Using Geographic Information Systems To Identify Bus Passengers

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ABSTRACT

Traditionally bus routes have largely been designed on the basis of historical precedence and bus passenger information regarding usage (frequency and purpose of journey) and user (demographic or socio-economic) characteristics has been obtained through user surveys. New technologies including 'Geographic Information Systems' (GIS), offer the ability to reconsider the design of bus routes by integrating survey data with additional information, particularly census data. The key advantages of a GIS approach to bus passenger information are the ability to produce maps of passenger characteristics which are a powerful means of gaining insights to patterns contained within complex data and also the ability to optimise routes using conventional linear programming approaches which may then be mapped. This paper will show how GIS technologies may be applied to: (1) explore 'potential' user characteristics including evaluation of the extent to which the bus service is serving the potential market and (2) optimise bus routes with respect to user characteristics. These new approaches to obtaining, analysing and displaying bus passenger information are relevant for regional councils when tendering for bus services and also operators in finding the most cost effective means of providing bus services.

INTRODUCTION

1. The route configuration of bus services, along with that of many other transport services, has traditionally been based on historical precedent, within the framework of a production-orientated approach to the provision of such services. For example, rail services have been designed to connect with sea ferry terminals and long distance coach routes have their termini in parts of towns that many travellers would not normally visit. Consequently, little attention has been paid to redesigning existing services with a market or customer orientation, to respond to changing customer needs. Having said this, urban bus transit services which have a much more flexible infrastructure than other transport modes, have attempted to respond to changing residential patterns, serving new housing developments for example. However, there is little evidence in the literature to suggest that this is part of a market orientation and the suspicion remains that many services are still designed with a greater emphasis being placed on operational efficiency rather than a real willingness to identify and target particular customers and design a bus service to meet their needs.

2. One reason for the lack of attention to passenger needs may be an inability of the part of either transport operators or regional councils to identify where potential users may be found. Origin destination components of on board surveys, while useful in providing information about the travel patterns of existing customers do not help in identifying where further customers may be found. The spatial nature of a bus service means that the actual location of the passenger is of much greater significance than for many other service industries.

3. This paper will demonstrate how Geographic Information Systems (GIS) can contribute to a more market oriented approach to the design of bus services by providing the planner with both survey and census data in an easily interpretable, visual, format and how these data may be integrated with implications for service and route design. First however, it is appropriate to provide a short introduction to GIS and identify why this technology is useful to transport planners.

GEOGRAPHIC INFORMATION SYSTEMS

4. A GIS is:

> *"an organised collection of computer hardware, software, geographic data and personnel designed to efficiently capture, store, update, manipulate, analyse and display all forms of geographically referenced information"* (ESRI 1990).

5. It has been suggested that as much as 85% of the information held in corporate databases contains some geographic element such as an address, post code or telephone area code (Baker and Baker, 1993). GIS systems allow marketers, planners and operators to plot customer and other information on a map which will allow underlying geographic trends and relationships to be more clearly identified. The digital 'map' is constructed from areal units which are used as the basis for data display, for example, the number of households with one child under 5 years old. There are three standard areal units for New Zealand; territorial land areas, area units and meshblocks. The meshblocks contain between 150 and 200 households and are the finest level of resolution readily accessible. In other countries, particularly The Unites States of America, spatial databases are maintained at much more detailed levels.

6. Perhaps the most powerful feature of a GIS approach is its ability to present complex information in a form which is easily understood by personnel throughout the organisation, particularly those who are less familiar with the data, for example, executive management, but who will make decisions based on it. Increasingly complex data are presented by adding layers to the map so that individual features can be viewed or a combination of many features.

GIS IN BUSINESS

7. GIS have been used widely in natural resources management as both investigative tools and also decision support systems. The applications presented at a recent GIS user conference range from measuring the distance of elephant herds from roads in the Gabon (Beardsley and Barnes, 1995) to developing a local atlas for school children in Greece (Doganis, 1995). One of the most active areas of GIS usage is utility companies and local authorities planning for utility and water resource demand. It is estimated that already over half the cities and district councils in New Zealand use GIS to help manage infrastructure assets and that

some will use it to meet accounting requirements for public works assets (Hansen, 1995).

8. The fastest growing segment of the GIS industry is business applications. In turn, GIS are one of the fastest growing business computer applications (Beam, 1994) as more companies recognise the insights to be gained from being able to map their customers quickly and manipulate customer information on a map. An additional key factor has been the fall in price of both user friendly GIS software and the hardware required to run such an application. Within the business community GIS use has primarily been directed towards land use issues and also location analysis, including geodemographics.

TRANSPORT USES OF GIS

9. The inherently spatial nature of transport services would appear to make them an obvious area for GIS application. Transport applications of GIS include road and traffic environmental impact assessment (Filian and Higelin, 1995) and location and response times of emergency vehicles (Zura and Lipar, 1995). Prompted by declining ridership levels the San Diego Association of Governments (SANDAG) has used GIS to develop an integrated decision support tool called View2Transit for transport planners and operators (Culp and Woodall, 1995). The application allows decision makers to access a number of spatial databases which include historical, current estimates and forecasts of population, housing and employment, transit ridership, transit stop characteristics and route alignment. This however, is one of the few applications of GIS to urban passenger transport and is primarily concerned with light-rail.

10. This paper reports on an initial application of GIS to urban bus passenger transport. Unfortunately the restrictions of black and white paper publishing dilute the impact of the GIS approach which is best demonstrated in a colour dynamic environment.

METHODOLOGY

11. The data for this study were derived from 3 sources:
    i An on-board passenger survey conducted by Otago Regional Council
    ii. Census data held in geographically referenced digital databases.
    iii. Additional spatial data constructed for study purposes.

SURVEY DATA

12. The Otago Regional Council (ORC) survey was conducted on 10 routes serving Dunedin and suburbs. Three thousand, one hundred and seventy responses were obtained over a one week period. Each passenger was geographically referenced by both their boarding stop and also alighting stop. The geographical referencing

of the bus stops is addressed in paragraph 14. The primary focus of this survey was the measurement of service levels as part of the Regional Council's ongoing monitoring of bus services. However, demographic and socio-economic data were collected as part of this survey which could then be employed in developing user profiles for each of the routes surveyed (paragraph 15). The survey data were initially entered into Dbase but was then transferred to SPSS on an Otago University Vax computer for further analyses.

CENSUS DATA

13. GIS facilitate greater use of census data where each piece of census data is linked to the household from which it is collected. The census data were extracted from 2 databases, the VIEWNZ data distributed by Eagle Technology Group Ltd and the Small Area Database for the Otago Regional Council Area prepared by the Customer Services Section, Department of Statistics, Christchurch. The contribution of these organisations, along with that of the Department of Survey and Land Information (DOSLI) is gratefully acknowledged. Relevant census data were plotted to provide demographic and socio-economic profiles of bus routes using ARCINFO on a HP900 workstation in the Otago University Spatial Information Laboratory. ARCVIEW2 was also used for mapping on a 486dx computer (16mb RAM) within a windows environment. The figures presented in this paper were developed in ARCVIEW2 with data exported from ARCINFO. Hard copy colour output was produced on HP560C colour ink jet and HP1200ps printers using HP CX series cut paper.

ADDITIONAL SPATIAL DATA

14. Where spatial data were not pre-existing they were created in the Spatial Information Laboratory. The major task, was to convert bus stop locations to a GIS format which could be plotted on a map. The bus routes were also constructed, allowing distance measurement for the total route and also between bus stops. The routes surveyed are presented in Figure 1. Although the survey only covered 10 primary routes, when all the route variations were included this increased to over 30 routes for analysis purposes. It was then possible to match user characteristics to boarding and alighting stops. This will be addressed in a forthcoming publication.

ROUTE PROFILES FOR POTENTIAL USERS

15. The potential users of bus services were defined as residents of meshblocks where the centre of the meshblock was within 500m of the route on flat terrain and 375m of hilly terrain. The choice of which variables to map was determined by the overlap between the census data and survey data. The selected variables are presented in table 1. The variables for age, gender and number of household vehicles available can be matched directly between census and survey data.

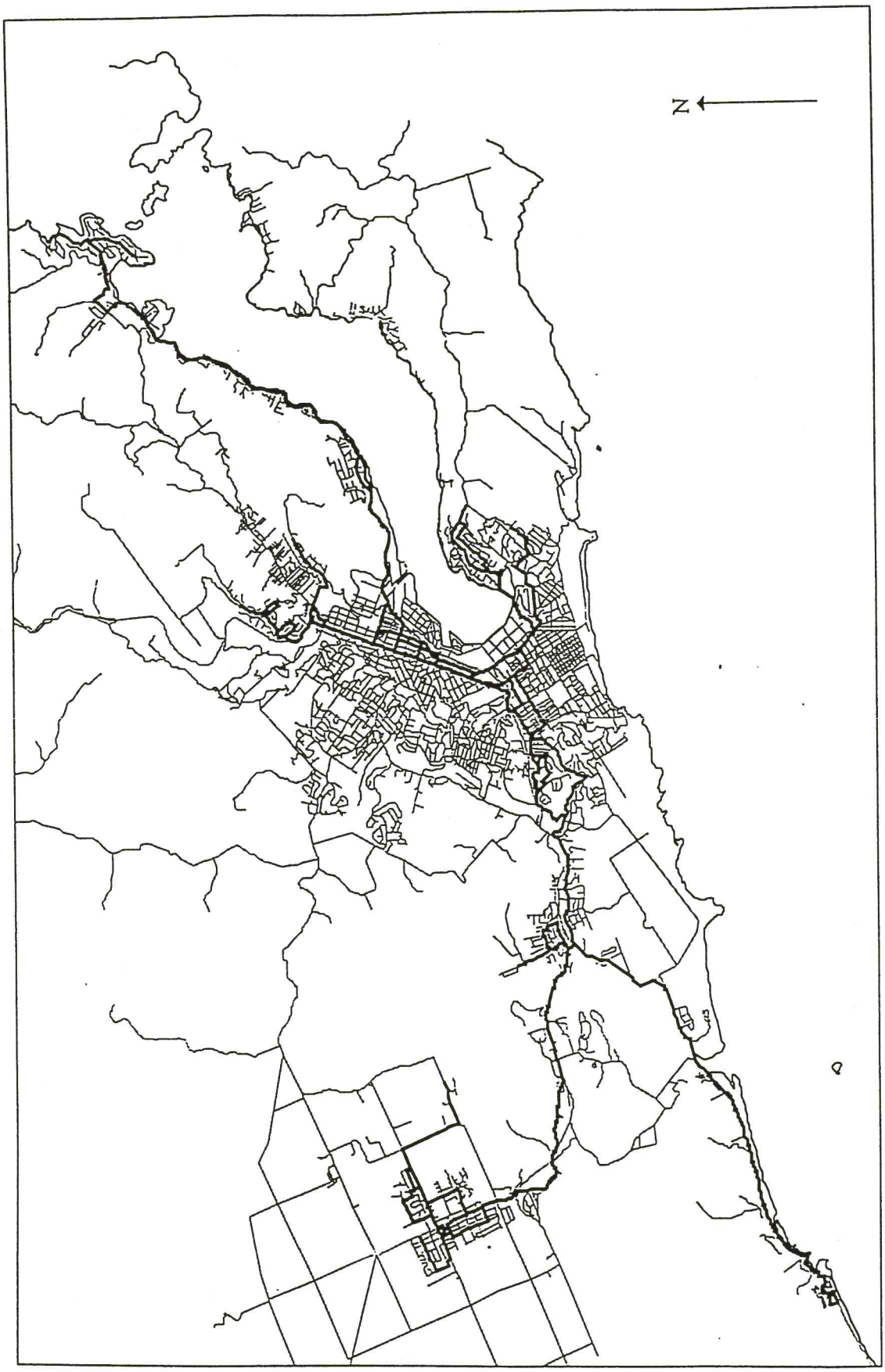

Fig. 1 - Routes Surveyed And Mapped

Survey data for where the passenger is travelling to and from and the reason for the journey form a quasi-match for the census mode of travel to work data. It should be noted that household income data were not collected in the on-board survey. They are included in the plots as it was considered that household income may also influence use of bus.

Table 1: **CENSUS DATA SELECTED FOR POTENTIAL USER ROUTE PROFILES**

USER CHARACTERISTICS	SUB-PLOTS CONSTRUCTED (PERCENTAGE OF POPULATION PER MESHBLOCK)
Gender	Female Male
Age	Under 15 years of age 15 to 24 years of age 25 to 44 years of age 45 to 59 years of age Over 60 years of age
Household income	Income is less than $15,000 pa Income between $15,000 and $30,000 pa Income is greater than $30,000 pa
Household motor vehicle ownership	Households with no motor vehicles Households with one motor vehicle Households with more than one vehicle
Means of travel to work	Travel by public bus Travel by motor vehicle Travel by bicycle Walk to work

16. The routes under investigation were divided into 3 areas. Each of the census variables in table 1 was plotted for the 3 areas. An example of these plots is given in Figure 2 which shows the number of households with 1 vehicle in the meshblocks within or intersecting a distance of 375m or 500m depending on the terrain, around the bus stops on these routes.

17. It is possible to use these plots to evaluate the performance of the routes serving these areas with respect to particular user characteristics by making comparison between the census and the survey data. These data may also be plotted for individual routes or specific sections of a route depending on whether the analyst wishes to gain an overall view of an area or focus on the performance of an individual route. There are 451 meshblocks included in figure 2. According to the census data these contain a total of 5,769 households which have 1 motor vehicle. The survey data only identify 353 households in this area with 1

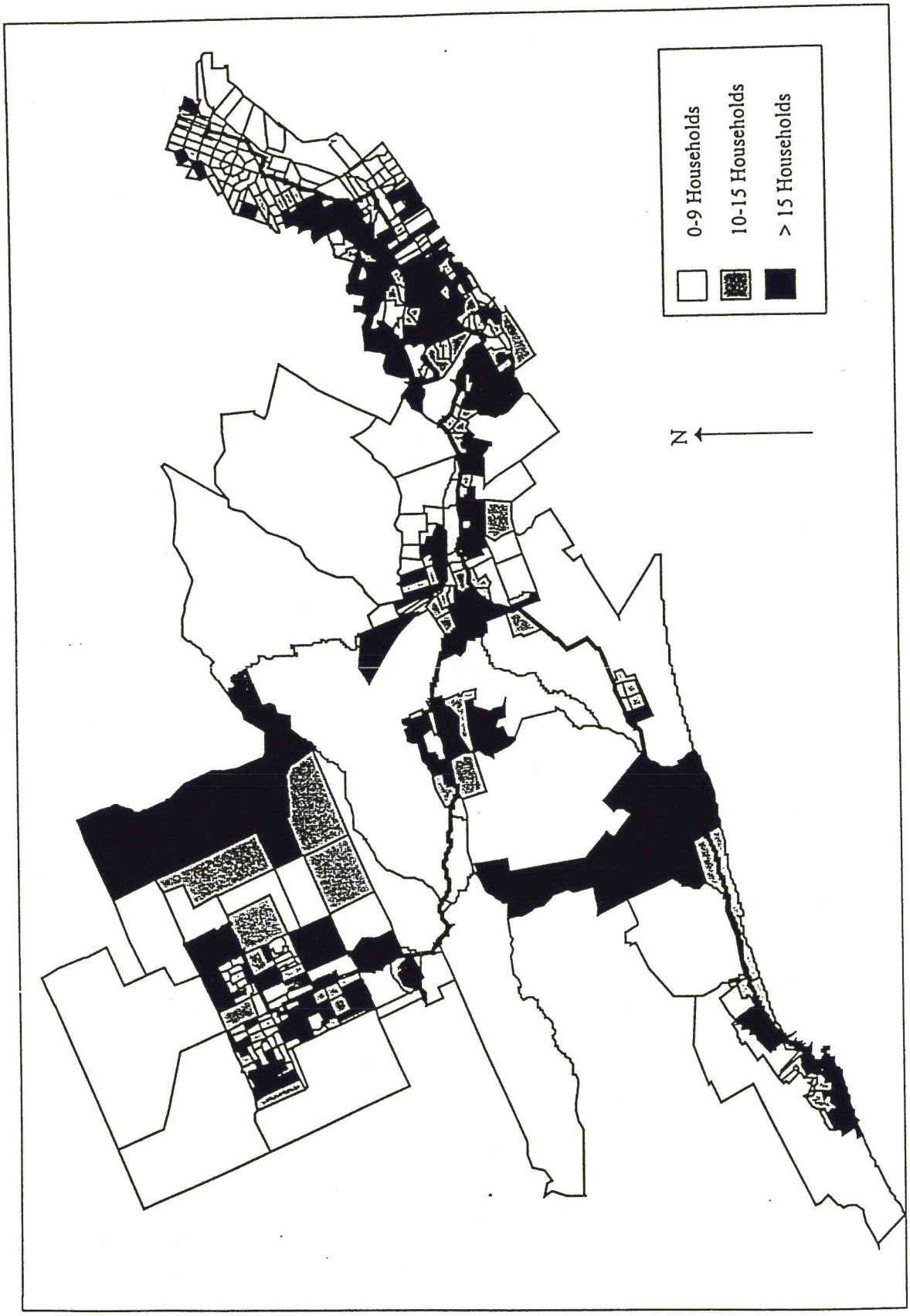

Fig. 2 - Households per Meshblock with One Motor Vehicle

household vehicle, suggesting a low level market penetration (6%) of this segment of potential users.

18. Using the GIS package, plots of individual characteristics can be overlain to give a composite picture of the potential population of bus users. For example, females aged 25-44 with household income between $15,000 and $20,000 and one household car who travel to work by motor vehicle, as opposed to those who travel by car.

RE-DESIGNING ROUTE STRUCTURE

19. Survey data may also be used in conjunction with census data to design optimal routes to service either particular areas or entire cities. This is a marketing-oriented approach whereby routes may be redesigned to target areas which have a higher proportion of the population sharing key characteristics with current users. It is suggested that if the population of these areas has similar characteristics to current users, they would also be likely to use a bus service, if it was available.

20. A suburb to the west of Dunedin was selected for attempting to optimise the route structure. This suburb is at the limit of the service area with no through routes and is also relatively isolated with no alternative bus services nearby. Currently the Western suburb is served by 3 overlapping routes (Figure 3). Survey data were used to develop a profile of current passengers travelling to and from the Western suburb by bus. The dominant characteristics of these passengers are presented in table 2.

Table 2: WESTERN SUBURB BUS USERS

% PASSENGERS	DOMINANT CHARACTERISTICS
63%	Female
46%	Aged 25-44
26%	Aged 45-59
31%	One household vehicle

Source: Otago Regional Council On-board Survey, 1994.

21. A location/allocation algorithm was used to generate the 20 locations where the maximum number of people in the Western suburb would be within 150m of the location, with a maximum allowable distance of 250m. These distances were measured between the centre of a meshblock and the allocation point (or location). The dominant characteristics of current bus users formed the basis for the location/allocation problem. The results of location/allocation analyses are presented in tables 3 and 4. Although total population had a slightly lower percentage of total demand assigned to one of the 20 locations, it was decided that the higher absolute numbers involved (and limitations of the census data)

Table 3: **SUMMARY OF LOCATION/ALLOCATION BASED ON USER CHARACTERISTICS**

User characteristic	Total Demand	Assigned demand within 150m	Assigned Demand Between 150m and 250m	Total Assigned Demand	Percentage Demand Assigned
Total Population	9561	3771	2685	6456	67
Total Female Population	5004	1995	1503	3498	69
Total Pop. Aged Between 25 and 44 Years	2664	1110	762	1872	70
Total Pop. Aged between 45 and 59 Years	1494	657	483	1140	76
Total Pop. With One Motor Vehicle per Household	1599	687	519	1206	75

Table 4: **SUMMARY OF AVERAGE AND FURTHEST DISTANCE FROM CALCULATED STOPS**

User characteristic	Average Distance Travelled by Assigned Demand (m)	Furthest Distance Travelled by Assigned Demand (m)
Total Population	118.7	241.5
Total Female Population	116.8	242.2
Total Pop. Aged Between 25 and 44 Years	116.4	244.4
Total Pop. Aged between 45 and 59 Years	115.9	244.4
Total Pop. With One Motor Vehicle per Household	118.0	242.3

justified its use in further analysis. This solution places 67% of the total population of the area within 250m of one of 20 locations.

22. Once the initial 20 locations had been identified, meshblocks with inadequate road access and those which fell outside the service area were discarded. The location/allocation algorithm was rerun to determine the 20 serviceable locations with the highest catchments. These locations were then approximated to the nearest suitable street before using an optimal path algorithm to calculate a shortest distance route to serve all 20 locations. Finally the optimal path was manipulated to remove a small amount of backtracking, introduced by the optimisation process. The resulting route is presented in Figure 4.

DISCUSSION

23. The analyses presented in the preceding sections have demonstrated how census and survey data may be integrated to provide a powerful and flexible approach to route design. The power of the GIS approach is derived from the ease of interpretation of having the data presented visually. The flexibility of the GIS is also a key advantage as it allows the analyst to focus on either an entire city route network or a specific section of a route. Interpretation of linear programming techniques of location/allocation and shortest distance optimisation, frequently confined to the operations department, is also enhanced within the visual format. The optimal route based on user characteristics, but optimised for shortest distance offers advantages to both the marketing and operations departments. Additionally, having marketing and operational solutions presented within a common visual format will improve each department's understanding of the concerns and methodologies employed by the other.

24. Several issues must be considered in using census data as a basis for performance evaluation. Of paramount concern is the issue of standardising for the total number of bus journeys over a day. A further issues is the number of other routes serving sections of the route in question as this will affect the number of potential passengers available. While it is not possible to determine all the journeys an individual person makes, some assumptions (possibly based on previous research), should be possible. For instance, the number of trips to the CDB per given time period or trips to the nearest supermarkets or high schools could be investigated. Further insights might be gained by integrating transport surveys such as this with supermarket retail catchment models with benefits for both the retailer and the transport operator.

25. Care must also be taken with the use of survey data in this form as the basis for route design. Greater attention should perhaps be paid to origin-destination data to allow for passengers who board and alight at mid-points along the route. It this study these potential problems were avoided with the use of total population as the basis for route design. As evidenced by the lower percentage of assigned

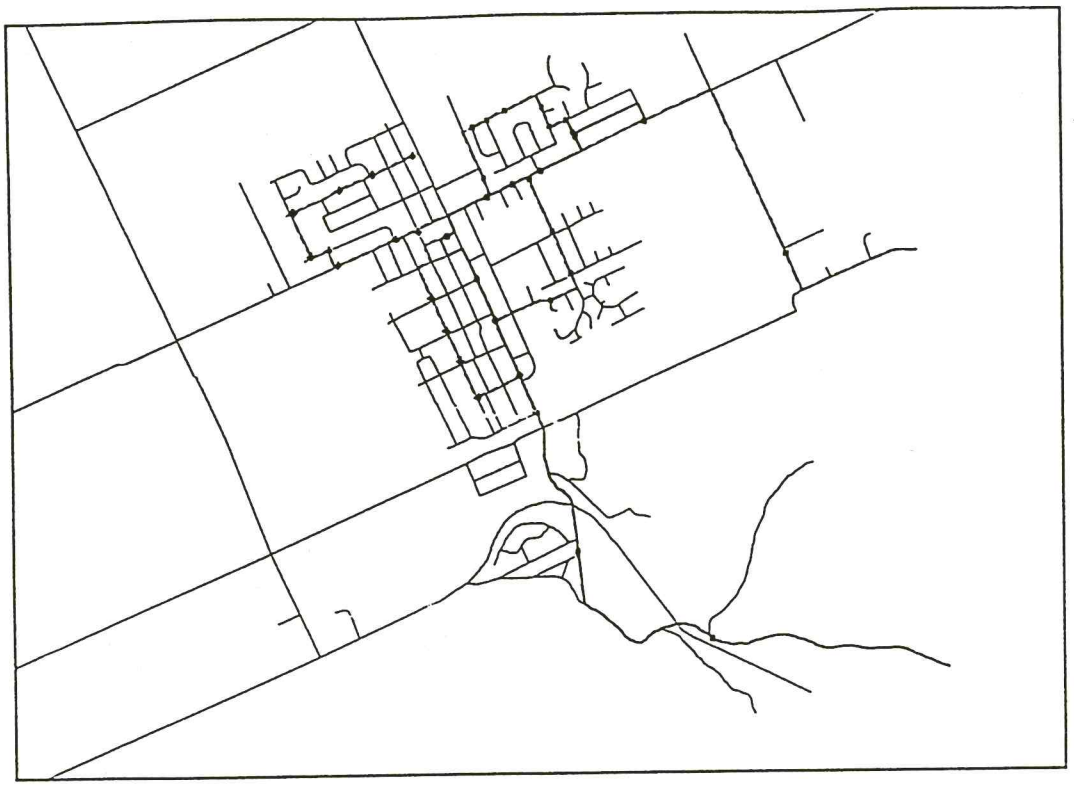

Fig. 3 - Western Suburb Existing Routes

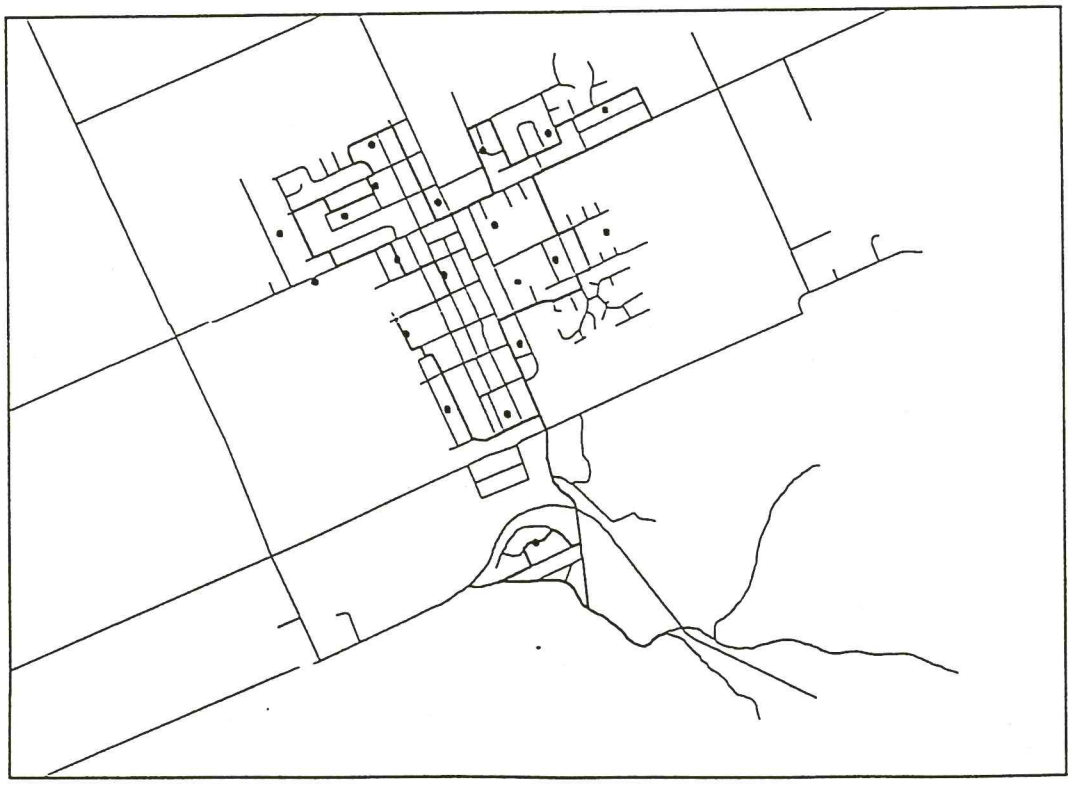

Fig. 4 - Western Suburb Optimal Route

demand for total population, this characteristic is less than ideal for route design as it cannot target more specific sub-groups of users and potential users.

26. Despite the comprehensive coverage and richness of census data, there are also disadvantages associated with its use. A disadvantage of census data is obviously its temporal robustness and applicability. The data utilised in this study were derived from the 1991 census and it is to be expected that changes in the population will have occurred. The inability of census data to track changes in population on an annual basis may pose problems for companies using such data as an input into route planning. However, the GIS approach allows streets within targeted catchment areas around bus stops to be easily identified and therefore it may be possible to undertake annual surveys of these areas to monitor key characteristics between censuses.

27. This interim monitoring function is to some extent fulfilled by the annual onboard surveys conducted by the regional council. These surveys allow the collection of further important data not provided by the census. A particularly important aspect of this is the origin destination data. As well as identifying passenger flows throughout the area, it allows passenger characteristics to be attached to both the origin (boarding stop) and destination (alighting stop) of the journey. The census data only permit analysis based on place of residence. However, origin-destination data, in conjunction with user characteristics, would allow spatial analysis based on workplace or another place of origin and combined origin-destination patterns. Preliminary investigation has focussed upon matching user characteristics to boarding and alighting stops.

28. Ideally, it would be desirable to match actual passenger origins and destination to meshblocks, rather than simply matching the boarding and alighting stops to meshblocks, to gain a more detailed picture of travel patterns. However, there are obvious difficulties associated with this. Passengers will, without exception, not know in what meshblock they started or will finish their journey. Advances in geocoding and address matching are starting to allow specific street addresses to be matched to meshblocks. It may well be considered that asking passengers for the address of their journey origin and destination would be inappropriate in an onboard survey. The definition of geographical data needs for transport planners and marketers is an area which requires further attention.

29. In undertaking this research, it became apparent that many marketing managers (and probably transport planners) are unlikely to have the skills necessary to utilise GIS technologies without training. However, GIS software has made significant advances in user friendliness in the last 18 months and this trend is likely to continue with several non-GIS packages now incorporating a mapping and spatial analysis function. It has been suggested (Beam, 1994) that GIS will form an integral component of executive information systems, as frequently used as spreadsheets and databases.

30. Allied to this issue of required GIS skills, is the issue of data transfer and compatibility between the GIS software and other (conventional?) analytical software. Survey data are generally structured on a case by case basis. The base unit of GIS data is the areal unit, with a frequency of population or households displaying a particular characteristic, for example, the frequency of households with zero cars. Although the GIS datafiles have a relatively simple format, the transfer of survey data into a form useable by the GIS software proved cumbersome and time consuming. There is a need for improved methods of data transfer or means of interfacing between conventional analytical tools and the GIS approach to analysis. It would appear that the SANDAG View2Transit program represents an advance with respect to this issue.

31. The availability and quality of data are fundamental to the successful application of GIS technologies to bus marketing applications. In addition to timeliness and geographical accuracy of the data, the cost if acquiring such data must also be considered. The effort involved in providing census data in a digital spatial format, as well as the recognition of the potential commercial advantages to be gained through using GIS has resulted in high data acquisition costs from both government and private suppliers. Conversely, GIS software providers are recognising that it is the ability to explore, analyse and present data in a spatial format that is driving the increase in GIS software use and GIS software providers are bundling data along with the package. Other developments which may improve the availability (although not in New Zealand) of spatial data include the National Spatial Data Infrastructure Initiative of the U.S. federal government which will facilitate identification, location and acquisition of existing spatial data via the internet (Plewe, 1995).

CONCLUSIONS AND AREAS FOR FURTHER WORK

32. This paper has demonstrated that GIS may be used to integrate census and survey data within a visual, easily interpretable format. In so doing GIS provide the opportunity to examine relevant population characteristics of the area surrounding the bus route. Comparison of census data with survey data may form a basis for evaluating the performance of individual routes or areas. A combination of survey and census data may also be used to give a marketing-orientation to route design where the route is designed to target areas which reflect characteristics of current users. Other user requirements such as short journey times and operator requirements such as low cost are addressed through the use of optimisation routines to find the shortest path.

33. It seem likely that GIS will be used increasingly in the future for planning and monitoring of performance. The impetus for this increased use will come from operators and planners who recognise the advantages in ease of interpretation and analytical options afforded by the approach. An additional driver will be GIS

vendors who seek to tap the lucrative business market, with transport and other inherently spatial industries a likely point for market entry.

34. Potential users of GIS will have to be aware of the expertise required to take advantage of the technology. Data compatibility and ease of data transfer, as well as availability and cost of data, are areas which must be addressed as transport planners and operators define their need for GIS-based analysis. It should also be recognised that use of GIS will not provide a single solution to areas of concern facing planners and operators, but must be integrated with other forms of research and analysis.

35. Once these issues have been addressed however, there is a great deal of potential for the use of GIS within urban transport, particularly with respect to the marketing of such services to maintain and if possible increase ridership levels. Further uses of GIS, currently under investigation at Otago University, include visual analysis of origin destination flows and matching user characteristics by both point of origin and destination. This preliminary paper forms part of a collaborative research project between the Otago University Marketing Department, the Otago University Spatial Information Laboratory and the Otago Regional Council. This collaboration has allowed a GIS approach to be a powerful tool in understanding and encouraging use of bus services.

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