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INTERACTIVE-GRAPHIC FACILITIES FOR BUS SERVICE DESIGN

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ABSTRACT: *The total process of planning and operating urban bus services comprises a complex set of inter-related tasks. One of these tasks, service design, is concerned with identifying opportunities for operational efficiency gains and assessing the impacts of proposed new or modified services. This paper considers the information needs for service design and the adequacy of existing data collection and processing techniques in providing this information. It appears that there is need for processing facilities which would enable use of detailed trip-end data and facilitate the designer's search for improved service arrangements. The paper then presents and briefly demonstrates an interactive and graphics based processing system, designed to meet these requirements. Features of the system are that it: is structured for portability between design situations and computing equipment; requires low-cost digitising facilities; and, could aid in service design in a range of urban situations. Several issues associated with predicting the impacts of service changes are briefly discussed. The paper concludes with an indication of directions for further development of the system.*

INTRODUCTION

In recent years there has been widespread interest in improving the efficiency and effectiveness of urban fixed-route public transport systems. This efficiency-effectiveness objective has given rise to the development of detailed network analysis techniques to aid in comprehensive reviews of existing bus networks and assessments of alternative networks (Last 1979a, Rieple et al. 1978, Andreasson 1977). Bowyer and Last (1980) indicate that these network assessment techniques have met with mixed success in practice and there now exists uncertainty as to their utility in many urban situations, particularly at the urban corridor, or sub-area, level (Barrett et al. 1979, Veitch 1979).

The efficiency-effectiveness objective has given rise to many studies at the urban corridor level (Hellewell 1979, Barrett et al. 1979, Alan M. Voorhees 1979, Loder and Bayley 1977, Melbourne and Metropolitan Tramways Board 1979). A feature common to these studies has been the detailed investigation of particular services, to either identify opportunities for operational efficiency gains or assess the possible impacts of new or modified services. Barrett et al. (1979) refer to this as the 'service design' task. They argue that it calls for detailed and accurate data, particularly relating to travel demand, and for analytical techniques which can provide information appropriate to the design task.

This paper considers the information needs at the corridor level of investigation and the adequacy of existing techniques in providing such information. It then presents an alternative technique, based on interactive and graphic facilities, and indicates its potential as an aid to service design.

BUS NETWORK PLANNING AND SERVICE DESIGN

Tasks and Techniques The total process of planning and operating urban bus services comprises a complex set of inter-related tasks. As depicted in Fig. 1, the total process spans from the broad, infrequent strategic planning task, through to the very detailed, and frequent, task of scheduling vehicles and crews to particular bus services. Many tasks lie between these two extremes and they might be loosely classified as either network planning or service design. Of interest to this paper is the relationship between network planning, service design and resource scheduling tasks.

Network planning studies are typically concerned with comparisons of alternative bus networks or service policies.

ACKNOWLEDGEMENT: The bus service and travel survey data used in this paper were supplied by the Metropolitan Transit Authority, Brisbane. The support of Mr. M. Veitch and Mr. I. Scholes is strongly acknowledged. The responsibility for interpretation of the analyses rests, of course, solely with the authors.

SCALE, FREQUENCY	GENERAL TASKS			
	Strategic Planning	Network Planning	Service Design	Resource Scheduling
Physical Scale	System Wide	System-Wide, Corridor	System-Wide, Corridor, Service	Service
Time Scale	Long-Term	Long-Medium	Short-Medium	Short-Term
Frequency of Task	Infrequent	Infrequent	Occasional	Frequent

Figure 1 - Bus Service Planning - Design Process

Comparisons are usually made in terms of total system operating costs and user benefits, based on networks defined by routes and service policies defined by frequencies and fares on routes. Network analysis techniques (Urban Mass Transportation Administration 1977, Last 1979a) are developed on this level of detail and are intended as aids to the network planning task. In practice, however, these techniques have met with mixed success, the primary problems being related both to the data required for the techniques and to the utility of the information generated from them. More particularly, input data is costly to collect and maintain and information generated lacks detail on travel impacts (Veitch 1979) and realism in terms of service timing and coordination and, thus, vehicle utilisation. Significant manual 'adjustments' are often required to enable the resource scheduling task (Fig. 1) to be undertaken (Last 1979b).

As a consequence, recent attention both in practice and in technique development has focused on the intermediate task of service design. The common interest is on identifying and designing specific service improvements rather than on broad comparisons of total networks. This requires attention not just to route locations and service frequencies but also to service timing, coordination and resource scheduling.

In the European context, this is still being viewed as a network-wide task because of the high urban densities and complex transport networks (Andreasson 1977). Network planning techniques have been enhanced. They now utilise interactive and graphic facilities to aid in identifying and designing service improvements, and detailed algorithms to reflect service coordination and vehicle scheduling processes. Elsewhere, service design practice appears to be related more to the corridor scale and analytical techniques are much less automated. In the MAP system (Barrett et al. 1979), for example, computer facilities aid the processing and reporting of travel survey and bus service data. However, the service designer has then to manually relate the resultant information and to identify and design options for service improvements. A similar, but less structured approach seems to have been taken in reported Australian studies (Loder and Bayley 1977, Alan M. Voorhees 1979).

<u>Information Forms and Analysis Issues</u> Corridor-level service design studies appear to have two common elements- assessment of existing conditions to identify supply inefficiencies or deficiencies, and prediction of the impacts of proposed new or modified services. These two elements require information to:

(a) describe and quantify the components of existing person-journeys;

(b) describe existing services and quantify usage;

(c) identify and quantify factors influencing travel choice; and,

(d) estimate the impacts of new or modified services on operating costs and traveller segments.

On-board travel surveys and operating records provide the primary data sources to meet these four needs. Travel-surveys can vary in form but typically provide data on the items listed in Table 1. Several important issues arise with regard to the procedures which have been used in practice for processing and analysing these data sources. These issues relate to the storage and use of data on trip-ends and travellers, and to the techniques for predicting impacts.

TABLE 1 - Items Typically Surveyed in Corridor Level Studies

<u>Trip (or Journey) Details</u>

- **Origin, destination — purpose (e.g. work)**
  — location (street reference)
- **Access, egress arrangements — mode(s) used**
  — distance travelled
- **Ticket types**
- **Frequency of travel**

<u>Person Details</u>

- **Sex**
- **Age**

<u>Factors Influencing Travel Choice</u>

- **Vehicle availability for the journey**
- **Travel constraints — time of travel**
  -- mode(s) of travel

Data on trip-end locations is commonly sought. This is coded to some zonal reference system, from which travel patterns can be generated. This raises the issue of the adequacy of zonal-based data for bus service design. Intuitively, the importance of this issue will depend on a number of factors. These include zone size, zonal homogeneity, zonal orientation about the bus route(s), and the form of investigations and level of detail sought. Zonal reference systems used in Australia are commonly based on the census collection districts (CCD). However, Figure 2 suggests caution in the use of the CCD. It can be seen that zones vary markedly in size and, in some cases, are not oriented about the bus routes. Further, travellers who walk to the bus will board at points nearest their trip-end. These trips will not be accurately represented by a zonal centroid and associated connector to the bus network. Data based on the CCD would therefore seem suitable only for coarse travel analyses. To investigate existing services or assess the impacts of proposed service changes on travellers it is necessary to go to very fine zones (Barrett et al. 1979) or perhaps to a person-record (Alan M. Voorhees 1979).

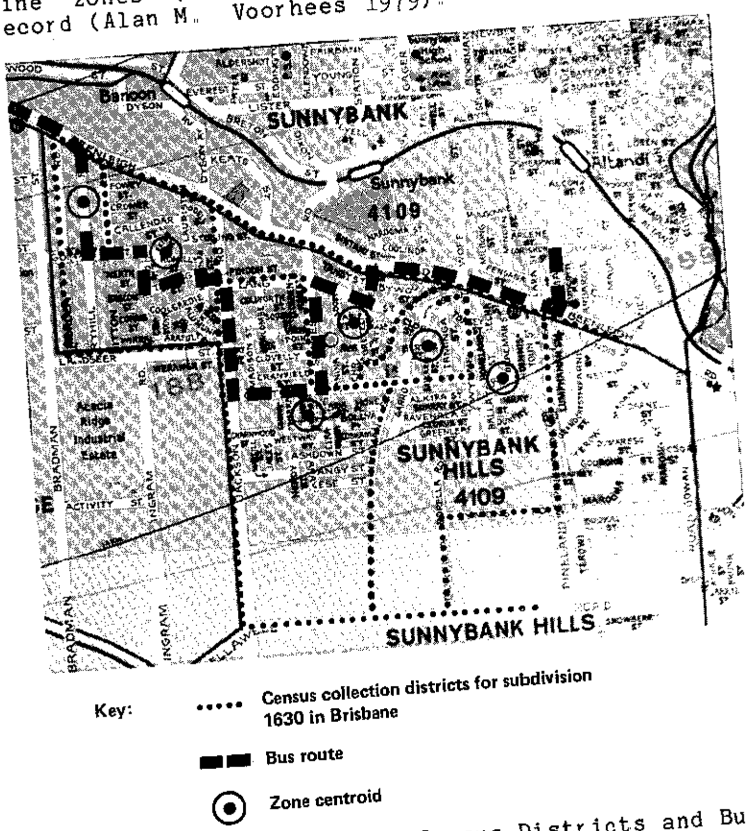

Figure 2 - Relationship Between Census Districts and Bus Routes

Data describing travellers and their journeys varies in form and use across reported studies. There is common interest in the segmentation of travel data on various items (including travel purpose, traveller 'type', time period), to profile a corridor and aid in the assessment of existing conditions. Also, Veitch (1979) indicates that in some situations, identification of impacts across traveller segments is highly desirable to assist in gaining political acceptance of proposed new or modified services. Standard survey analysis techniques are suited to the general task of segmenting and tabulating travel data, although they typically do not enable interactive search. More importantly, such techniques do not aid the matching of travel demand to particular services, which Barrett (1979) and Veitch (1979) indicate are necessary for service design.

Finally, the prediction of travel behaviour changes resulting from service changes is commonly recognised as a variable and potentially complex task. Minor changes to school bus services, for example, are not likely to induce any change in travel behaviour. On the other hand, restructuring of several services to improve coordination and operational efficiency could induce varied changes across traveller groups or segments (i.e change in service used on a route, in route used, or in mode used). In reported studies a range of prediction techniques has been used and it would seem that no one technique is appropriate to all situations.

It seems then that there is need for data processing and analysis techniques to complement existing techniques in the service design task. Processing facilities to aid the investigation and assessment of existing conditions would seem to be a first priority. These should enable storage and use of more detailed trip-end data and facilitate the designer's search for improved service arrangements. The processing system should also be structured to enable interfacing with prediction techniques appropriate to particular situations and travel data forms.

INTERACTIVE AND GRAPHIC FACILITIES

While interactive and graphic facilities have been extensively employed in network planning-design techniques, they have not found similar use at the corridor level. This section considers how an interactive-graphic system might meet the above general statement of processing-analysis need.

System Structure

A necessary start point is to specify the basic function and conditions which the processing system should meet. These might be expressed as:

(a) aid the investigation of existing bus services and the design of new or modified services in an urban corridor;

(b) use commonly collected and readily available data sources;

(c) be easy to use; and,

(d) be easily adaptable to different corridor and user situations and computing equipment.

A general system structure consistent with these criteria is depicted in Fig. 3. The primary data sources which it requires are on-board travel surveys and operating records for the services covered by the corridor of interest. In addition, some form of mapping for the street network is required. The main processing- analysis phases can be viewed as data preparation, corridor definition, assessment and prediction. A brief comment on the modules in the corridor definition and the prediction phases is appropriate before considering the other two modules in some detail.

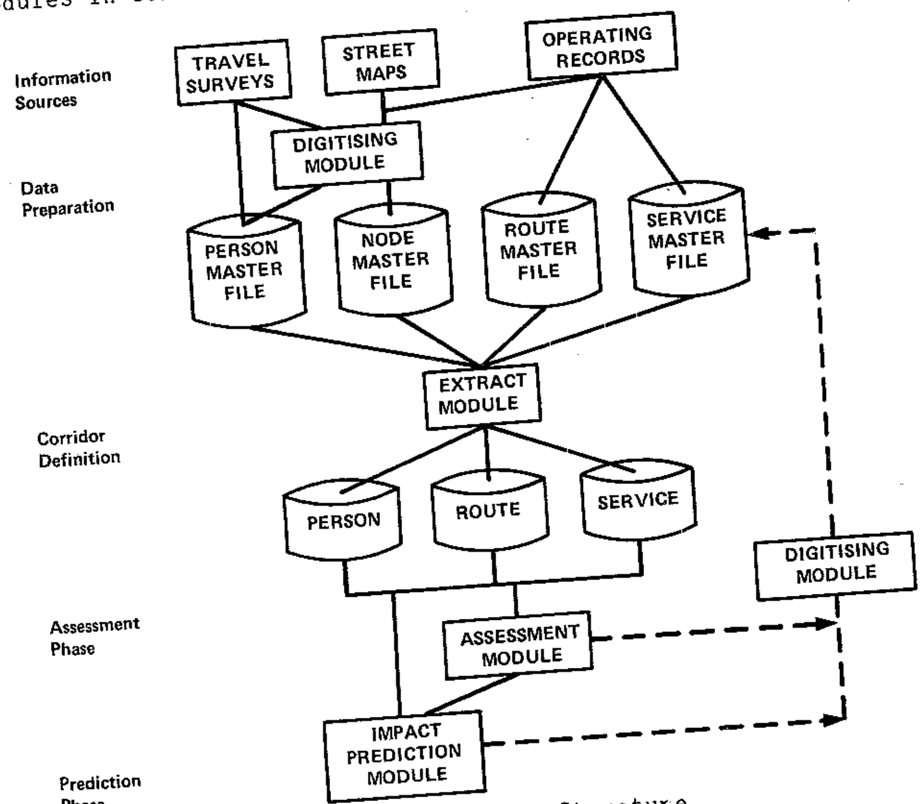

Figure 3 - System Structure

<u>Corridor Definition</u> The extent of a corridor can be difficult to specify in detail and, as Loder and Bayley (1977) note, the corridor might vary within an investigation, depending on the particular forms of enquiry being undertaken. Hence there is need for a facility to enable the designer to easily define

and redefine a corridor. The EXTRACT module provides such a facility. The user can define a time-space corridor on a set of criteria (e.g. a particular bus route or a service within a route) and the module extracts all appropriate travel and service data and produces files for subsequent phases. This extract process is particularly important in situations where one has master files spanning a large part of the urban area or where one is limited to the file handling capabilities of a micro-processor.

<u>Prediction Phase</u> There are two common tasks in this phase: predicting the response of travellers and, perhaps, non-travellers to some proposed service change; and, estimating the impact of this response on bus services. The complexity of these tasks is likely to be strongly dependent on a number of factors, including the type and scale of service change; the conditions prevailing in a corridor, the time period for assessment, and the travel choice related data items collected in the travel surveys. At one extreme, minor changes in the routing or timing of a school bus service is likely to induce no change in travel behaviour, since school travellers are likely choice-constrained. This prediction phase would then be primarily concerned with estimating changes in operating costs. At the other extreme, restructuring of several bus services to act as feeders to a line-haul service (bus or rail) could induce a varied set of changes in travel behaviour and service usage. For example, a restructured feeder service will load its passengers on at an early point of the line-haul service and could have an impact on those travellers who board at later points. If line-haul capacity is limited, then some of these travellers might respond by changing to a later service or another mode. The detailed analysis of these changes is likely to be complex and involve some form of interative analysis of demand and supply changes, reflecting the varied impacts on traveller segments.

Because of the diversity and possible complexity of the prediction phase, a rigorous treatment is beyond the scope of this paper and, in fact, the current development of the interactive-graphic system. However, the person and service based data files are consistent with the information detail required by existing travel choice prediction techniques. It would be feasible, therefore, to develop an impact prediction module which provides options appropriate to a range of situations either directly or by interfacing with other systems.

<u>Digitising Module</u>

The portability and ease of use conditions, set as a basis for the system, have implications for the form of the digitising module. Two basically different approaches can be taken to the digitising task - use a comprehensive street index reference system, or use a direct referencing system for bus routes and person trip ends. A street index system enables any address oriented data to be automatically converted to some set of co-ordinates. Comprehensive, metropolitan-wide index systems have been, or are being developed, in many cities overseas (Gehner 1978) and in some Australian cities (Field 1980). These are powerful data sources, usually related to a national grid. However, they require substantial effort and specialised computing resources to develop and maintain. Thus they would seem restricted to use in situations where corridor studies are large and frequent and where service designers have ready access to computing facilities capable of accessing and processing the index system.

In the interests of portability and ease of use, particularly towards the small-scale or infrequent design situations, a direct referencing approach has been taken. While less detailed than the street index approach, it requires only low cost and readily available mapping, such as in urban street directories. Digitising equipment costs will depend on the user's existing computing facilities. If these require only the addition of a digitiser, then the equipment cost could be as low as $A2000 (Computer Graphics World 1980). A data set relating to the two bus routes shown in Fig. 4 has been generated using a street directory and a Tektronix 4662 digitiser/plotter, interfaced to a Tektronix 4025 graphics display terminal. The

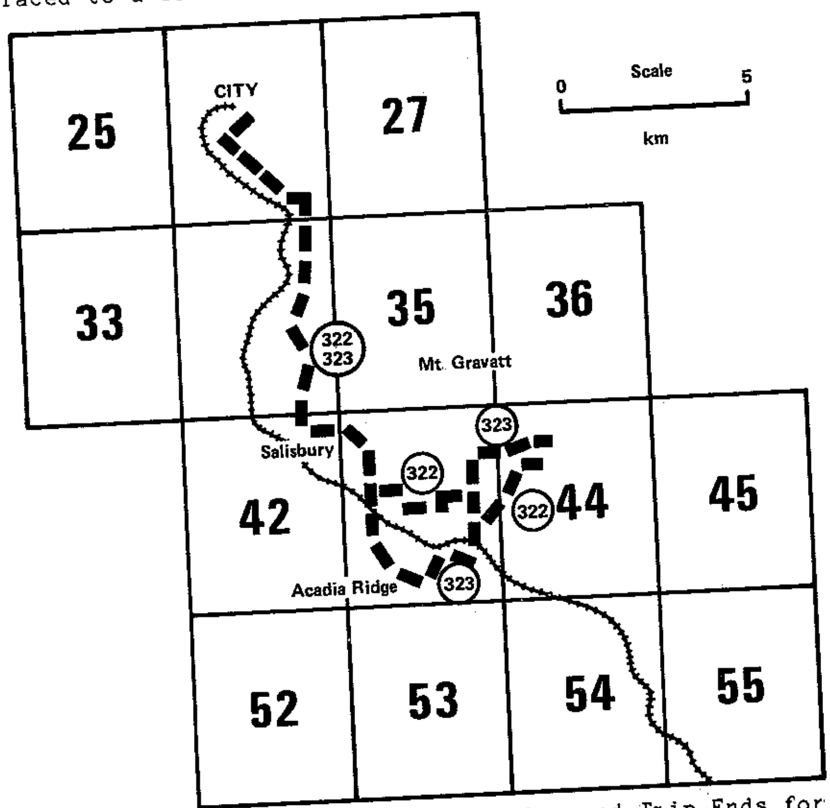

Figure 4 - Maps for Digitising Routes and Trip-Ends for Bus Routes 322, 323, Brisbane

central processor is a Cyber 171/NOS, which is much more powerful than is necessary for this particular case. The co-ordinate reference system is established by indexing the corners of each directory map to some convenient reference point. In this case the GPO is taken as the co-ordinate origin and thirteen directory maps are sufficient to span the travel patterns for persons travelling on the two bus routes.

Digitising of bus routes and person trip ends is conducted under program control. It requires the user to place and initialise the appropriate map on the digitiser, successively locate points to be digitised, and press a button to transmit the co-ordinates. For bus routes this is a fast process, requiring some 30 minutes for the 90 bus stops on route 322 (Fig. 4). The time requirement is much more variable for person trip-ends. It depends primarily on the user's knowledge of the street system and on the spread of trip-ends within a map. In this case, with reasonable knowledge of the street system, 50 trips (100 trip-ends) required of the order of one hour. A survey procedure in which travellers indicate the trip end(s) on a map (Loder and Bayley 1977) would substantially reduce this time.

Assessment Module

Perhaps the most critical word relating to this module is 'options'. The notion of interactive search and graphic display is potentially powerful for the bus service designer, but potentially hazardous for the computer system designer.

By its nature, interactive search involves the user in exploring a sequence of questions, with the form of each question being, typically, dependent on the outcome of the preceeding question(s). Such processes can become somewhat open-ended and complex as the number of questions or options for search increases. A simple example could involve the service designer beginning by wishing to develop an understanding of the travel and operating characteristics for a particular bus route. This requires the specification of an option on a bus route, but not on persons. On the findings from this step, the designer might wish to investigate other options, to provide a more detailed and informative picture of conditions. These options could require specifications on services within the route (e.g. peak services) or person segments (e.g. those travelling to school, those who walk to the bus).

A processing structure such as that depicted in Fig. 5 facilitates such lines of enquiry. It provides options in basically three ways- through the specification of conditions on buses and persons and on general output details, the form(s) of processing to be undertaken, and the device(s) on which output is desired. A brief indication of the possible options is given in Fig. 5. The sequence of program instructions which the designer might use in beginning to investigate existing services is shown in Fig. 6. As indicated in Fig. 6, the system has its own internal 'command language' (e.g. /BUS) which enables the designer to interact with the system and specify options via a set of simple commands and associated parameters. The command language enhances the flexibility and ease of use of the system.

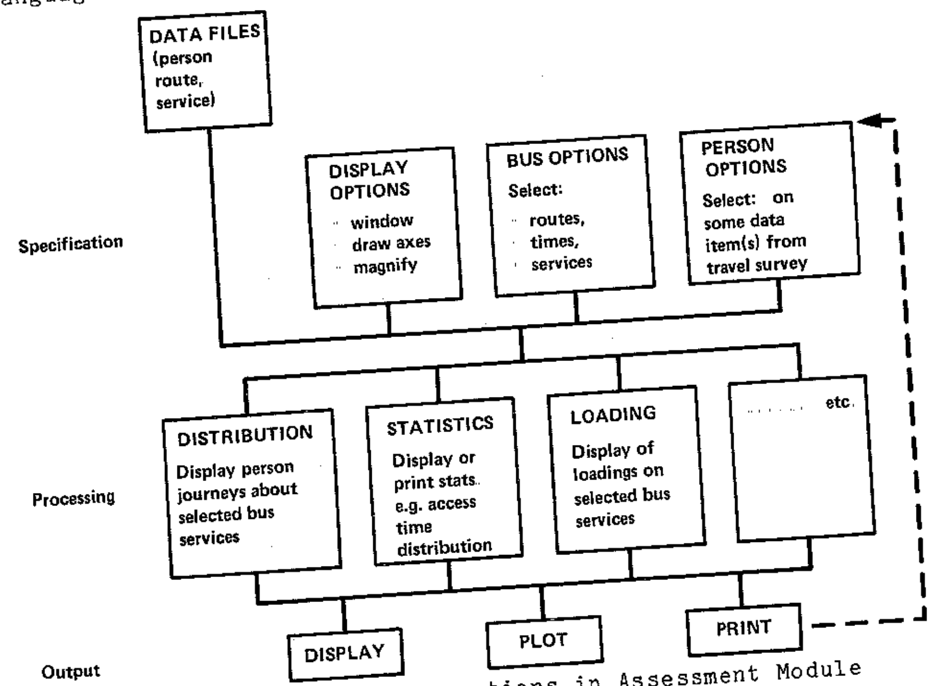

Figure 5 - Primary Interactions in Assessment Module

SEARCH STEP	PROGRAM INSTRUCTIONS	INTERPRETATION
1	/BUS	– Call in bus selection routine
	7,322	– Select route 322
	/DIS	– Display route 322 and the distribution of journeys for persons using this route
2	/BUS	– Call in bus selection routine
	7,*	– Select all routes in the corridor
	/DIS	– Display all routes and associated person journeys

Figure 6 - Instruction Sequence for a Two Step Search

Two other features are of general importance. The first concerns programming language and operating systems. The system is written in FORTRAN V and the internal command language uses only FORTRAN facilities. This therefore minimise the dependence of the system on the operating system features of the host computer (currently NOS on the Cyber 171). Operating system independence is necessary to facilitate transfer of the technique to different computing systems. The second feature is also related to device independence. The system does not use any special-purpose graphics generating software. Rather, it generates a unitised output file for all co-ordinate data. This can then be interrogated during the interactive session by separate device-related routines (e.g. DISPLAY, PLOT, PRINT in Fig. 5) to generate output files appropriate to the desired device.

<u>Application of the Assessment Module</u> Data for the 'corridor' defined in Fig. 4 provides a base for seeing how the assessment module might be used to investigate existing services. The corridor is defined by two bus routes (322, 323 in Fig. 4) and an adjacent rail route. Two questions might be posed:

(a) are the bus routes and services efficiently designed?; and,

(b) is bus-rail coordination feasible and at which station?

Both of these questions call for a detailed understanding of the operating conditions and travel arrangements related to the two routes. One start point for developing this understanding could be to draw a sample of travellers on each route and investigate their travel arrangements. The investigation will involve specifying a sequence of program instructions, of the form shown in Fig. 6, to select buses, persons, displays and processing options. One option, the distribution of persons travelling on the two routes in the peak period (7.30-8.30 am), produces displays of the form shown in Figs. 7 and 8. Fig. 7 indicates a significant proportion of persons with long access distances - presumably by bus or car. What do we find if we consider only those who walk to or from the bus? Fig. 8 provides several interesting observations:

(a) There are two sections of low utilisation in which operational efficiencies might be improved without too severe an impact on travellers. These involve (Fig. 8a) running the service short at A on route 322 and route relocation along B for route 323;

(b) A long walk access occurs from outside the corridor (intersecting the Y-axis at -12 km). This questions the adequacy of services in that area;

(c) There is no obvious bus-rail link prior to Salisbury station (Fig. 8a); and,

(d) Beyond Salisbury station, a high proportion of trip ends are within close proximity to rail stations (Fig. 8b). This suggests that bus-rail coordination at Salisbury could be feasible.

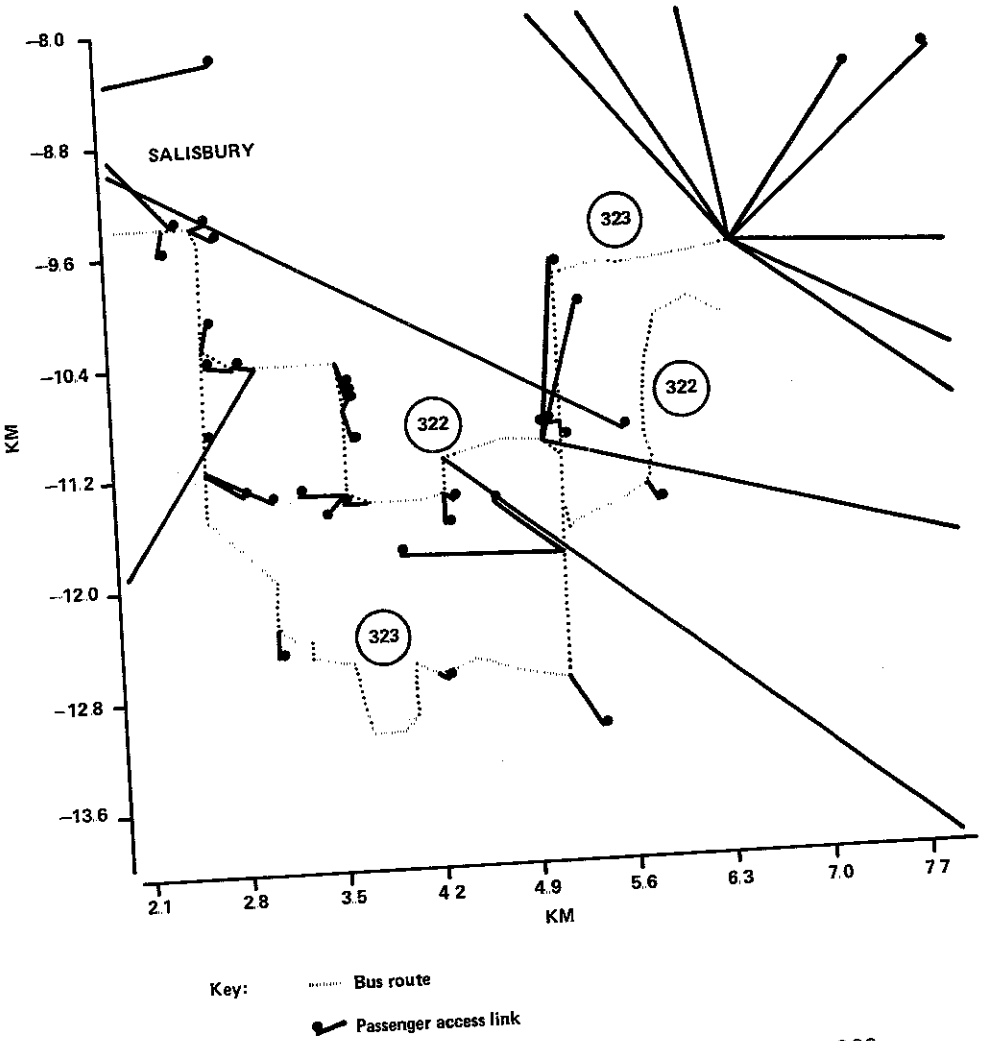

Figure 7 - Passenger Distribution on Routes 322, 323 Prior to Salisbury

A number of lines of enquiry might be considered from this point. Perhaps the most productive would be to draw a larger sample of persons and services and test whether the initial observations (a) and (d) are supported by the larger sample. Further enquiry into observation (a) could be facilitated by selecting only those travellers who have trip ends within the areas of interest and by windowing displays to obtain a more detailed view. If the initial observation is supported, then the digitising module (Fig. 3) could be used to generate a

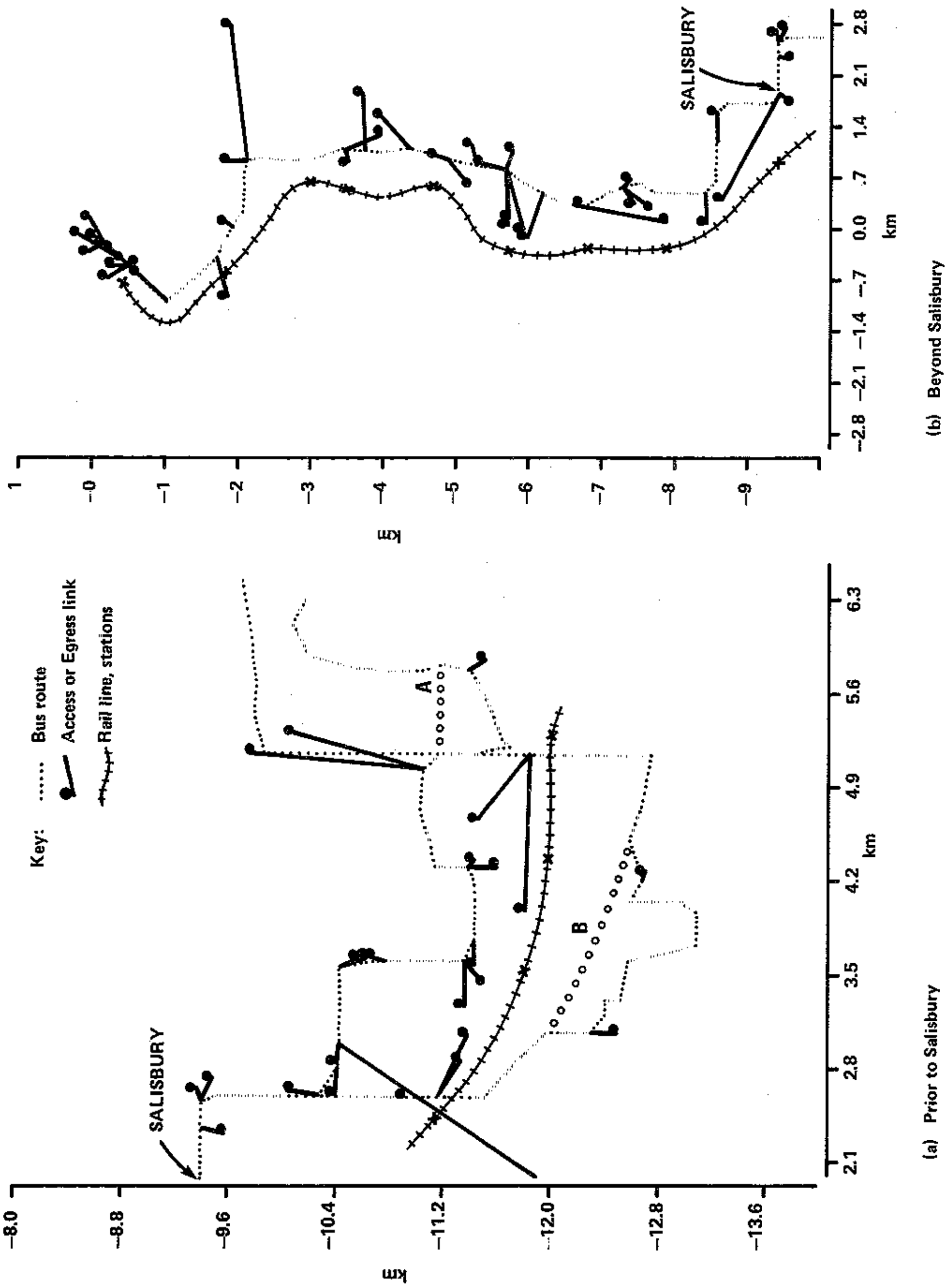

Figure 8 - Passenger Distribution for Persons Who Walk to or From the Bus

revised route and service file. In turn, the assessment module could provide a statistical report of the change in traveller conditions.

This example has been concerned with modifying existing bus services. The assessment module could also aid the design of bus services in previously uncovered areas. Home-based travel surveys could provide trip-end locations, desired times for travel, and indications of the likely tolerable access-egress distances for persons who would use a bus service. With these data, the assessment module could aid in determining the best location for the bus route(s) and timing of service(s).

CONCLUSIONS

Corridor-level bus service design appears to be a widely occurring task. While service design studies have location specific features, they have several features in common. These are the requirement for detailed investigation of existing conditions and prediction of impacts of service changes, and the use of person-based travel surveys.

Existing processing and analysis techniques lose detail in trip information, through zonal reference systems, and have limited facilities for aiding the investigation of existing conditions and the design of improved services. The interactive-graphic system presented in this paper could complement and, in some situations, replace existing techniques. It provides a flexible framework for interactive search with graphic display or other output forms to facilitate the design process. The system has a modular structure with isolated device-dependent routines, uses only FORTRAN code and has flexible low-cost digitising facilities. These features should enable its adaptation to suit a wide range of situations, in terms of physical conditions and user computing facilities. Future development effort should be directed towards increasing the processing options in the assessment module and specifying a prediction module appropriate to service design situations in Australian cities.

Note: Conditions for the supply of the programs by ARRB can be obtained from the authors.

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