION OF THE OUTPUT

The secondary aim of this thesis is the writing and development of a set of programmes to facilitate the investigation of many aspects of capacity restrained assignment. The three programmes tested, which have been discussed above are FLOCAP, FLOWNET and FLOWSEL. Some of the outputs obtained during the programme testing on a test network are included and discussed below.

8.5.1. OUTPUT FROM FLOCAP

Table 8.5A shows the output of the link data read into the programme from the data cards after the calculation of the third of the link time, length and speed from any given two. I is the sequential number assigned to the links. The other parameters for link I are the origin node No (I), destination node ND(I), time on link (TLINK(I)), link distance (DIST) link free flow speed (SPD), link capacity (CAP), link capacity class (KAPCL), link curve type (NCURV), and parameters of the speed/flow relationship other than capacity viz FFL, VC, FFS. This print out of the coded network data is the same for FLOWNET and FLOWSEL.

In the runs of FLOCAP the CAPRE loading method is used in conjunction with the MALTS speed/flow relationship. This speed/flow relationship is intended

JOB COMPOSED ENTER AT CHAIN 1 15.17.20 12/11/74

PROGRAM ENTRY AT CHAIN 01 15.17.21 12/11/74

I	NN(I)	NN(J)	TRLNK(I)	DIST	SPD	CAP	KABCL	NCURV	FFL	VC	FFS	TRLNK(I)	SPD
1	1	15	0.90	0.30	20.	0.	1	0	0.	0.	0.	0.90	20.PK-HR CACITY
2	2	13	0.90	0.30	20.	0.	1	0	0.	0.	0.	0.90	20.PK-HR CACITY
3	3	9	0.90	0.30	20.	0.	1	0	0.	0.	0.	0.90	20.PK-HR CACITY
4	4	10	1.00	0.20	12.	0.	1	0	0.	0.	0.	1.00	12.PK-HR CACITY
5	5	6	0.90	0.30	20.	0.	1	0	0.	0.	0.	0.90	20.PK-HR CACITY
6	6	5	0.90	0.30	20.	0.	1	0	0.	0.	0.	0.90	20.PK-HR CACITY
7	6	7	0.94	0.55	35.	2000.	3	5	1100.	19.	35.	0.94	35.PK-HR CACITY
8	6	8	1.29	0.75	35.	2000.	3	5	1100.	19.	35.	1.29	35.PK-HR CACITY
9	7	6	0.94	0.55	35.	2000.	2	5	1100.	19.	35.	0.94	35.PK-HR CACITY
10	7	10	1.35	0.45	20.	750.	2	3	400.	15.	20.	1.35	20.PK-HR CACITY
11	7	13	2.50	1.25	30.	1200.	2	4	600.	19.	30.	2.50	30.PK-HR CACITY
12	8	6	1.29	0.75	35.	2000.	2	5	1100.	19.	35.	1.29	35.PK-HR CACITY
13	8	9	2.70	1.35	30.	1200.	2	4	600.	19.	30.	2.70	30.PK-HR CACITY
14	8	10	1.05	0.35	20.	750.	2	3	400.	15.	20.	1.05	20.PK-HR CACITY
15	9	3	0.90	0.30	20.	0.	1	0	0.	0.	0.	0.90	20.PK-HR CACITY
16	9	8	2.70	1.35	30.	1200.	3	4	600.	19.	30.	2.70	30.PK-HR CACITY
17	9	11	1.00	0.50	30.	1200.	2	4	600.	19.	30.	1.00	30.PK-HR CACITY
18	9	12	2.10	0.70	20.	750.	2	3	400.	15.	20.	2.10	20.PK-HR CACITY
19	10	4	1.00	0.20	12.	0.	1	0	0.	0.	0.	1.00	12.PK-HR CACITY
20	10	7	1.35	0.45	20.	750.	2	3	400.	15.	20.	1.35	20.PK-HR CACITY
21	10	8	1.05	0.35	20.	750.	2	3	400.	15.	20.	1.05	20.PK-HR CACITY
22	10	12	3.75	0.75	12.	1000.	2	1	500.	9.	12.	3.75	12.PK-HR CACITY
23	11	9	1.00	0.50	30.	1200.	2	4	600.	19.	30.	1.00	30.PK-HR CACITY
24	11	15	1.80	0.75	25.	1100.	2	2	550.	15.	25.	1.80	25.PK-HR CACITY
25	12	9	2.10	0.70	20.	750.	2	3	400.	15.	20.	2.10	20.PK-HR CACITY
26	12	10	3.75	0.75	12.	1000.	2	1	500.	9.	12.	3.75	12.PK-HR CACITY
27	12	13	2.25	0.75	20.	750.	2	3	400.	15.	20.	2.25	20.PK-HR CACITY
28	12	15	6.00	1.20	12.	1000.	3	1	500.	9.	12.	6.00	12.PK-HR CACITY
29	13	2	0.90	0.30	20.	0.	1	0	0.	0.	0.	0.90	20.PK-HR CACITY
30	13	7	2.50	1.25	30.	1200.	3	4	600.	19.	30.	2.50	30.PK-HR CACITY
31	13	12	2.25	0.75	20.	750.	2	3	400.	15.	20.	2.25	20.PK-HR CACITY
32	13	14	0.70	0.35	30.	1200.	2	4	600.	19.	30.	0.70	30.PK-HR CACITY
33	14	13	0.70	0.35	30.	1200.	2	4	600.	19.	30.	0.70	30.PK-HR CACITY
34	14	15	2.04	0.85	25.	1100.	2	2	550.	15.	25.	2.04	25.PK-HR CACITY
35	15	1	0.60	0.20	20.	0.	1	0	0.	0.	0.	0.60	20.PK-HR CACITY
36	15	11	1.80	0.75	25.	1100.	2	2	550.	15.	25.	1.80	25.PK-HR CACITY
37	15	12	6.00	1.20	12.	1000.	2	1	500.	9.	12.	6.00	12.PK-HR CACITY
38	15	14	2.04	0.85	25.	1100.	2	2	550.	15.	25.	2.04	25.PK-HR CACITY

TABLE 8.5A PRINT OUT OF THE INPUT LINK DATA

to be used with networks not loaded beyond capacity so that links are not effectively removed from network even when vastly overloaded. It is thus possible that even links already loaded some way beyond capacity will attract more load during further loading increments. This accounts for the increases in the values of XP(1) on links already loaded beyond capacity see Table 8.5B.

Table 8.5B shows an updated link data from FLOCAT at the end of the second iteration. At this stage the P(2) which is 42% of the total distribution has been added to the load left on the network following the removal of 22% of the total initially loaded. The convergence indicators are of course not functioning as measures of convergence and hence comparisons are not representative of their performance when used in the role for which they are strictly intended.

TLINK(I), DIST, and SPD in the table are the coded link time, length and speed respectively while ULINK(I), USPD(I) and XP(I) are the updated link cost, speed and cumulative load respectively. The origin node (NO(I)), destination node (ND(I)) and the capacity class (KAPCL) of the link are not updated but remain constant throughout the assignment process. Links representing local streets are labelled so for ease of identifying them. NUM is a sequential number assigned to the links.

The frequency table for the values of DEL (section 8.2.7.) is also shown on table 8.5B. For the current iteration the frequency table indicates that for all of the links considered (34 of them) DEL values calculated in terms of cost are less than or equal to 5%. For DEL values calculated in terms of loads, two are less than or equal to 5%, twenty-eight are less than or equal to 30% but greater than 10%, one is less than or equal to 50% but greater than 30%, and three are less than or equal to 100% but greater than 50%.

Following the frequency table is the print out of the convergence

2	2	13	0.90	0.30	20.	0.	1	1392.	0.90	20.	LOCAL T.
3	3	9	0.90	0.30	20.	0.	1	2784.	0.90	20.	LOCAL T.
4	4	10	1.00	0.20	12.	0.	1	4176.	0.90	20.	LOCAL T.
5	5	6	0.90	0.30	20.	0.	1	5568.	1.00	12.	LOCAL T.
6	6	5	0.90	0.30	20.	0.	1	6960.	0.90	20.	LOCAL T.
7	6	7	0.94	0.55	35.	2000.	3	3480.	0.90	20.	LOCAL T.
8	6	8	1.29	0.75	35.	2000.	3	5220.	3.42	44.	LOCAL T.
9	7	6	0.90	0.55	35.	2000.	3	1740.	4.64	45.	
10	7	10	1.35	0.45	20.	750.	2	2268.	3.41	45.	
11	7	13	2.50	1.25	30.	1200.	2	2436.	3.72	25.	
12	8	6	1.29	0.75	35.	2000.	2	4872.	8.97	33.	
13	8	9	2.70	1.35	30.	1200.	2	1212.	4.64	45.	
14	8	10	1.05	0.35	20.	750.	2	4524.	9.69	33.	
15	9	3	0.90	0.30	20.	0.	1	1392.	2.87	26.	
16	9	8	0.90	1.35	30.	1200.	3	4176.	0.90	20.	LOCAL T.
17	9	11	1.00	0.50	30.	1200.	2	2604.	9.67	33.	
18	9	12	2.10	0.70	20.	750.	2	2436.	3.58	33.	
19	10	4	1.00	0.20	12.	0.	1	1044.	5.73	26.	
20	10	7	1.35	0.45	20.	750.	2	3828.	1.00	12.	
21	10	8	1.05	0.35	20.	750.	2	2784.	3.75	25.	LOCAL T.
22	10	12	3.75	0.75	12.	1000.	2	2784.	2.91	25.	
23	11	9	1.00	0.50	30.	1200.	2	0.	7.91	17.	
24	11	15	1.80	0.75	25.	1100.	2	864.	3.58	33.	
25	12	9	2.10	0.70	20.	750.	2	2436.	5.84	28.	
26	12	10	3.75	0.75	12.	1000.	2	696.	5.73	26.	
27	12	13	2.25	0.75	20.	750.	2	0.	7.91	17.	
28	12	15	6.00	1.20	12.	1000.	3	1044.	6.14	26.	
29	13	2	0.90	0.30	20.	0.	1	0.	12.65	17.	
30	13	7	2.50	1.25	30.	1200.	3	4524.	0.90	20.	
31	13	12	2.25	0.75	20.	750.	2	1572.	8.95	33.	LOCAL T.
32	13	14	0.70	0.35	30.	1200.	2	696.	6.14	26.	
33	14	13	0.70	0.35	30.	1200.	2	2436.	2.51	33.	
34	14	15	2.04	0.85	25.	1100.	2	528.	2.50	33.	
35	15	1	0.60	0.20	20.	0.	1	2436.	6.62	28.	
36	15	11	1.80	0.75	25.	1100.	2	4872.	0.60	20.	
37	15	12	6.00	1.20	12.	1000.	2	864.	5.82	28.	LOCAL T.
38	15	14	2.04	0.85	25.	1100.	2	0.	12.65	17.	
								528.	6.60	28.	

Updated link data

. NO	IFR(1)	IFR(2)	IFR(3)	IFR(4)	IFR(5)	IFR(6)
2	34	0	0	0	0	0
2	2	0	28	1	3	0

Frequency table for DEL

VDIF1	AVDIF2	AVCFLO	TCCH1	TCCH2	TLCH	CCH	PRCN	CAPCH	PCCAP	AVSUMM	AVDIFF
0.895	0.204	0.203	0.000	0.000	0.000	0.000	001	0.766	0.000	0.000	0.000

Conv
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TABLE 8-5B UPDATED LINK DATA FROM FLOCAP AT ITERATN TWO

1	1	15	6.60	0.30	20.	0.	1	1600.	0.90	20.	LOCALST.	
2	2	13	0.90	0.30	20.	0.	1	3200.	0.90	20.	LOCALST.	
3	3	9	0.90	0.30	20.	0.	1	4800.	0.90	20.	LOCALST.	
4	4	10	1.00	0.20	12.	0.	1	6400.	1.00	12.	LOCALST.	
5	5	6	0.90	0.30	20.	0.	1	8000.	0.90	20.	LOCALST.	
6	6	5	0.90	0.30	20.	0.	1	4000.	0.90	20.	LOCALST.	
7	6	7	0.94	0.55	35.	2000.	3	6000.	3.42	44.		
8	6	8	1.29	0.75	35.	2000.	3	2000.	4.64	45.		
9	7	6	0.90	0.55	35.	2000.	2	2511.	3.41	45.		
10	7	10	1.35	0.45	20.	750.	2	2800.	3.75	25.		
11	7	13	2.50	1.25	30.	1200.	2	5600.	8.98	33.		
12	8	6	1.29	0.75	35.	2000.	2	1489.	4.64	45.		
13	8	9	2.70	1.35	30.	1200.	2	5200.	9.70	33.		
14	8	10	1.05	0.35	20.	750.	2	1600.	2.87	25.		
15	9	3	0.90	0.30	20.	0.	1	4800.	0.90	20.	LOCALST.	
16	9	8	0.90	1.35	30.	1200.	3	3089.	9.67	33.		
17	9	11	1.00	0.50	30.	1200.	2	2800.	3.58	33.		
18	9	12	2.10	0.70	20.	750.	2	1200.	5.74	26.		
19	10	4	1.00	0.20	12.	0.	1	4400.	1.00	12.	LOCALST.	
20	10	7	1.35	0.45	20.	750.	2	3200.	3.80	24.		
21	10	8	1.05	0.35	20.	750.	2	3200.	2.96	24.		
22	10	12	3.75	0.75	12.	1000.	2	0.	7.91	17.		
23	11	9	1.00	0.50	30.	1200.	2	1089.	3.58	33.		
24	11	15	1.80	0.75	25.	1100.	2	2800.	5.85	28.		
25	12	9	2.10	0.70	20.	750.	2	800.	5.73	26.		
26	12	10	3.75	0.75	12.	1000.	2	0.	7.91	17.		
27	12	13	2.25	0.75	20.	750.	2	1200.	6.15	26.		
28	12	15	6.00	1.20	12.	1000.	3	0.	12.65	17.		
29	13	2	0.90	0.30	20.	0.	1	5200.	0.90	20.	LOCALT.	
30	13	7	2.50	1.25	30.	1200.	3	1711.	8.95	33.		
31	13	12	2.25	0.75	20.	750.	2	800.	6.14	26.		
32	13	14	0.70	0.35	30.	1200.	2	2800.	2.51	33.		
33	14	13	0.70	0.35	30.	1200.	2	511.	2.50	33.		
34	14	15	2.04	0.85	25.	1100.	2	2800.	6.63	28.		
35	15	1	0.60	0.20	20.	0.	1	5600.	0.60	20.	LOCALT.	
36	15	11	1.80	0.75	25.	1100.	2	1089.	5.83	28.		
37	15	12	6.00	1.20	12.	1000.	2	0.	12.65	17.		
38	15	14	2.04	0.85	25.	1100.	2	511.	6.60	28.		

} Updated link data

ITER. NO	IFR(1)	IFR(2)	IFR(3)	IFR(4)	IFR(5)	IFR(6)
5	34	0	0	0	0	0
5	32	2	0	0	0	0

} Frequency table for DEL

AVDIF1	AVDIF2	AVCFLO	TCCH1	TCCH2	TLCH	CCH	PRM	CAPCH	PCCAP	AVSUMM	AV
0.006	0.006	0.006	0.000	0.000	0.000	0.000	000	0.900	0.000	0.005	

TABLE 8-5C UPDATED LINK DATA FROM FLOCAP ALTERATION FIVE

NN(I)	ND(I)	TLINK(I)	DIST	SPD	CAP	KAPLL	XP(I)	VLINK(I)	USPD(I)	
1	15	0.90	0.30	20.	0.	1	369.	0.90	20.	LOCAL ST.
2	13	0.90	0.30	20.	0.	1	738.	0.90	20.	LOCAL ST.
3	9	0.90	0.30	20.	0.	1	1108.	0.90	20.	LOCAL ST.
4	10	1.00	0.20	12.	0.	1	1477.	1.00	12.	LOCAL ST.
5	6	0.90	0.30	20.	0.	1	1846.	0.90	20.	LOCAL ST.
6	5	0.90	0.30	20.	0.	1	923.	0.90	20.	LOCAL ST.
6	7	0.94	0.55	35.	2000.	3	1385.	4.14	35.	LINK DELAY
6	8	1.29	0.75	35.	2000.	3	462.	13.02	35.	TOO LOW
7	6	0.94	0.55	35.	2000.	2	640.	9.55	35.	TOO LOW
7	10	1.35	0.45	20.	750.	2	646.	5.07	20.	INTER. DELA
7	13	2.50	1.25	30.	1200.	5	1292.	511.58	30.	**SATURATED
8	6	1.29	0.75	35.	2000.	2	284.	13.02	35.	TOO LOW
8	9	2.70	1.35	30.	1200.	5	1200.	512.32	30.	**SATURATED
8	10	1.05	0.35	20.	750.	2	369.	7.88	20.	TOO LOW
9	3	0.90	0.30	20.	0.	1	1108.	0.90	20.	LOCAL ST.
9	8	2.70	1.35	30.	1200.	3	653.	24.97	30.	TOO LOW
9	11	1.00	0.50	30.	1200.	2	646.	9.25	30.	TOO LOW
9	12	2.10	0.70	20.	750.	2	277.	15.75	20.	TOO LOW
10	4	1.00	0.20	12.	0.	1	1015.	1.00	12.	LOCAL ST.
10	7	1.35	0.45	20.	750.	2	738.	6.15	20.	INTER. DELA
10	8	1.05	0.35	20.	750.	2	738.	5.20	20.	INTER. DELA
10	12	3.75	0.75	12.	1000.	2	0.	10.12	12.	TOO LOW
11	9	1.00	0.50	30.	1200.	2	191.	9.25	30.	TOO LOW
11	15	1.80	0.75	25.	1100.	2	646.	6.48	25.	INTER. DELA
12	9	2.10	0.70	20.	750.	2	185.	15.75	20.	TOO LOW
12	10	3.75	0.75	12.	1000.	2	0.	10.12	12.	TOO LOW
12	13	2.25	0.75	20.	750.	2	277.	16.87	20.	TOO LOW
12	15	6.00	1.20	12.	1000.	3	0.	16.20	12.	TOO LOW
13	2	0.90	0.30	20.	0.	1	1200.	0.90	20.	LOCAL ST.
13	7	2.50	1.25	30.	1200.	3	455.	23.12	30.	TOO LOW
13	12	2.25	0.75	20.	750.	2	185.	16.87	20.	TOO LOW
13	14	0.70	0.35	30.	1200.	2	646.	6.48	30.	TOO LOW
14	13	0.70	0.35	30.	1200.	2	178.	6.48	30.	TOO LOW
14	15	2.04	0.85	25.	1100.	2	646.	7.31	25.	INTER. DELAY
15	1	0.60	0.20	20.	0.	1	1292.	0.60	20.	LOCAL ST.
15	11	1.80	0.75	25.	1100.	2	191.	15.08	25.	TOO LOW
15	12	6.00	1.20	12.	1000.	2	0.	16.20	12.	TOO LOW
15	14	2.04	0.85	25.	1100.	2	178.	17.09	25.	TOO LOW

} UPDATED LINK DATA

)	IFR(1)	IFR(2)	IFR(3)	IFR(4)	IFR(5)	IFR(6)
	15	0	2	0	0	17
	2	29	3	0	0	0

} Frequency table for DEL

F1	AVDIF2	AVCFLO	TCCH2	TCCH2	TLCH	CCH	PRPT	CAPCH	PCCAP	AVSUMM	AVDIFF
95	0.329	0.065	0.000	0.000	0.000	0.000	0.5	0.429	0.000	0.000	0.000

} Convergence indica

TABLE 8.5D UPDATED LINK DATA FROM FLOWNET

) 369.23	1.00	15.00	0.90	0.30	20.00	0.00	1.00	00	20.00	1.00	0.00	0.00	0.00	
0.00		0.00		369.23		0.00		00		332.31		332.31		0.

indicators. The indicators used in the convergence criteria, i.e. in determining when the programme should stop, have been underlined. These are:

AVDIF1 - the average over the network links of the absolute difference between the 'total link cost' of the last iteration and the 'total link cost' of the present iteration expressed as a fraction of the latter where the cost corresponds to the cost obtained from the assigned load.

AVCFLO - is the average over the network links of the absolute difference bwtween the link load in the last iteration and the link load in the current iteration expressed as a fraction of the latter.

TCCH1 - the number of links for which DELPR1 is greater than 0.1 expressed as a fraction of the total number of network links where DELPR1 is the absolute difference between the 'total link cost' in the last iteration and that of the current iteration expressed as a fraction of the latter where the link cost corresponds to that used in building the trees.

TCCH2 - the number of links for which DELPR2 is greater than 0.1 expressed as a fraction of the total number of network links where DELPR2 is the absolute difference between the 'total link cost' in the last iteration and that of the current iteration expressed as a fraction of the latter where the cost corresponds to that obtained from the assigned load

TLCH - the number of links for which NCHLI is greater than 0.1 where NCHLI is the absolute difference between the load in the last iteration and that of the current iteration expressed as a fraction of the latter.

CCH - the number of links for which DELTIM is greater than 0.1 expressed as a fraction of the total network links where DELTIM is the absolute difference between the cost in the last iteration and

that in the current iteration expressed as a fraction of the latter.

PRPTIM - the average over the network links of the absolute difference between the link cost in the last iteration and that in the current iteration expressed as a fraction of the latter.

The other convergence indicators not used for determining when a satisfactory solution has been achieved are:

CAPCH - the average over the network links of the absolute difference between the link load in the current iteration and the capacity of the link, expressed as a fraction of the latter.

PCCAP - the number of links for which EFE is greater than 0.1 expressed as a fraction of the total number of network links, where EFE is the absolute difference between the link load at the current iteration and the capacity of the link, expressed as a fraction of the latter.

AVSUMM - the average over the network links of the absolute difference between the link load at the current iteration and that at the end of the incremental loading procedure expressed as a fraction of the latter.

AVDIFF - the number of links for which DIFF is greater than 0.1 expressed as a fraction of the total network links where DIFF is the absolute difference between the link load at the current iteration and that at the end of the incremental loading procedure expressed as a fraction of the latter.

Table 8.5C shows a similar output at the end of the fifth iteration (the last iteration of FLOCAP). At this stage of the programme all the values of DEL calculated in terms of cost are less than or equal to 5%; thirty-two of the links' DEL values calculated in terms of link loads are less than or equal to 5%, two of them have DEL values less than 10% but

greater than 5% These values of DEL satisfy the condition for convergence and this fact is reinforced by the fact that the convergence indicators to be tested show that the convergence of the assignment has been reached. The programme, therefore, terminates. Data stored on the magnet tape have not been shown here becasue they are basically the same as those discussed.

8.5.2. OUTPUT FROM FLOWNET

The print out of the input link data is the same as that shown on Table 8.5A. Table 8.5D shows the link data from FLOWNET after iteration number two This output is similar to that of table 8.5B or C except that the capacity class (KAPCL) of any link loaded to capacity is changed to 5 and the link concerned labelled '** saturated **'. The links are also labelled to indicate whether or not they are local streets or they experience intersection delay or link delay and any arterial link with intersection or link delay whose volume/capacity ratio is less than 0.5 is labelled 'too low'.

The layout of the frequency table for DEL and the method of outputting the convergence indicators are the same as thoseof FLOCAP discussed above.

8.5.3. OUTPUT FROM FLOWSEL

The input data is printed out in the same manner as in FLOCAP. It does not output the updated link data like the other two above; the new link loads alone are output. But the frequency table for DEL and convergence indicator output by this programme are, however, the same as those discussed for FLOCAP above.

9 CONCLUSION AND RECOMMENDATIONS FOR FURTHER RESEARCH

In concluding this work it may be well to mention once more that the usefulness of the output from traffic assignment depends on whether or not the inputs reflect the real life situation. For example, a route choice criterion which takes account of probable behavioural tendencies of the traveller (e.g. taking into account comfort and convenience of route) would produce a better simulation than one which uses only distance or time.

From the discussion of various assignment techniques it can be said that the greater the desired degree of accuracy the more costly is the technique required in terms of computer time and storage requirements. These requirements not withstanding, work done on the measures of convergence has shown that if the measures are to be sensitive at all then link flows and times or costs should be measured in units of at most 0.1 p.c.u./hr. and 0.1 cost mins respectively in order to provide a satisfactory solution at convergence.

The three sets of programmes developed in this work can be used to investigate the effects on a stable solution of the following:

(i) speed/flow relationship assumed;

(ii) the loading method used;

(iii) variations in network flow densities;

(iv) use of time or cost;

(v) use of integer and real flow and time or cost;

(vi) use of averages of time or cost;

(vii) convergence indicators.

A total of twelve convergence indicators have been included see 8.5.1; eight of these are tested to determine when convergence is achieved,

two are indicators of the way the convergence is proceeding but are not tested and the other two indicate the difference between the solution when the total load is first assigned and the solution at any stage during the subsequent flow iteration. For the indicators used in the convergence criteria, the different times in the programme when each of them is satisfied before the required convergence is reached can be observed.

The frequency table included shows how the assignment is converging to a stable solution. From the table a comparison of the effect of using changes in link load or time (or cost) as the measure of convergence can be made. A desirable further development to the programme as written is the use of the averages of link time or cost for the first few iterations before reverting to using the non-averaged values in the subsequent iterations. This will help to dampen the initial alternating of loads between parallel and competing routes.

9.1. RECOMMENDATIONS FOR FURTHER RESEARCH

The author would like to make the following recommendations for the further use and extension of the programme developed in this dissertation.

1. Measures of Time or Cost and Flow

More research is needed into the use of finer measures of costs or times and flows (than 0.1 units) which may not necessarily require larger amount of computer facilities.

2. Randomisation of Link Times

The effect of Randomisation of link times in conjunction with the flow iteration method should be investigated since flow iteration appears to produce the most efficient loading method in terms of convergence and the randomiastion of link choice furnishes a facility for random evaluation of the chosen impedance criterion by travellers.

3. Perturbation Approach

To test the validity of the convergence results obtained a perturbation approach should be adopted following the final assignment. The perturbation approach introduces small elements of link cost into an assignment and thereby reduces very considerably the probability of accepting a quasi stable solution. In fact a perturbation model should be incorporated in all transportation studies.

4. Sensitivity of the Network

The effect of speed/flow relationship needs to be investigated. Especially in facility design the model solution should agree closely with the flows under the conditions modelled. It is, therefore, essential that the theoretical speed/flow relationship should reflect actual events on the network.

5. Queueing Assignment

Queueing assignment should be included in traffic assignment models to be applied to congested networks so as to reflect what happens in practical situations.

6. Distribution - Modal Split and Assignment Interface

The interface between distribution - modal split and assignment models should be closely investigated so that the former two phases of transport planning use the latest network impedance before the capacity restraint assignment is completed.

APPENDIX

```
EGTRAN COMPILER          MARK NO. 302          DATE     16/10/74          TIME
      SUBROUTINE NET06
      DIMENSION NO(450),ND(450),TLINK(450),TCUM(60),NN(175),TSUM(175),
     1K1(175),NSKIP(8),TREE(70),RA(24),TRIPS(36,36),DISTN(36,36),
     2N(68),XRA(24),TR(36),VOL(450),NCUM(60),IFR(6),CON(10,10),
     4DUM(10,10),USPD(450),ULINK(450),XP(450),VCUM(450),LLOAD(450),
     5LLAST(450),TLAST(450),LCOST1(450),LCOST2(450),TCOST1(450),
     6TCOST2(450)
      COMMON NO,ND,TLINK,TCUM,NCUM,NN,TSUM,K1,NSKIP,CAP,KAPCL,DIST,
     1TREE,RA,XRA,TRIPS,N,TR,VOL,A,SPD,NCURV,FFL,FFS,WL,VC,LLOAD,
     3LLAST,TLAST,LCOST1,LCOST2,IC1,IC2,KC,NCENT,NFLAG,IT,NLINK,DISTN,
     4ITER,NTREE,NCM,NM,TMIN,NTEST,NNODE,NHOME,NSTOP,NODIST,IDIST,
     5XMAX,LCRIT,X,XP,ILOAD,ULINK,USPD,DUM,ALPHA,BETA,GAMMA,DELTA,
     6JWIST,CON,C,A1,A2,A3,A4,B,BB,BD,IPREND,ITIME,CAPCH,PCCAP,ERUR,
     7NEFE,EFE,SUMM,AVSUMM,AVDIFF,NDIFF,DIFF,NNO,ICRIT,IFR,DEL,TCOST1,
     8TCOST2,VCUM,PP,P,S,Q,QQ,ICOST,CT,CD
      DO 20 I=1,NLINK
      READ 101,NO(I),ND(I),NCURV,DIST,SPD,TLINK(I),WL,CAP,KAPCL,FFL,
     1VC,FFS                                                          } Network data
  101 FORMAT(3X,3I3,F6.2,F4.0,F6.2,F4.0,F6.0,I3,F6.0,2F4.0)
      IERROR=0
      IF (KAPCL) 9,25,15
   15 GO TO (1,1,1,17),KAPCL
    1 JJ=0
      IF(TLINK(I)) 3,2,3
    2 J=1
      JJ=JJ+1
    3 IF(SPD) 5,4,5
    4 J=2
      JJ=JJ+1
    5 IF(DIST) 7,6,7
    6 J=3
      JJ=JJ+1
    7 IF(JJ-1) 14,8,9
    9 PRINT 104,I,NO(I),ND (I),TLINK(I)
      IERROR=1
  104 FORMAT(3I5,F6.2,1X,21HDATA MISSING OR WRONG)
      GO TO 20
    8 GO TO (11,12,13),J
   11 TLINK(I)=60.*DIST/SPD
      GO TO 14
   12 SPD=60.*DIST/TLINK(I)
      GO TO 14
   13 DIST=SPD*TLINK(I)/60.
   14 GO TO (17,16,16,17),KAPCL
   16 IF(CAP) 9,18,17
   18 PRINT 105,I,NO(I),ND(I),TLINK(I),DIST,SPD,CAP,KAPCL,NCURV,FFL,
     1VC,FFS,TLINK(I),SPD
  105 FORMAT(3I3,2F6.2,F4.0,F6.0,2I3,F6.0,2F4.0,8X,F6.2,F4.0,
     215HINSERT CAPACITY)
      GO TO 10
   17 PRINT 102,I,NO(I),ND(I),TLINK(I),DIST,SPD,CAP,KAPCL,NCURV,FFL,
     1VC,FFS,TLINK(I),SPD
  102 FORMAT(3I3,2F6.2,F4.0,F6.0,2I3,F6.0,2F4.0,8X,F6.2,F4.0,
     414HPK-HR CAPACITY)
      GO TO 10
   25 PRINT 103,I,NO(I),ND(I),TLINK(I),DIST,SPD,CAP,KAPCL,NCURV,FFL,
     1VC,FFS,TLINK(I),SPD
  103 FORMAT(3I3,2F6.2,F4.0,F6.0,2I3,F6.0,2F4.0,8X,F6.2,F4.0,
     612HINSERT KAPCL)
   10 RA(1)=0.0
      RA(2)=0.0
      RA(3)=NO(I)
      RA(4)=ND(I)
```

Checks for missing link time, speed or length. If two or more are missing, error is reported.

Inserts missing link time, speed or length, if the other two items are given

Output of link deck

```
      RA(6)=DIST
      RA(7)=SPD
      RA(8)=CAP
      RA(9)=KAPCL
      RA(10)=TLINK(I)
      RA(11)=SPD
      RA(12)=KAPCL
      RA(13)=NCURV
      RA(14)=FFL
      RA(15)=VC
      RA(16)=FFS
      RA(17)=WL
      RA(18)=0.
      RA(19)=0.
      RA(20)=0.
      RA(21)=0.
      RA(22)=0.
      RA(23)=0.
      RA(24)=0.
      WRITE ARRAY TO TAPE1,RA
   20 CONTINUE
      IF(IERROR-1)22,21,22
   21 CALL EXIT
   22 REWIND1
      DO 60 I=1,NLINK
      READ ARRAY FROM TAPE1,RA
   60 PRINT 111,(RA(J),J=1,24)
  111 FORMAT(12F10.2)
      REWIND1
      RETURN
      END
```

Reads array value onto the magnetic tape

Output of values on the tape for cross-checking.

Dataset Limited

```
                                                    REFERENCE TABLES
     0    00000/0          101    00030/5          9    00055/2
     1    00035/5           17    00146/2          3    00043/0
     4    00044/0            7    00052/2          6    00047/4
   104    00071/2           20    00273/2         11    00073/5
    16    00110/2           18    00112/4        105    00145/5
   103    00235/1           22    00300/1         21    00277/4

        ROUTINE COMPILED
        TIME  LESS THAN 11 SECS
        NUMBER OF INSTRUCTION WORDS 210
        * * * * * * * * * * * * * * * * * * * *

NUMBER OF INSTRUCTION WORDS 0209

EXTERNAL ROUTINES REQU.
   NET06  WONT30  WONT31  WONT32  DONT50  WONT40  WONT41  WONT42  WONT11
  WONT08  WONT10
*FORTRAN
```

```
EGTRAN COMPILER        MARK NO. 302        DATE    07/11/74        TIME
      SUBROUTINE NET101
      DIMENSION NO(450),ND(450),TLINK(450),TCUM(60),NN(175),TSUM(175),
     1K1(175),NSKIP(8),TREE(70),RA(24),TRIPS(36,36),DISTN(36,36),
     2N(68),XRA(24),TR(36),VOL(450),NCUM(60),IFR(6),CON(10,10),
     4DUM(10,10),USPD(450),ULINK(450),XP(450),VCUM(450),LLOAD(450),
     5LLAST(450),TLAST(450),LCOST1(450),LCOST2(450),TCOST1(450),
     6TCOST2(450)
      COMMON NO,ND,TLINK,TCUM,NCUM,NN,TSUM,K1,NSKIP,CAP,KAPCL,DIST,
     1TREE,RA,XRA,TRIPS,N,TR,VOL,A,SPD,NCURV,FFL,FFS,WL,VC,LLOAD,
     3LLAST,TLAST,LCOST1,LCOST2,IC1,IC2,KC,NCENT,NFLAG,IT,NLINK,DISTN,
     4ITER,NTREE,NCM,NM,TMIN,NTEST,NNODE,NHOME,NSTOP,NODIST,IDIST,
     5XMAX,LCRIT,X,XP,ILOAD,ULINK,USPD,DUM,ALPHA,BETA,GAMMA,DELTA,
     6JWIST,CON,C,A1,A2,A3,A4,B,BB,BD,IPREND,ITIME,CAPCH,PCCAP,ERUR,
     7NEFE,EFE,SUMM,AVSUMM,AVDIFF,NDIFF,DIFF,NNO,ICRIT,IFR,DEL,TCOST1,
     8TCOST2,VCUM,PP,P,S,Q,QQ,ICOST,CT,CD
      PRINT 122
  122 FORMAT(1H1)
      GO TO (15,5,5,24), NFLAG
   15 L1=1
      IF(ITER)11,12,11
   12 CONTINUE
      READ 100,NCENT,NNODE,NHOME,NSTOP,A,(NSKIP(I),I=1,8)
  100 FORMAT(4I5,F8.2,8I5)
      PRINT 100,NCENT,NNODE,NHOME,NSTOP,A,(NSKIP(I),I=1,8)
   11 NHOME=1
      K1(L1)=1
      READ ARRAY FROM TAPE1,RA
      PRINT 131,(RA(J),J=1,24)
  131 FORMAT(////15F8.2/9F16.2)
      NO(1)=RA(3)
      ND(1)=RA(4)
      TLINK(I)=RA(10)
     PKAPCL=RA(12)
      IF(NO(1)-1) 26,25,26
   26 I=1
   28 PRINT 105,I
  105 FORMAT(1X,4HCARD,I3,1X,25HIN LINK DECK OUT OF ORDER)
      CALL EXIT
   25 DO 2 I=2,NLINK
      READ ARRAY FROM TAPE1,RA
      PRINT 132,(RA(J),J=1,24)
  132 FORMAT(15F8.2/9F16.2)
      NO(I)=RA(3)
      ND(I)=RA(4)
      TLINK(I)=RA(10)
     PKAPCL=RA(12)
      IF(NO(I)-NO(I-1)) 29,2,43
   29 PRINT 105,I
      CALL EXIT
   43 L1=L1+1
      K1(L1)=I
    2 CONTINUE
   35 DO 150 I=1,60
      TCUM(I)=0.0
  150 NCUM(I)=0
    5 PRINT 103, NHOME
  103 FORMAT (1H1/25X,14HTREE FROM NODE,I4/)
      NFLAG=2
      DO 1 I=1,NNODE
    1 TSUM(I)=9999.
      NTREE=1
      NN(NHOME)=0
      TSUM(NHOME)=0.0
```

Reads link data (adjusted link data if iteration is more than one) from magnetic tape and checks that it is in order and in the format for tree building

K1 is an index which speeds up the search for links out of any node the tree has found

← Program starts building each tree

Initialization

```
      NM=NHOME
      RETURN
   24 DO 22 I=1,NNODE
      IF(TSUM(I)=9999.0) 22,23,22
   23 PRINT 106,I
  106 FORMAT (4HNODE,I4,1X,7HMISSING)
   22 CONTINUE
      CALL EXIT
      END
```

Error message and exit when all the nodes are not reached in NET102

```
                                                    REFERENCE TABLES
    0     00000/0          122     00002/2          15     00004/2
   11     00045/0           12     00006/2         100     00025/4          1
   25     00076/1           28     00072/4         105     00075/4          1
    2     00132/1           43     00126/4          35     00134/5          1
    1     00150/5           22     00172/2          23     00167/2          1

        ROUTINE COMPILED
        TIME  LESS THAN 7 SECS
        NUMBER OF INSTRUCTION WORDS 126
        * * * * * * * * * * * * * * * * *

NUMBER OF INSTRUCTION WORDS 0126

EXTERNAL ROUTINES REQU.
  NET101  WONT40  WONT42  DONT50  WONT30  WONT31  WONT32  WONT41  WONT10  D
    EXIT
#FORTRAN
```

```
EGTRAN COMPILER        MARK NO. 302        DATE    07/11/74        TIME
      SUBROUTINE NET102
      DIMENSION NO(450),ND(450),TLINK(450),TCUM(60),NN(175),TSUM(175),
     1K1(175),NSKIP(8),TREE(70),RA(24),TRIPS(36,36),DISTN(36,36),
     2N(68),XRA(24),TR(36),VOL(450),NCUM(60),IFR(6),CON(10,10),
     4DUM(10,10),USPD(450),ULINK(450),XP(450),VCUM(450),LLOAD(450),
     5LLAST(450),TLAST(450),LCOST1(450),LCOST2(450),TCOST1(450),
     6TCOST2(450)
      COMMON NO,ND,TLINK,TCUM,NCUM,NN,TSUM,K1,NSKIP,CAP,KAPCL,DIST,
     1TREE,RA,XRA,TRIPS,N,TR,VOL,A,SPD,NCURV,FFL,FFS,WL,VC,LLOAD,
     3LLAST,TLAST,LCOST1,LCOST2,IC1,IC2,KC,NCENT,NFLAG,IT,NLINK,DISTN,
     4ITER,NTREE,NCM,NM,TMIN,NTEST,NNODE,NHOME,NSTOP,NODIST,IDIST,
     5XMAX,LCRIT,X,XP,ILOAD,ULINK,USPD,DUM,ALPHA,BETA,GAMMA,DELTA,
     6JWIST,CON,C,A1,A2,A3,A4,B,BB,BD,IPREND,ITIME,CAPCH,PCCAP,ERUR,
     7NEFE,EFE,SUMM,AVSUMM,AVDIFF,NDIFF,DIFF,NNO,ICRIT,IFR,DEL,TCOST1,
     8TCOST2,VCUM,PP,P,S,Q,QQ,ICOST,CT,CD
   6  L1=NM
      L2=K1(L1)
      DO 7 I=L2,NLINK
      IF(NO(I)-NM) 7,3,8
   3PK=ND(I)
      IF(TSUM(K)-9999.) 7,18,7
  18PNCM=NCM+1
      IF(60-NCM) 40,41,41
  40  NFLAG=3
  41PTCUM(NCM)=TSUM(NM)+TLINK(I)
      NCUM(NCM)=I
   7  CONTINUE
   8  TMIN=999.9
      DO 9 K=1,NCM
      IF(TMIN-TCUM(K)) 9,9,10
  10PTMIN=TCUM(K)
      L=NCUM(K)
      M=K
   9  CONTINUE
      K=ND(L)
      IF(TSUM(K)-TMIN) 11,11,13
  13  TSUM(K)=TMIN
      NN(K)=L
      I=0
      NTREE=NTREE+1
      IF(NTREE-NNODE) 12,19,12
  11  I=1
  12PNCM=NCM-1
      IF(NCM)21,27,27
  21  NFLAG=4
      RETURN
  27  DO 14 NM=M,NCM
      TCUM(NM)=TCUM(NM+1)
  14  NCUM(NM)=NCUM(NM+1)
      IF(I) 8,17,8
  17  NM=K
      IF(NM-NCENT) 8,8,6
  19  RETURN
      END
```

Locates all links out of the node nearest origin which has not yet been built beyond and adds these links to working table

Working table overflow table

Finds link in working table to the node not yet include in tree which is nearest the origin. Inserts tree in link in tree table and remove from working table. Insert node in tree by labelling time from origin and previous node

Paths end when centroids are reached and are not allowed to continue through them to other nodes.

REFERENCE TABLES

0	00000/0	6	00000/5	7	00026/2
18	00014/5	40	00020/1	41	00021/1
11	00057/4	13	00050/2	12	00060/4
27	00065/4	14	00070/3	17	00076/0

ROUTINE COMPILED
TIME LESS THAN 5 SECS

```
EGTRAN COMPILER          MARK NO. 302          DATE     07/11/74          TIME
      SUBROUTINE NET103
      DIMENSION NO(450),ND(450),TLINK(450),TCUM(60),NN(175),TSUM(175),
     1K1(175),NSKIP(8),TREE(70),RA(24),TRIPS(36,36),DISTN(36,36),
     2N(68),XRA(24),TR(36),VOL(450),NCUM(60),IFR(6),CON(10,10),
     4DUM(10,10),USPD(450),ULINK(450),XP(450),VCUM(450),LLOAD(450),
     5LLAST(450),TLAST(450),LCOST1(450),LCOST2(450),TCOST1(450),
     6TCOST2(450)
      COMMON NO,ND,TLINK,TCUM,NCUM,NN,TSUM,K1,NSKIP,CAP,KAPCL,DIST,
     1TREE,RA,XRA,TRIPS,N,TR,VOL,A,SPD,NCURV,FFL,FFS,WL,VC,LLOAD,
     3LLAST,TLAST,LCOST1,LCOST2,IC1,IC2,KC,NCENT,NFLAG,IT,NLINK,DISTN,
     4ITER,NTREE,NCM,NM,TMIN,NTEST,NNODE,NHOME,NSTOP,NODIST,IDIST,
     5XMAX,LCRIT,X,XP,ILOAD,ULINK,USPD,DUM,ALPHA,BETA,GAMMA,DELTA,
     6JWIST,CON,C,A1,A2,A3,A4,B,BB,BD,IPREND,ITIME,CAPCH,PCCAP,ERUR,
     7NEFE,EFE,SUMM,AVSUMM,AVDIFF,NDIFF,DIFF,NNO,ICRIT,IFR,DEL,TCOST1,
     8TCOST2,VCUM,PP,P,S,Q,QQ,ICOST,CT,CD
      DO 200 I=1,70
  200 TREE(I)=0.0
      GO TO (60,60,61,62),NFLAG
   61 PRINT 302,NHOME
  302 FORMAT(1H1, 9HTREE FROM,I4,16H = TCUM OVERFLOW)
      GO TO 74
   60 DO 16 J1=1,NNODE
      K=NN(J1)
      IF(J1-NHOME) 4,16,4
    4 NN(J1)=NO(K)
   16 CONTINUE
      DO 30 I=1,NCENT
       N1=1
      IF(NN(I))35,30,35
   35 J1=NN(I)
   55 NCUM(N1)=NN(J1)
      IF(NN(J1)-NHOME) 56,58,56
   56 N1=N1+1
       J1=NN(J1)
       GO TO 55
   58 IF(TSUM(I)) 57,59,57
   59 TSUM(I)=0.01
   57 TREE(1)=NHOME
      TREE(2)=TSUM(I)
      TREE(3)=I
      TREE(4)=NN(I)
      DO 210 J1=1,N1
  210 TREE(4+J1)=NCUM(J1)
      PRINT 102, TSUM(I),I,NN(I),(NCUM(J1),J1=1,N1)
      WRITE ARRAY TO TAPE 1,TREE
  102 FORMAT(F10.2,17I4/10X,17I4/10X,17I4)
   30 CONTINUE
   74 NHOME=NHOME+1
      IF(NHOME-NSTOP) 73,73,72
   72 NFLAG=5
      RETURN
   73 DO 70 I=1,8
      IF(NHOME-NSKIP(I)) 70,71,70
   71 PRINT 104,NHOME
  104 FORMAT (1H1/15X14HTREE FRON NODE,I3,21H OMITTED AS SPECIFIED/12X,
     1 2H=1)
      TREE(3)=-1
      WRITE ARRAY TO TAPE 1,TREE
      GO TO 74
   70 CONTINUE
   62 RETURN
      END
```

Reports of working table overflow. Tree is omitted. Can be corrected by increasing dimensions of TCUM and NCUM and adjusting the DO 150 loop in NET101 and the overflow check statement in NET102

'Skims' the trees

Outputs each path of a tree and also reads it into the magnetic tape

Checks on next tree to be built

```
EGTRAN COMPILER          MARK NO. 302          DATE    16/10/74          TIME
      SUBROUTINE NET301
      DIMENSION NO(450),ND(450),TLINK(450),TCUM(60),NN(175),TSUM(175),
     1K1(175),NSKIP(8),TREE(70),RA(24),TRIPS(36,36),DISTN(36,36),
     2N(68),XRA(24),TR(36),VOL(450),NCUM(60),IFR(6),CON(10,10),
     4DUM(10,10),USPD(450),ULINK(450),XP(450),VCUM(450),LLOAD(450),
     5LLAST(450),TLAST(450),LCOST1(450),LCOST2(450),TCOST1(450),
     6TCOST2(450)
      COMMON NO,ND,TLINK,TCUM,NCUM,NN,TSUM,K1,NSKIP,CAP,KAPCL,DIST,
     1TREE,RA,XRA,TRIPS,N,TR,VOL,A,SPD,NCURV,FFL,FFS,WL,VC,LLOAD,
     3LLAST,TLAST,LCOST1,LCOST2,IC1,IC2,KC,NCENT,NFLAG,IT,NLINK,DISTN,
     4ITER,NTREE,NCM,NM,TMIN,NTEST,NNODE,NHOME,NSTOP,NODIST,IDIST,
     5XMAX,LCRIT,X,XP,ILOAD,ULINK,USPD,DUM,ALPHA,BETA,GAMMA,DELTA,
     6JWIST,CON,C,A1,A2,A3,A4,B,BB,BD,IPREND,ITIME,CAPCH,PCCAP,ERUR,
     7NEFE,EFE,SUMM,AVSUMM,AVDIFF,NDIFF,DIFF,NNO,ICRIT,IFR,DEL,TCOST1,
     8TCOST2,VCUM,PP,P,S,Q,QQ,ICOST,CT,CD
      REWIND 1
      REWIND 2
      READ ARRAY FROM TAPE 2,TRIPS
      READ ARRAY FROM TAPE 2,DISTN
      DO 601 J=1,36
      DO 601 K=1,36
  601 TRIPS(J,K)=DISTN(J,K)
      PRINT 605
  605 FORMAT(28H1   TRIP DISTRIBUTION MATRIX//)
      DO 550 J=1,NCENT
      DO 550 K=1,NCENT,12
      KK=K+11
  550 PRINT 551,(TRIPS(J,L),L=K,KK),J,K,KK
  551 FORMAT((12F8.0),2X,3HPTM,I2,1H,,I2,1H=,I2)
  609 CONTINUE
      PRINT 610
  610 FORMAT(1H1)
     PL1=1
     PK1(L1)=1
      READ ARRAY FROM TAPE1,RA
      IF(ITER-1)31,32,32
   31 XRA(1)=0.
      XRA(2)=0.
   32 DO 10 I=1,24
   10 XRA(I)=RA(I)
      WRITE ARRAY TO TAPE 2,XRA
      J=1
      PRINT 520,J,(RA(II),II=2,24)
      NO(1)=RA(3)
      ND(1)=RA(4)
      DO 2 L=2,NLINK
      READ ARRAY FROM TAPE 1,RA
      IF(ITER-1)33,34,34
   33 XRA(1)=0.
      XRA(2)=0.
   34 DO 15 I=1,24
   15 XRA(I)=RA (I)
      WRITE ARRAY TO TAPE 2,XRA
      PRINT 520,L,(RA(II),II=2,24)
  520 FORMAT(I5,11F10.2/12F10.2)
      NO(L)=RA(3)
      ND(L)=RA(4)
      IF(NO(L)-NO(L-1)) 4,2,3
    4 PRINT 111,L
  111 FORMAT (5H CARD,I3, 26H IN LINK DECK OUT OF ORDER)
      CALL EXIT
    3PL1=L1+1
     PK1(L1)=L
```

Skips the distribution matrix 'TRIPS' and assigns to array TRIPS the interzonal 'separation' matrix previously stored in array DISTN

Outputs trips matrix

Reads array from 1st magnetic tape, checks that origin and destination nodes are in order and writes to 2nd magnetic tape

```
      DO 6 I=1,NLINK
    6 VOL(I)=0.0
      REWIND 2
      DO 20 I=1,2
   20 READ ARRAY FROM TAPE2,DISTN
      NFLAG=1
      IT=1
      RETURN
      END
```

Clears the storage positions for the total load that can be put on network if all trips were put on it

REFERENCE TABLES

0	00000/0	601	00010/5	605	00024/2
609	00053/3	610	00055/0	31	00063/3
33	00117/0	34	00121/0	15	00122/0
2	00157/4	3	00154/1	111	00153/4

```
      ROUTINE COMPILED
      TIME  LESS THAN 7 SECS
      NUMBER OF INSTRUCTION WORDS 130
      * * * * * * * * * * * * * * * * *

NUMBER OF INSTRUCTION WORDS 0130

EXTERNAL ROUTINES REQU.
  NET301  WONT08  WONT10  WONT40  WONT42  WONT41  WONT11  DONT84    EXIT
*FORTRAN
```

```
EGTRAN COMPILER        MARK NO. 302        DATE    07/11/74        TIME
      SUBROUTINE NET302(I,J)
      DIMENSION NO(450),ND(450),TLINK(450),TCUM(60),NN(175),TSUM(175),
     1K1(175),NSKIP(8),TREE(70),RA(24),TRIPS(36,36),DISTN(36,36),
     2N(68),XRA(24),TR(36),VOL(450),NCUM(60),IFR(6),CON(10,10),
     4DUM(10,10),USPD(450),ULINK(450),XP(450),VCUM(450),LLOAD(450),
     5LLAST(450),TLAST(450),LCOST1(450),LCOST2(450),TCOST1(450),
     6TCOST2(450)
      COMMON NO,ND,TLINK,TCUM,NCUM,NN,TSUM,K1,NSKIP,CAP,KAPCL,DIST,
     1TREE,RA,XRA,TRIPS,N,TR,VOL,A,SPD,NCURV,FFL,FFS,WL,VC,LLOAD,
     3LLAST,TLAST,LCOST1,LCOST2,IC1,IC2,KC,NCENT,NFLAG,IT,NLINK,DISTN,
     4ITER,NTREE,NCM,NM,TMIN,NTEST,NNODE,NHOME,NSTOP,NODIST,IDIST,
     5XMAX,LCRIT,X,XP,ILOAD,ULINK,USPD,DUM,ALPHA,BETA,GAMMA,DELTA,
     6JWIST,CON,C,A1,A2,A3,A4,B,BB,BD,IPREND,ITIME,CAPCH,PCCAP,ERUR,
     7NEFE,EFE,SUMM,AVSUMM,AVDIFF,NDIFF,DIFF,NNO,ICRIT,IFR,DEL,TCOST1,
     8TCOST2,VCUM,PP,P,S,Q,QQ,ICOST,CT,CD
      DO 77 I=1,NCENT
      DO 8 J=1,NCENT
      TR(J)=TRIPS(I,J)
      IF(J-I) 15,8,15
   15 READ ARRAY FROM TAPE 1,TREE
      IF(TREE(3))77,21,21
   21 PN(1)=TREE(3)
      DO 22 M=4,70
      MM=M-2
      PN(MM)=TREE(M)
      IF(N (MM)-NCENT)25,25,22
   25 IF(N(MM)-I)50,20,50
   22 CONTINUE
   20 IF(N(1)-J) 50,17,50
   17 IF(TR(J)) 8,8,18
   18 K=MM-1
      DO 12 M=1,K
      L1=N(M+1)
      L2=K1(L1)
      DO 14 L=L2,NLINK
      IF(N(M+1)-NO(L)) 14,11,14
   11 IF(N(M)-ND(L)) 14,13,14
   14 CONTINUE
      NFLAG=2
      RETURN
   13 VOL(L)=VOL(L)+TR(J)
      LL=L
   12 CONTINUE
    8 CONTINUE
   77 CONTINUE
      REWIND1
      IC2=ITER+1
      PRINT 103,IC2
      IC2=0
  103 FORMAT(///7X,8HITER NO.,I3,6X,11HTOTAL LOADS//)
      DO 90 I=1,NLINK
      READ ARRAY FROM TAPE1,XRA
      XRA(1)=VOL(I)
      WRITE ARRAY TO TAPE2,XRA
   90 PRINT 109,(XRA(J),J=1,24)
  109 FORMAT(12F10.2)
      RETURN
   50 NFLAG=2
      NTEST=1
      PRINT 106,J,I
  106 FORMAT(7HPATH TO,I3,4HFROM,I3,40HOUT OF ORDER   CONTAINS NONEXISTE
     2NT LINK)
      CALL EXIT
      END
```

Trips from centroid i to all other centroids

Locates each link which is part of the path from i to j, and increases its traffic load by TR(J)

Changes the load on the 2nd magnetic tape and prints out the new values for examinations

```
EGTRAN COMPILER          MARK NO. 302          DATE     07/11/74          TIME
      SUBROUTINE NET401
      DIMENSION NO(450),ND(450),TLINK(450),TCUM(60),NN(175),TSUM(175),
     1K1(175),NSKIP(8),TREE(70),RA(24),TRIPS(36,36),DISTN(36,36),
     2N(68),XRA(24),TR(36),VOL(450),NCUM(60),IFR(6),CON(10,10),
     4DUM(10,10),USPD(450),ULINK(450),XP(450),VCUM(450),LLOAD(450),
     5LLAST(450),TLAST(450),LCOST1(450),LCOST2(450),TCOST1(450),
     6TCOST2(450)
      COMMON NO,ND,TLINK,TCUM,NCUM,NN,TSUM,K1,NSKIP,CAP,KAPCL,DIST,
     1TREE,RA,XRA,TRIPS,N,TR,VOL,A,SPD,NCURV,FFL,FFS,WL,VC,LLOAD,
     3LLAST,TLAST,LCOST1,LCOST2,IC1,IC2,KC,NCENT,NFLAG,IT,NLINK,DISTN,
     4ITER,NTREE,NCM,NM,TMIN,NTEST,NNODE,NHOME,NSTOP,NODIST,IDIST,
     5XMAX,LCRIT,X,XP,ILOAD,ULINK,USPD,DUM,ALPHA,BETA,GAMMA,DELTA,
     6JWIST,CON,C,A1,A2,A3,A4,B,BB,BD,IPREND,ITIME,CAPCH,PCCAP,ERUR,
     7NEFE,EFE,SUMM,AVSUMM,AVDIFF,NDIFF,DIFF,NNO,ICRIT,IFR,DEL,TCOST1,
     8TCOST2,VCUM,PP,P,S,G,GG,ICOST,CT,CD
   91 REWIND1
      REWIND2
      ITER=ITER+1
      XMAX=1.
      LCRIT=0.
      IC2=1
      READ ARRAY FROM TAPE2,TRIPS
      READ ARRAY FROM TAPE2,DISTN
      DO 35 I=1,NLINK
      READ ARRAY FROM TAPE2,XRA
      PRINT 999,(XRA(J),J=1,24)
  999 FORMAT(12F10.2)
      PJ=VOL(I)
      VOL(I)=XRA(1)
      PVCUM(I)=XRA(2)
      CAP=XRA(8)
      KAPCL=XRA(12)
      IF(VOL(I))12,35,12
   12 GO TO (35,15,15,35,35),KAPCL
   15 PX=(CAP-VCUM(I))/VOL(I)
      IF(XMAX-X)35,35,13
   13 XMAX=X
      LCRIT=I
   35 CONTINUE
      IF(1.-A/100.-XMAX)7,7,9
    7 XMAX=1.-A/100.
      LCRIT=0
    9 DO 10 I=1,NLINK
      VCUM(I)=VCUM(I)+XMAX*VOL(I)
      PXP(I)=VCUM(I)
   10 CONTINUE
      XMAX=XMAX*(100.-A)+0.005
      A=A+XMAX
      IF(ITER-6)39,41,41
   39 IF(100.-A)41,41,40
   41 ILOAD=3
      IC2=IC2+1
   40 PRINT 119, ITER,LCRIT,XMAX,A
  119 FORMAT (30X,13HITERATION NO.,I3//11HCRIT.LINK =,I4,18H. PERCENT LO
     1ADED =,F7.2,9H. TOTAL =,F7.2//6X,4HFROM,3X,2HTO,2X,14HIST  MILES 1
     2ST,2X,21HCAPA-  CAP.    CUMUL.,3X,8HNEW  NEW,5X,7HREMARKS/17X,4HTI
     3ME,7X,16HMPH  CITY  CLASS,4X,6HVOLUME,3X,8HTIME MPH/)
      RETURN
      END
```

Calculates maximum proportion of complete trips matrix which can be load (XMAX) and determines the critical link (LCRIT)

Adjusts XMAX so that no more than 100% of trip matrix will be load.

Adds appropriate volume to the link

```
                                  REFERENCE TABLES
   0     00000/0          91     00000/5          999     00026/5
  15     00042/2          13     00047/1            7     00056/5
```

```
EGTRAN COMPILER        MARK NO. 302        DATE    07/11/74        TIME
      SUBROUTINE CAPRE
      DIMENSION NO(450),ND(450),TLINK(450),TCUM(60),NN(175),TSUM(175),
     1K1(175),NSKIP(8),TREE(70),RA(24),TRIPS(36,36),DISTN(36,36),
     2N(68),XRA(24),TR(36),VOL(450),NCUM(60),IFR(6),CON(10,10),
     4DUM(10,10),USPD(450),ULINK(450),XP(450),VCUM(450),LLOAD(450),
     5LLAST(450),TLAST(450),LCOST1(450),LCOST2(450),TCOST1(450),
     6TCOST2(450),P(8),S(8)
      COMMON NO,ND,TLINK,TCUM,NCUM,NN,TSUM,K1,NSKIP,CAP,KAPCL,DIST,
     1TREE,RA,XRA,TRIPS,N,TR,VOL,A,SPD,NCURV,FFL,FFS,WL,VC,LLOAD,
     3LLAST,TLAST,LCOST1,LCOST2,IC1,IC2,KC,NCENT,NFLAG,IT,NLINK,DISTN,
     41TER,NTREE,NCM,NM,TMIN,NTEST,NNODE,NHOME,NSTOP,NODIST,IDIST,
     5XMAX,LCRIT,X,XP,ILOAD,ULINK,USPD,DUM,ALPHA,BETA,GAMMA,DELTA,
     6JWIST,CON,C,A1,A2,A3,A4,B,BB,BD,IPREND,ITIME,CAPCH,PCCAP,ERUR,
     7NEFE,EFE,SUMM,AVSUMM,AVDIFF,NDIFF,DIFF,NNO,ICRIT,IFR,DEL,TCOST1,
     8TCOST2,VCUM,PP,P,S,Q,QQ,ICOST,CT,CD
      DIAGNOSTIC PRINT
      REWIND1
      REWIND2
      IC2=1
      ITER=ITER+1
      IF(ITER-1)31,30,31
   30 READ 118,(P(I),I=1,4)
      READ 118,(S(I),I=1,4)
  118 FORMAT(4F10.2)
      PRINT 119,(P(I),I=1,4)
  119 FORMAT(//////49X,4H****,3X,19HLOADING PERCENTAGES,3X,4H****//
     132X,4HP(I),4F10.2)
      PRINT 120,(S(I),I=1,4)
  120 FORMAT(//32X,4HS(I),4F10.2)
      PP=0.0
   31 PP=PP+P(ITER)-S(ITER)
      READ ARRAY FROM TAPE2,TRIPS
      READ ARRAY FROM TAPE2,DISTN
      DO 39 I=1,NLINK
      READ ARRAY FROM TAPE2,XRA
      PVOL(I)=XRA(1)
      PVCUM(I)=XRA(2)
      PXP(I)=VOL(I)*P(ITER)/100.*VCUM(I)
      PVCUM(I)=XP(I)*PP/(PP+S(ITER))
   39 CONTINUE
      IF(S(ITER))33,33,34
   33 ILOAD=3
      IC2=IC2+1
   34 CONTINUE
      RETURN
      END
```

Reads loading percentages if iteration number is one

Outputs loading percentages read for checking

Adds the specified loading percentages to the link load.

Removes a specified percentage from the link load

```
                                                    REFERENCE TABLES
    0    00000/0          31    00047/3          30    00007/1
  120    00046/3          39    00101/2          33    00105/5

       ROUTINE COMPILED
       TIME  LESS THAN 5 SECS
       NUMBER OF INSTRUCTION WORDS 74
       * * * * * * * * * * * * * * * * * *


NUMBER OF INSTRUCTION WORDS 0074


EXTERNAL ROUTINES REQU.
   CAPRE  WONT08  WONT30  WONT31  WONT32  WONT40  WONT41  WONT42  WONT10
*FORTRAN
```

```
EGTRAN COMPILER        MARK NO. 302        DATE    07/11/74        TIME
      SUBROUTINE FLOITR
      DIMENSION NO(450),ND(450),TLINK(450),TCUM(60),NN(175),TSUM(175),
     1KI(175),NSKIP(8),TREE(70),RA(24),TRIPS(36,36),DISTN(36,36),
     2N(68),XRA(24),TR(36),VOL(450),NCUM(60),IFR(6),CON(10,10),
     4DUM(10,10),USPD(450),ULINK(450),XP(450),VCUM(450),LLOAD(450),
     5LLAST(450),TLAST(450),LCOST1(450),LCOST2(450),TCOST1(450),
     6TCOST2(450)
      COMMON NO,ND,TLINK,TCUM,NCUM,NN,TSUM,KI,NSKIP,CAP,KAPCL,DIST,
     1TREE,RA,XRA,TRIPS,N,TR,VOL,A,SPD,NCURV,FFL,FFS,WL,VC,LLOAD,
     3LLAST,TLAST,LCOST1,LCOST2,IC1,IC2,KC,NCENT,NFLAG,IT,NLINK,DISTN,
     4ITER,NTREE,NCM,NM,TMIN,NTEST,NNODE,NHOME,NSTOP,NODIST,IDIST,
     5XMAX,LCRIT,X,XP,ILOAD,ULINK,USPD,DUM,ALPHA,BETA,GAMMA,DELTA,
     6JWIST,CON,C,A1,A2,A3,A4,B,BB,BD,IPREND,ITIME,CAPCH,PCCAP,ERUR,
     7NEFE,EFE,SUMM,AVSUMM,AVDIFF,NDIFF,DIFF,NNO,ICRIT,IFR,DEL,TCOST1,
     8TCOST2,VCUM,PP,P,S,Q,QQ,ICOST,CT,CD
      REWIND2
      PRINT 150
  150 FORMAT(26H ITERATION NO. FOR FLOWITR,6X,2HXP)
      ITER=ITER+1
      READ ARRAY FROM TAPE2,TRIPS  } Reads Trips and Distribution Matrices
      READ ARRAY FROM TAPE2,DISTN  }   out of the way
      DO 3 I=1,NLINK
      READ ARRAY FROM TAPE2,XRA
      VOL(I)=XRA(1)
      VCUM(I)=XRA(2)
      VCUM(I)=VOL(I)/ITER+VCUM(I)*(ITER-1)/ITER  <- Adjusts the link loads
      XP(I)=VCUM(I)
    3 PRINT 151,ITER,XP(I)
  151 FORMAT(23X,I5,F8.2)
      RETURN
      END

                                                    REFERENCE TABLES
    0    00000/0          150    00003/2            3    00025/4

        ROUTINE COMPILED
        TIME  LESS THAN 4 SECS
        NUMBER OF INSTRUCTION WORDS 32
        * * * * * * * * * * * * * * * * *

NUMBER OF INSTRUCTION WORDS 0032

EXTERNAL ROUTINES REQU.
  FLOITR  WONT08  WONT40  WONT42  WONT10  DONT83  WONT41
*FORTRAN
```

```
EGTRAN COMPILER        MARK NO. 302        DATE    12/11/74        TIME
      SUBROUTINE TNETIM
      DIMENSION NO(450),ND(450),TLINK(450),TCUM(60),NN(175),TSUM(175),
     1K1(175),NSKIP(8),TREE(70),RA(24),TRIPS(36,36),DISTN(36,36),
     2N(68),XRA(24),TR(36),VOL(450),NCUM(60),IFR(6),CON(10,10),
     4DUM(10,10),USPD(450),ULINK(450),XP(450),VCUM(450),LLOAD(450),
     5LLAST(450),TLAST(450),LCOST1(450),LCOST2(450),TCOST1(450),
     6TCOST2(450)
      COMMON NO,ND,TLINK,TCUM,NCUM,NN,TSUM,K1,NSKIP,CAP,KAPCL,DIST,
     1TREE,RA,XRA,TRIPS,N,TR,VOL,A,SPD,NCURV,FFL,FFS,WL,VC,LLOAD,
     3LLAST,TLAST,LCOST1,LCOST2,IC1,IC2,KC,NCENT,NFLAG,IT,NLINK,DISTN,
     4ITER,NTREE,NCM,NM,TMIN,NTEST,NNODE,NHOME,NSTOP,NODIST,IDIST,
     5XMAX,LCRIT,X,XP,ILOAD,ULINK,USPD,DUM,ALPHA,BETA,GAMMA,DELTA,
     6JWIST,CON,C,A1,A2,A3,A4,B,BB,BD,IPREND,ITIME,CAPCH,PCCAP,ERUR,
     7NEFE,EFE,SUMM,AVSUMM,AVDIFF,NDIFF,DIFF,NNO,ICRIT,IFR,DEL,TCOST1,
     8TCOST2,VCUM,PP,P,S,Q,QQ,ICOST,CT,CD
      REWIND2
      PRINT 130
  130 FORMAT(1H1)
      IC2=IC2+1
      READ ARRAY FROM TAPE2,TRIPS   } Reads trips and distribution matrices
      READ ARRAY FROM TAPE2,DISTN   } out of the way
      DO 16 I=1,NLINK
      READ ARRAY FROM TAPE2,XRA
      VOL(I)=XRA(1)
      TLINK(I)=XRA(5)
      DIST=XRA(6)
      SPD=XRA(7)
      CAP=XRA(8)
      ULINK(I)=XRA(10)
      USPD(I)=XRA(11)
      KAPCL=XRA(12)
      LLOAD(I)=XRA(18)
      TLAST(I)=XRA(20)
      LCOST1(I)=XRA(21)
      LCOST2(I)=XRA(22)
      NUM=I
      GO TO (30,36,36,25,72),KAPCL
   25 JWIST=1 <- Identifies dummy links
      GO TO 55
   30 JWIST=2 <- Identifies local links
      GO TO 55
   36 IF(VCUM(I)/(CAP*Q)-0.5)40,40,60
   40 JWIST=3  <- Identifies arterial links for which volume/capacity <= 0.5
      IF(VCUM(I))20,21,20
   21 ULINK(I)=TLINK(I)
   20 IF(ICOST-1)11,12,12
   12 ULINK(I)=CT*ULINK(I)+CD*DIST
   11 CONTINUE
      GO TO 55
   60 GO TO (30,61,62,25,72),KAPCL
   61 ULINK(I)=TLINK(I)+VCUM(I)/CAP/(10.**(1.-VCUM(I)/(CAP*Q)))  } Identifies 'Inter-delay' links and computes new travel time
      IF(ICOST-1)7,48,48
   48 ULINK(I)=CT*ULINK(I)+CD*DIST
    7 CONTINUE
      JWIST=4
      GO TO 63
   62 ULINK(I)=TLINK(I)*(0.5+0.25/(1.-VCUM(I)/(CAP*Q)))  } Identifies 'link delay' links and computes new travel time
      IF(ICOST-1)37,38,38
   38 ULINK(I)=CT*ULINK(I)+CD*DIST
   37 CONTINUE
      JWIST=5
   63 USPD=60.*DIST/ULINK(I)
```

```
 70 ULINK(I)=ULINK(I)+500                    } identifies the critical air mass - collocal
    KAPCL=5                                    links, and adds 500 minutes to link time
 72 JWIST=6                                    to remove them from network
 64 CONTINUE
 55 GO TO (45,46,47,51,52,53),JWIST
 45 PRINT 111,NUM,NO(I),ND(I),TLINK(I),DIST,SPD,CAP,KAPCL,VCUM(I),
   1ULINK(I),USPD(I)
111 FORMAT(3I5,2F6.2,F4.0,F8.0,I3,3X,F9.0,F7.2,F4.0,11H DUMMY LINK)
    GO TO 54
 46 PRINT 112,NUM,NO(I),ND(I),TLINK(I),DIST,SPD,CAP,KAPCL,VCUM(I),
   1ULINK(I),USPD(I)
112 FORMAT(3I5,2F6.2,F4.0,F8.0,I3,3X,F9.0,F7.2,F4.0,9HLOCAL ST.)
    GO TO 54
 47 PRINT 113,NUM,NO(I),ND(I),TLINK(I),DIST,SPD,CAP,KAPCL,VCUM(I),
   1ULINK(I),USPD(I)
113 FORMAT(3I5,2F6.2,F4.0,F8.0,I3,3X,F9.0,F7.2,F4.0,7HTOO LOW)
    GO TO 54
 51 PRINT 114,NUM,NO(I),ND(I),TLINK(I),DIST,SPD,CAP,KAPCL,VCUM(I),
   1ULINK(I),USPD(I)
114 FORMAT(3I5,2F6.2,F4.0,F8.0,I3,3X,F9.0,F7.2,F4.0,12HINTER. DELAY)
    GO TO 54
 52 PRINT 115,NUM,NO(I),ND(I),TLINK(I),DIST,SPD,CAP,KAPCL,VCUM(I),
   1ULINK(I),USPD(I)
115 FORMAT(3I5,2F6.2,F4.0,F8.0,I3,3X,F9.0,F7.2,F4.0,10HLINK DELAY)
    GO TO 54
 53 PRINT 116,NUM,NO(I),ND(I),TLINK(I),DIST,SPD,CAP,KAPCL,VCUM(I),
   1ULINK(I),USPD(I)
116 FORMAT(3I5,2F6.2,F4.0,F8.0,I3,3X,F9.0,F7.2,F4.0,13H**SATURATED**)
 54 IF(ILOAD-2)57,57,58
 58 KAPCL=XRA(9)                             } Identifies the end of partial loading method
    ULINK(I)=ULINK(I)-500                      and prepares the program for total
    LLAST(I)=VCUM(I)                           loading method.
 57 CONTINUE
 16 CONTINUE
    RETURN
    END
```

Output of new link deck with traffic & loads

```
                                        REFERENCE TABLES
    0    00000/0          130    00003/2          30    00040/1
   72    00127/3           55    00130/3          40    00045/3
   21    00050/2           11    00057/4          12    00053/5
    7    00076/1           48    00072/2          63    00114/0
   64    00130/3           70    00123/3          45    00132/3
   51    00247/0           52    00300/3          53    00332/0
  112    00215/0          113    00246/3         114    00300/0
   57    00372/4           58    00364/4          16    00372/4

      ROUTINE COMPILED
      TIME  LESS THAN 11 SECS
      NUMBER OF INSTRUCTION WORDS 255
      * * * * * * * * * * * * * * * * *

NUMBER OF INSTRUCTION WORDS 0255

EXTERNAL ROUTINES REQU.
  TNETIM  WONT08  WONT40  WONT42  WONT10  DONT84  DONT50  DONT83  WONT41
*FORTRAN
```

```
EGTRAN COMPILER          MARK NO. 302          DATE    07/11/74          TIME
      SUBROUTINE MALTIM
      DIMENSION NO(450),ND(450),TLINK(450),TCUM(60),NN(175),TSUM(175),
     1K1(175),NSKIP(8),TREE(70),RA(24),TRIPS(36,36),DISTN(36,36),
     2N(68),XRA(24),TR(36),VOL(450),NCUM(60),IFR(6),CON(10,10),
     4DUM(10,10),USPD(450),ULINK(450),XP(450),VCUM(450),LLOAD(450),
     5LLAST(450),TLAST(450),LCOST1(450),LCOST2(450),TCOST1(450),
     6TCOST2(450),P(8),S(8)
      COMMON NO,ND,TLINK,TCUM,NCUM,NN,TSUM,K1,NSKIP,CAP,KAPCL,DIST,
     1TREE,RA,XRA,TRIPS,N,TR,VOL,A,SPD,NCURV,FFL,FFS,WL,VC,LLOAD,
     3LLAST,TLAST,LCOST1,LCOST2,IC1,IC2,KC,NCENT,NFLAG,IT,NLINK,DISTN,
     4ITER,NTREE,NCM,NM,TMIN,NTEST,NNODE,NHOME,NSTOP,NODIST,IDIST,
     5XMAX,LCRIT,X,XP,ILOAD,ULINK,USPD,DUM,ALPHA,BETA,GAMMA,DELTA,
     6JWIST,CON,C,A1,A2,A3,A4,B,BB,BD,IPREND,ITIME,CAPCH,PCCAP,ERUR,
     7NEFE,EFE,SUMM,AVSUMM,AVDIFF,NDIFF,DIFF,NNO,ICRIT,IFR,DEL,TCOST1,
     8TCOST2,VCUM,PP,P,S,Q,QQ,ICOST,CT,CD
      PRINT 130
  130 FORMAT(1H1)
      REWIND1
      REWIND2
      IC2=IC2+1
      IF(ITER-1)83,81,83
   81 READ 222,((DUM(I,J),I=1,5),J=1,4)
  222 FORMAT(5F10.4)
      PRINT 222,((DUM(I,J),I=1,5),J=1,4)
   83 CONTINUE
      READ ARRAY FROM TAPE2,TRIPS
      READ ARRAY FROM TAPE2,DISTN
      DO 21 I=1,NLINK
      READ ARRAY FROM TAPE2,XRA
      VOL(I)=XRA(1)
      DIST=XRA(6)
      SPD=XRA(7)
      CAP=XRA(8)
      ULINK(I)=XRA(10)
      USPD(I)=XRA(11)
      KAPCL=XRA(12)
      NCURV=XRA(13)
      WL=XRA(17)
      M=NCURV
      IF(M)11,84,11
   11 CONTINUE
      ALPHA=DUM(M,1)
      BETA=DUM(M,2)
      GAMMA=DUM(M,3)
      DELTA=DUM(M,4)
      GO TO (84,85,85,84),KAPCL
   85 IF(ILOAD-3)50,51,50
   50 T=ALPHA*(2*XP(I)/WL-GAMMA)+SQRT(ALPHA*ALPHA*(2*XP(I)/WL-
     1GAMMA)**2+BETA)+DELTA
      GO TO 53
   51 T=ALPHA*(2*VCUM(I)/WL-GAMMA)+SQRT(ALPHA*ALPHA*(2*VCUM(I)/WL-
     1GAMMA)**2+BETA)+DELTA
   53PJ=T
      IF(T-1000.)31,30,30
   30 USPD(I)=0.
      T=1000.
      GO TO 8
   31 IF(T-.2)41,41,40
   41 USPD(I)=SPD
      GO TO 25
   40 USPD(I)=60./T
    8 CONTINUE
      ULINK(I)=T*DIST
   25 IF(ICOST-1)23,24,24
```

Reads the MALTS constants from card at iteration one only and outputs them

Reads Trips and Distribution Matrices out of the way

Calculates the time spent on the unit length of the roads

```
   24 ULINK(I)=CT*ULINK(I)*CD*DIST
   23 CONTINUE
   84 CONTINUE
      LLOAD(I)=XRA(18)
      LLAST(I)=XRA(19)
      TLAST(I)=XRA(20)
      LCOST1(I)=XRA(21)
      LCOST2(I)=XRA(22)
      GO TO (1,2,2,3),KAPCL
    2 PRINT 111,I,NO(I),ND(I),TLINK(I),DIST,SPD,CAP,KAPCL,XP(I),
     1ULINK(I),USPD(I)
  111 FORMAT(3I5,2F6.2,F4.0,F8.0,I3,3X,F9.0,F7.2,F4.0)
      GO TO 21
    1 PRINT 120,I,NO(I),ND(I),TLINK(I),DIST,SPD,CAP,KAPCL,XP(I),
     1ULINK(I),USPD(I)
  120 FORMAT(3I5,2F6.2,F4.0,F8.0,I3,3X,F9.0,F7.2,F4.0,5X,9HLOCAL ST.)
      GO TO 21
    3 PRINT 121,I,NO(I),ND(I),TLINK(I),DIST,SPD,CAP,KAPCL,XP(I),
     1ULINK(I),USPD(I)
  121 FORMAT(3I5,2F6.2,F4.0,F8.0,I3,3X,F9.0,F7.2,F4.0,5X,10HDUMMY LINK)
   21 CONTINUE
      RETURN
      END
```

Output showing the adjusted speed, time and load of the link

```
                                                REFERENCE TABLES
    0     00000/0          130     00002/2          83     00041/4
   11     00065/3           84     00161/5          85     00077/0
   53     00134/5           31     00143/2          30     00140/0
   40     00147/2           25     00154/2          23     00161/5
    2     00173/4            3     00256/4         111     00224/4
  121     00307/4

        ROUTINE COMPILED
        TIME  LESS THAN 10 SECS
        NUMBER OF INSTRUCTION WORDS 204
        * * * * * * * * * * * * * * * * * *

NUMBER OF INSTRUCTION WORDS 0204

EXTERNAL ROUTINES REQU.
  MALTIM  WONT40  WONT42  WONT08  WONT30  WONT31  WONT32  WONT41  WONT10
  DONT50   SQRT  DONT83  DONT53
*FORTRAN
```

```
EGTRAN COMPILER        MARK NO. 302        DATE    07/11/74        TIME
      SUBROUTINE SELTIM
      DIMENSION NO(450),ND(450),TLINK(450),TCUM(60),NN(175),TSUM(175),
     1K1(175),NSKIP(8),TREE(70),RA(24),TRIPS(36,36),DISTN(36,36),
     2N(68),XRA(24),TR(36),VOL(450),NCUM(60),IFR(6),CON(10,10),
     4DUM(10,10),USPD(450),ULINK(450),XP(450),VCUM(450),LLOAD(450),
     5LLAST(450),TLAST(450),LCOST1(450),LCOST2(450),TCOST1(450),
     6TCOST2(450)
      COMMON NO,ND,TLINK,TCUM,NCUM,NN,TSUM,K1,NSKIP,CAP,KAPCL,DIST,
     1TREE,RA,XRA,TRIPS,N,TR,VOL,A,SPD,NCURV,FFL,FFS,WL,VC,LLOAD,
     3LLAST,TLAST,LCOST1,LCOST2,IC1,IC2,KC,NCENT,NFLAG,IT,NLINK,DISTN,
     4ITER,NTREE,NCM,NM,TMIN,NTEST,NNODE,NHOME,NSTOP,NODIST,IDIST,
     5XMAX,LCRIT,X,XP,ILOAD,ULINK,USPD,DUM,ALPHA,BETA,GAMMA,DELTA,
     6JWIST,CON,C,A1,A2,A3,A4,B,BB,BD,IPREND,ITIME,CAPCH,PCCAP,ERUR,
     7NEFE,EFE,SUMM,AVSUMM,AVDIFF,NDIFF,DIFF,NNO,ICRIT,IFR,DEL,TCOST1,
     8TCOST2,VCUM,PP,P,S,Q,QQ,ICOST,CT,CD
      REWIND2
  130 FORMAT(1H1)
      PRINT 130
      IF(ITER-1)40,41,40
   41 READ 131,((CON(I,J),I=1,7),J=1,4)
  131 FORMAT(7F10.4)
      PRINT 131,((CON(I,J),I=1,7),J=1,4)
   40 CONTINUE
      READ ARRAY FROM TAPE2,TRIPS
      READ ARRAY FROM TAPE2,DISTN
      DO 32 I=1,NLINK
      READ ARRAY FROM TAPE2,XRA
      WL=XRA(17)
      DIST=XRA(6)
      CAP=XRA(8)
      KAPCL=XRA(12)
      FFS=XRA(16)
      GO TO (32,42,42,32,32),KAPCL
   42 CONTINUE
      IF(VCUM(I))11,11,12
   11 USPD(I)=FFS
      GO TO 96
   12 IF(CAP-VCUM(I))53,54,55
   53 M=NCURV
      A1=CON(M,1)
      A2=CON(M,2)
      A3=CON(M,3)
      A4=CON(M,4)
      C=A1*WL/2.+A2*DIST+A3
      BD=C*C-4*A4*VCUM(I)
      IF(BD)15,15,16
   15 B=0.
      GO TO 9
   16 B=SQRT(BD)
      IC2=0
      IF(C-B)4,4,6
    4 IC2=IC2+1
      GO TO 9
    6 SPD1=0.5*(C-B)
    9 USPD(I)=0.5*(C+B)
      IF(USPD(I)-80)96,96,8
    8 IF(IC2-1)21,20,21
   20 USPD(I)=80
      GO TO 96
   21 USPD(I)=SPD1
      GO TO 96
   54 USPD(I)=FFS*FFS/4.*CAP
   96 ULINK(I)=DIST*60./USPD(I)
```

Reads the SELNEC SPEED/FLOW relationship constants from card at iteration equal to one and prints them.

Reads Trips and Distribution matrices out of the way

Solves for the speed in the SELNEC speed/flow relationship and then determines the time or cost.

```
   19 ULINK(I)=ULINK(I)*CT+DIST*CD
   18 CONTINUE
      GO TO 32
   55 SPD1=FFS*FFS/4.*CAP
      ULINK(I)=DIST*60./SPD1+2.5*(VCUM(I)/CAP-1)
      IF(ICOST-1)27,28,28
   28 ULINK(I)=ULINK(I)*CT+DIST*CD
   27 CONTINUE
      USPD(I)=DIST*60./ULINK(I)
   32 CONTINUE
      RETURN
      END

                                                    REFERENCE TABLES
    0    00000/0          130    00001/5          40    00037/0
   32    00175/3           42    00055/3          11    00057/2
   53    00065/3           54    00136/3          55    00153/3
    9    00122/1            4    00115/4           6    00117/5
   20    00131/1           18    00153/0          19    00147/1

      ROUTINE COMPILED
      TIME  LESS THAN 8 SECS
      NUMBER OF INSTRUCTION WORDS 130
      * * * * * * * * * * * * * * * * * *

NUMBER OF INSTRUCTION WORDS 0130

EXTERNAL ROUTINES REQU.
  SELTIM  WONT08  WONT40  WONT42  WONT30  WONT31  WONT32  WONT41  WONT10
  DONT50  DONT83   SQRT
*FORTRAN
```

```
EGTRAN COMPILER        MARK NO. 302        DATE    07/11/74        TIME
      SUBROUTINE CONVER
      DIMENSION NO(450),ND(450),TLINK(450),TCUM(60),NN(175),TSUM(175),
     1K1(175),NSKIP(8),TREE(70),RA(24),TRIPS(36,36),DISTN(36,36),
     2N(68),XRA(24),TR(36),VOL(450),NCUM(60),IFR(6),CON(10,10),
     4DUM(10,10),USPD(450),ULINK(450),XP(450),VCUM(450),LLOAD(450),
     5LLAST(450),TLAST(450),LCOST1(450),LCOST2(450),TCOST1(450),
     6TCOST2(450),P(8),S(8)
      COMMON NO,ND,TLINK,TCUM,NCUM,NN,TSUM,K1,NSKIP,CAP,KAPCL,DIST,
     1TREE,RA,XRA,TRIPS,N,TR,VOL,A,SPD,NCURV,FFL,FFS,WL,VC,LLOAD,
     3LLAST,TLAST,LCOST1,LCOST2,IC1,IC2,KC,NCENT,NFLAG,IT,NLINK,DISTN,
     4ITER,NTREE,NCM,NM,TMIN,NTEST,NNODE,NHOME,NSTOP,NODIST,IDIST,
     5XMAX,LCRIT,X,XP,ILOAD,ULINK,USPD,DUM,ALPHA,BETA,GAMMA,DELTA,
     6JWIST,CON,C,A1,A2,A3,A4,B,BB,BD,IPREND,ITIME,CAPCH,PCCAP,ERUR,
     7NEFE,EFE,SUMM,AVSUMM,AVDIFF,NDIFF,DIFF,NNO,ICRIT,IFR,DEL,TCOST1,
     8TCOST2,VCUM,PP,P,S,Q,QQ,ICOST,CT,CD
      REWIND1
      REWIND2
      NDIFF=0
      NEFE=0
      ITIMCH=0
      NCHLI=0.0
      NCASS=0
      NCOLO=0
      SUMM=0.
      TIMEX=0
      ERUR=0.0
      COSDI1=0
      COSDI2=0
      CHFLOW=0
      PRINT 120
  120 FORMAT(///9H ITER. NO,4X,6HIFR(1),4X,6HIFR(2),4X,6HIFR(3),4X,
     16HIFR(4),4X,6HIFR(5),4X,6HIFR(6))
      DO 13 I=1,6
   13 IFR(I)=0
      ICRIT=1
      IF(ITER-1)200,200,100
  100 DO 10 I=1,NLINK
      IF(LLOAD(I))10,10,45
   45 CONTINUE
      IF(ICRIT.EQ.2)DEL=ABS(XP(I)-LLOAD(I))/LLOAD(I)
      IF(ICRIT.EQ.1)DEL=ABS(ULINK(I)-TLAST(I))/TLAST(I)
      IF(DEL-0.05)23,23,24
   23 IFR(1)=IFR(1)+1
      GO TO 10
   24 IF(DEL-0.1)25,25,26
   25 IFR(2)=IFR(2)+1
      GO TO 10
   26 IF(DEL-0.3)27,27,28
   27 IFR(3)=IFR(3)+1
      GO TO 10
   28 IF(DEL-0.5)31,31,32
   31 IFR(4)=IFR(4)+1
      GO TO 10
   32 IF(DEL-1.)33,33,34
   33 IFR(5)=IFR(5)+1
      GO TO 10
   34 IFR(6)=IFR(6)+1
   10 CONTINUE
      PRINT 121,ITER,(IFR(J),J=1,6)
  121 FORMAT(//I5,6I10)
      DO 300 J=1,6
  300 IFR(J)=0
      ICRIT=ICRIT+1
```

Clean the frequency table for use in the program

Sets up the frequency table for the values of DEL and then outputs the table.

Clears the table for any likely repeat calculation of DEL

```
200 CONTINUE
    READ ARRAY FROM TAPE2,TRIPS
    READ ARRAY FROM TAPE2,DISTN
    DO 48 I=1,NLINK
    READ ARRAY FROM TAPE2,XRA
    CAP=XRA(8)
    LLOAD(I)=XRA(18)
    LLAST (I)=XRA(19)
    TLAST(I)=XRA(20)
    LCOST1(I)=XRA(21)
    LCOST2(I)=XRA(22)
    IF(ILOAD-3)37,35,37
 35 IF(LLAST(I))36,37,36
 37 DIFF=0.
    GO TO 41
 36 DIFF=ABS(XP(I)-LLAST(I))/LLAST(I)
    IF (DIFF-0.1)41,41,42
 42 NDIFF=NDIFF+1
 41 SUMM=SUMM+DIFF
    TCOST1(I)=TLAST(I)*XP(I)
    TCOST2(I)=ULINK(I)*XP(I)
    IF(TCOST1(I))38,39,38
 39 DELPR1=0.
    GO TO 7
 38 DELPR1=ABS(LCOST1(I)-TCOST1(I))/TCOST1(I)
    IF(DELPR1-0.1)7,7,8
  8 NCASS=NCASS+1
  7 COSDI1=COSDI1+DELPR1
    IF(TCOST2(I))46,47,46
 47 DELPR2=0.
    GO TO 9
 46 DELPR2=ABS(LCOST2(I)-TCOST2(I))/TCOST2(I)
    IF(DELPR2-0.1)9,9,53
 53 NCOLO=NCOLO+1
  9 COSDI2=COSDI2+DELPR2
    IF(XP(I))49,50,49
 50 DELINK=0.
    GO TO 14
 49 DELINK=ABS(LLOAD(I)-XP(I))/XP(I)
    IF(DELINK-0.1)14,14,15
 15 NCHLI=NCHLI+1
 14 CHFLOW=CHFLOW+DELINK
    DELTIM=ABS(TLAST(I)-ULINK(I))/ULINK(I)
    IF(DELTIM-0.1)16,16,17
 17 ITIMCH=ITIMCH+1
 16 TIMEX=TIMEX+DELTIM
    EFE=ABS(XP(I)-CAP)/CAP
    IF(EFE-0.1)21,21,22
 22 NEFE=NEFE+1
 21 ERUR=ERUR+EFE
    XRA(1)=0.
    XRA(2)=VCUM(I)
    XRA(10)=ULINK(I)
    XRA(11)=USPD(I)
    XRA(18)=XP(I)
    IF(IC2-3)81,82,81
 82 XRA(19)=XP(I)
 81 CONTINUE
    XRA(20)=ULINK(I)
    XRA(21)=TCOST1(I)
    XRA(22)=TCOST2(I)
    WRITE ARRAY TO TAPE1,XRA
 48 CONTINUE
    REWIND1
    PRINT 400
400 FORMAT(//1X,6HAVDIF1,1X,6HAVDIF2,4X,6HAVGFL0,1X,5HTTCCH2,4X
```

Calculates the convergence indicators and outputs them

```
     15HTCCH2,7X,4HTLCH,7X,3HCCH,4X,6HPRPTIM,6X,5HCAPCH,4X,5HPCCAP,4X,
     26HAVSUMM,4X,6HAVDIFF//)
      AVDIFF=NDIFF/NLINK
      AVSUMM=SUMM/NLINK
      AVDIF1=COSDI1/NLINK
      AVDIF2=COSDI2/NLINK
      AVCFLO=CHFLOW/NLINK
      TCCH1=NCASS/NLINK
      TCCH2=NCOLO/NLINK
      TLCH=NCHLI/NLINK
      CCH=ITIMCH/NLINK
      PRPTIM=TIMEX/NLINK
      CAPCH=ERUR/NLINK
      PCCAP=NEFE/NLINK
      PRINT 444,AVDIF1,AVDIF2,AVCFLO,TCCH1,TCCH2,TLCH,CCH,PRPTIM,
     1CAPCH,PCCAP,AVSUMM,AVDIFF
  444 FORMAT(12F10.3)
      IF(ITER-4)71,71,2
    2 IF(ITER-NNO)90,78,78
   90 IF(AVDIF1-0.1)70,70,71
   70 IF(AVDIF2-0.1)72,72,71
   72 IF(AVCFLO-0.1)73,73,71
   73 IF(TCCH1-0.1)74,74,71
   74 IF(TCCH2-0.1)75,75,71
   75 IF(TLCH-0.1)76,76,71
   76 IF(CCH-0.1)77,77,71
   77 IF(PRPTIM-0.1)78,78,71
   71 IPREND=1
      RETURN
   78 IPREND=2
      RETURN
      END
```

Tests the convergence criteria

```
                                                REFERENCE TABLES
    0    00000/0          120    00020/3          13    00021/3
   10    00074/3           45    00033/1          23    00051/2
   26    00057/2           27    00061/0          28    00063/1
   33    00070/4           34    00072/5         121    00110/3
   35    00142/3           36    00145/5          41    00156/2
   39    00165/1            7    00176/4           8    00175/0
    9    00213/4           53    00212/0          49    00220/4
   15    00227/0           16    00241/5          17    00240/1
   81    00265/1           82    00263/2          48    00273/0
   71    00401/2            2    00362/2          90    00364/0
   72    00367/2           73    00371/0          74    00372/4
   77    00377/4

       ROUTINE COMPILED
       TIME  LESS THAN 18 SECS
       NUMBER OF INSTRUCTION WORDS 263
       * * * * * * * * * * * * * * * * *

NUMBER OF INSTRUCTION WORDS 0262

EXTERNAL ROUTINES REQU.
  CONVER  WONT08  DONT84  WONT40  WONT42  DONT57   EXIT  DONT83  WONT41
  WONT11 DONT52
*PREDATA

JOB ORGANISED  17.46.47        07/11/74
```

A C K N O W L E D G E M E N T S

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