Modelling Rural Accessibility.

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Abstract:

Methods to assess the economic and environmental considerations of transport planning are reasonably well established, and these issues are usually well-covered in assessments for investment decisions. There is, however, an increasing interest by Governments in considering social impacts; in particular, accessibility - the measure of people's access to economic and social opportunities.

In urban areas, there are proven methods for assessing accessibility. However, little substantive work has been done to provide measures for rural accessibility in Australia.

This paper has three elements:

- the first is a discussion of modelling techniques appropriate for the development of performance indicators for rural accessibility. A network model developed for the NSW Roads and Traffic Authority, Rmodel, was used in the work.
- the second is a presentation of the calculation of a variety of accessibility indicators that are appropriate for different purposes, e.g. personal access to services, and freight access to ports.
- finally the utilisation of geographic information systems (GIS) such as the NETWORK and TIN modules of ARC/INFO, in the presentation and analysis of such indicators is discussed, using examples from the state of NSW as a whole, and from the Hunter region of NSW.

The paper provides a starting point for the further development of relevant objectives and performance indicators, as called for by the House of Representatives' Inquiry into the Efficiency of Road Construction and Maintenance (December 1993), the Land Transport Strategy announced by the Federal Minister for Land Transport in 1993, and of other recent policy directions announced by State and Federal Governments

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1. INTRODUCTION

The theme of this conference invites us to consider a fundamental question: why does the Australian community (through its transport and road authorities) build and maintain roads as part of the transport system? The answer is, of course, a mixture of political, economic and social objectives, and the trade-offs involved in meeting those objectives. In particular, the development of economic analysis techniques and their application to road projects has in recent years provided the main filter through which decision-making has flowed. Projects which provided substantial returns to road users were considered "economic" and, if within budget constraints, generally proceeded. Those that did not but for which there was some other over-riding reason to proceed were often described as Community Service Obligations.

In recent years the community has provided another series of filters - road development and maintenance programs must demonstrate an acceptably low level of environmental impact. Furthermore road authorities must be able to demonstrate that road transport can provide substantially greater utility for users than can other more "environmentally-friendly" modes.

Thus transport reform, is in part, about economic returns to the community and minimising environmental impacts of those returns. It is also about equity - who gains and who loses through the reform process.

Social impacts of road programs have received little attention in the decision-making process and, until recently, one aspect of social impact - accessibility, has been all but ignored. That is changing, however. Governments at all levels and of most persuasions are now, in their policy documents at least, giving consideration to accessibility as an ingredient to add to the decision-making process.

For example, the Final Report by the Transport Working Group enquiring into Ecologically Sustainable Working Groups (Commonwealth of Australia, 1991) has acknowledged the seriousness of accessibility problems in rural Australia, and that policies must have regard to accessibility levels. Further, the Land Transport Strategy, announced by the Federal Minister for Land Transport in 1993 also recognises poor levels of accessibility in rural Australia. The strategy states that, "... Social justice requires that the broader community provides appropriate transport (services and infrastructure) access for people who may otherwise be disadvantaged by geographic or social isolation " (p2).

Finally, it should be stressed that this issue has also been recognised by other authorities. The National Health Strategy (1991) and the NSW Health Department (1992) Corporate Plan address inequities in access to health care services in rural areas.

Such statements of intent are, of course, laudable. The difficulty is, however, that judgements relating to accessibility, like any other analysis, have to be made on the basis of information and particularly on the basis of measurement. The development of measurement and analysis techniques in non-urban Australia, which assess existing and future levels of accessibility, has been lacking. This paper suggests some paths which might be taken.

2. THE RECENT LITERATURE

Several recent studies have examined the concept of accessibility for purposes of evaluating transport infrastrucuture developments. These studies generally deal with the concept of integral accessibility -- a measure of access to all activities or opportunities from a given zone.

The study by Linneker and Spence (1992) provides one approach to the measurement and analysis of regional accessibility. It examines the impact of the M25 London Orbital Motorway on accessibility to population (market potential) and access-cost accessibility in the UK. Basic inputs in the analysis are a network model of the study region and heavy goods vehicles (HGV) generalised transport cost functions for links on the network. Information on population and economic activity is obtained from the census. Generalised transport costs are calculated from least cost paths which are output from the study area network model. Pre and post M25 access measures are presented for market potential and access-cost (access to employment weighted by transport costs). Spatial variations are shown to exist in distributions of accessibility as a result of the M25, and as a result of which form of accessibility measure is used.

On the other hand, a study by Hansen (1993) examines changes in overall accessibility patterns due to the construction of two major bridges in Denmark. A gravity measure of accessibility is calculated using the motorway network for Denmark -- impedances in the road network are represented by travel time. Basic inputs for measurement of accessibility in this study are similar to the above study. The presentation of accessibility results is undertaken using a Geographical Information Systems (GIS) framework. Results are displayed using Arc/Info's TIN module (briefly described later) which generates iso-accessibility contours. They indicate substantial changes in overall accessibility patterns between 1992 and 2002 due to the two major bridges.

A national motorway accessibility model for Spain has been developed by Gutierrez et.al (1993) to aid regional road planning by the Ministry of Works and Transportation. The current and proposed motorway accessibility of 450 Spanish populated places to 30 economic activity centres are calculated using ARC/INFO. A etwork model with appropriate node and link data is developed using the NETWORK iodule of ARC/INFO. Real impedance in this study is based upon shortest path routes ı the network. This measure is then compared with a measure of ideal (straight line) npedance from each zone to centre to generate a measure of relative accessibility for ıch zone. Isolines are then constructed using the TIN module to indicate variations accessibility to economic centres in 1992 and 2007 based on proposed changes to e motorway network.

The above studies are of significance for transport authorities in Australia for they provide a benchmark for the measurement and analysis of regional accessibility. Futhermore, these studies illustrate the value of GIS based approaches which enable ready assessment of 'what-if/where-if' scenarios.

3. SOME AVAILABLE TOOLS

RMODEL

RMODEL is a computer model developed by Bill McDougall of Travers Morgan, as part of the *Road Transport - Future Directions* study conducted for the RTA in 1991. The model is a strategic road network traffic forecasting tool that involves four steps:

- building a road network
- finding the shortest paths between places on the network
- estimating daily vehicle trips between places on the network, using gravity model techniques
- assigning the trips to the network to arrive at estimates of traffic on a link-by-link basis

RMODEL is built around a series of FORTRAN computer programs which read user-prepared data files (in ASCII format). The first program, RNET, reads and checks the road network data file, identifying the individual links and checking for data consistency.

The second program, RPATH, finds the minimum paths through the road network between every zone pair in the model. The program provides as output a "trees" file (listing the links forming the shortest paths) and an interzonal cost matrix file (a file with the generalised cost of travel between each zone pair given in matrix form).

The third program, RTRIP, estimates the trips between each zone pair based on the population of each and the cost of travel between them on the shortest path. A series of gravity model expressions are used to estimate the trips between zones of different types - capital cities, regional centres and local centres - and the program saves the results as a trip matrix file.

The fourth and final program, RLOAD, loads the estimated vehicle trips (from RTRIP) onto the road network, again following the shortest paths between zones. The program also calculates a number of network performance indicators, such as vehicle-kilometres, vehicle-hours and the like.

RMODEL was used in the *Future Directions* study to forecast future traffic on the rural road network in New South Wales. Forecasts were made for different future population growth scenarios, and the results were used to estimate strategic road improvement needs for each scenario. The outputs thus formed an important part of the overall strategic planning process that the *Future Directions* study used.

Since *Future Directions*, RMODEL has been enhanced for use on a number of other regional roads studies, including a study into possible routes for the Melbourne-Brisbane and Sydney-Adelaide National Highway links, and a national study into travel demand in the intercapital corridors. The road network now covers all of Australia.

Measuring rural accessibility in New South Wales

In common with other transport network modelling software tools, RMODEL can be used to explore the least-cost routes between places on a road network. This makes it an ideal tool for working out accessibility indices. RMODEL can be configured to find the shortest paths between places according to distance between them, travel time between them or any weighted combination of the two in the form of a generalised cost function. Since the model was already built for New South Wales, it took relatively little work to add the necessary links and zones to cover the state to the level of detail desired.

The *zone system* comprised all LGA with some aggregation or disaggregation as required. All zonal characteristics were assigned to nodes within each zone. The *road links* comprised the national highways, state roads and regional roads in New South Wales, with connecting links into adjoining states for completeness, and a number of local roads were also added where necessary to connect some of the more remote zones into the state and regional road network.

The first two programs in RMODEL - RNET and RPATH - were used in the accessibility work. RNET was used to check the road network, and RPATH was used to create a matrix of least-cost paths (shortest travel times) between all of the zones in the model.

The interzonal cost matrix from RPATH was saved in AASCII format and imported into a Lotus spreadsheet. A simple macro was then used to organise the matrix into conventional form - a row for each origin zone, and a column for each destination zone. The matrices were manipulated within Lotus to calculate various accessibility indices (see section 4).

ARC/INFO's Network Module

The modelling of accessibility is readily facilitated by the NETWORK module of ARC/INFO. NETWORK uses a Hansen-type gravity based accessibility measure to calculate accessibility between points, or nodes, on a network. Both 'relative' and 'integral' access measures can be calculated. Impedances can be based on attributes of network links or can be input from other network analysis procedures such as RMODEL.

The following data items are required for an accessibility analysis:

1. Polygon layers: primarily census statistics on spatial units in the study area. For example, population of employment data for census collection districts or urban centres which are linked to the network.

2. Road-related statistics: including a highway network for the study region, with attributes describing links in the network (time, distance or cost, etc).

3. Point or node statistics: including data on towns or cities, etc (population or some measure of attraction).

Other modules of ARC/INFO, such as the TIN module, can then be used to generate iso-accessibility contour maps based upon indices created either externally or within ARC/INFO's accessibility functions described above. The first study described below used the former technique.

4. SOME RESULTS

Rural Accessibility in NSW

The issue of accessibility within rural areas of Australia is as, if not more, significant for rural communities than for those in urban areas. The literature in Australia, however, concentrates heavily on the latter.

An attempt to (i) explore issues, (ii) devise measures and (iii) suggest policy implications for road planners of rural accessibility was undertaken by Nichols (1993). This study utilised the RModel procedures described above to explore all three areas.

Central to any analysis of accessibility is the choice of measure. The study considered a variety of measures. These ranged from simple relative measures of distance to the nearest attraction to integral measures using Hansen-type gravity measures. The latter combine internodal distances with a distance decay function and a measure of the attractiveness of all other centres from the location considered.

If use is to be made in future studies of the latter type of measure considerable work needs to be undertaken on the measurement of resistance to travel - distance decay. Clearly this will vary depending on trip purpose and geographic location, amongst other factors. Another issue is the treatment of attraction within a zone.

Despite the qualifications described above a reasonable picture of current rural accessibility conditions is provided by **Figures 1 and 2**. The attractors in these examples are city sizes of 100,000 and 20,000 respectively - indicative of high order functions generally available in such centres.

There are, of course, no surprises in the patterns displayed. Generally accessibility declines where it could be expected to decline - in the north and west of the State. The same pattern is evident from consideration of Hansen-type indices displayed in **Figure 3** or in heavy vehicle costs displayed in **Figure 4**.

For road planners the issue, however, is to what degree are these variations in rural accessibility a result of the roads they provide rather than the geography of attractors that may or may not have developed independently of the road system.

Figure 5 is an attempt to illustrate such a pattern. The indices underlying the map are a result of the calculation of shortest path distances from any centre to all other centres measured in two ways:

1. By the total of linear distance measured in kilometres.
2. By the total of distance measured as light vehicle travel costs.

The map of "anomalous accessibility" illustrates indices of the relative difference between the two measures. Strongly positive indices represent road network

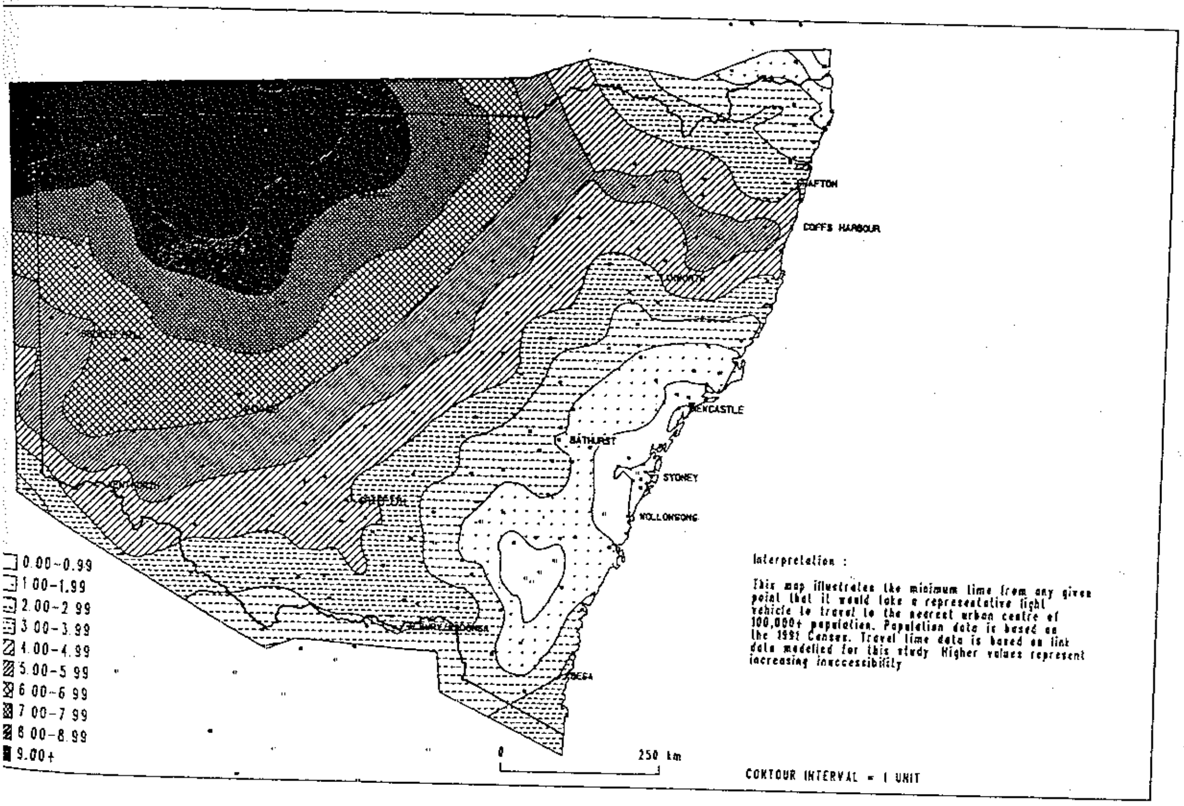

Figure 1 Light vehicle time (in hours) to nearest centre 100,000+ population

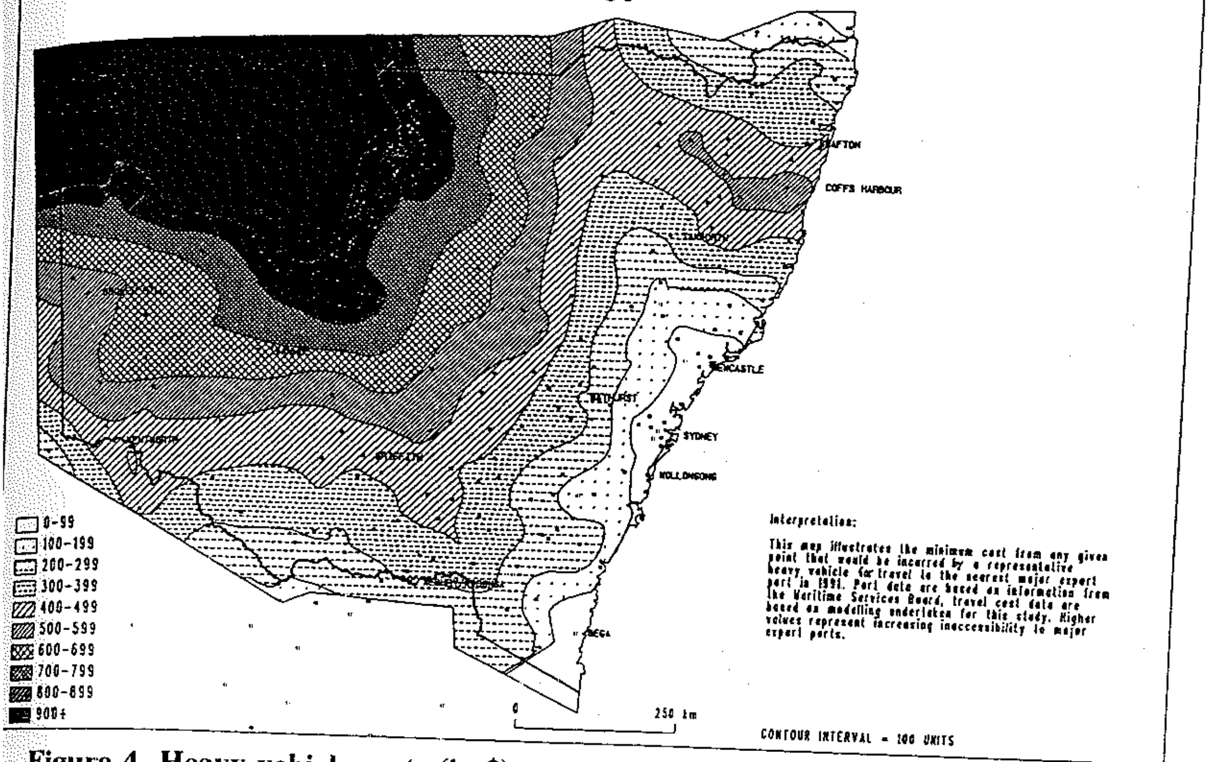

Figure 4 Heavy vehicle costs (in $) to nearest port

conditions in which total travel costs are less than could be expected given location and strongly negative figures represent the reverse.

Those areas demonstrating high relative costs of road transport fall into basically two categories:

1. The far west of the state (with some corridor exceptions).
2. The coastal fringe.

The former is a result primarily of the existence of unsealed and, in particular, earth roads within the network. It is not a function of distance from major centres or lack of network density (see above). Light vehicle operating costs for travel on earth roads are approximately two times higher than those for comparable sealed roads (RTA, 1993). The ratio for heavy vehicles is greater. Despite the high speeds that are possible (and usual) on such roads, thereby reducing travel time costs, the increased vehicle operating costs generate substantially higher total road user costs.

Within this general area of high travel costs, however, the existence of low cost corridors is apparent. These include the impact of the Barrier Highway between Cobar and Broken Hill, the Sturt and Mid-Western Highways centred upon Hay and the Silver City Highway between Wentworth and Broken Hill. The latter provides amongst the cheapest per kilometre travel in the state. Straight, sealed routes with low traffic levels therefore permit low cost travel. Away from the major routes, however, the cost of access in the far west is high.

Centres such as White Cliffs, Tibooburra and Ivanhoe thus not only demonstrate low access as a result of a lack of proximate functions, population and relative location, they are also handicapped by high cost road surfaces. In addition a given number of locations are also handicapped by isolation during heavy rain. This factor has not been demonstrated in **Figure 5** but it is nevertheless real for many communities. Ivanhoe, for example is cut off from its major sources of supply, markets and social activity for approximately thirty days per annum by closure of the Cobb Highway.

High cost travel demonstrated near the coast is a function of two major factors (i) topographic difficulties and associated poor road geometry, and (ii) high levels of traffic. In these locations populations are greater, traffic volumes are greater and both are growing more rapidly than is the case in the west of the state.

The real value of such analyses lies in their ability to compare the accessibility impacts of road development scenarios. Nichols' study illustrates changes in accessibility due to

1. projected population changes illustrated by **Figure 6**, and
2. changes in accessibility as a result of two road projects - the proposed Motorway Pacific (**Figure 7**) and the sealing of two outback links (**Figure 8**).

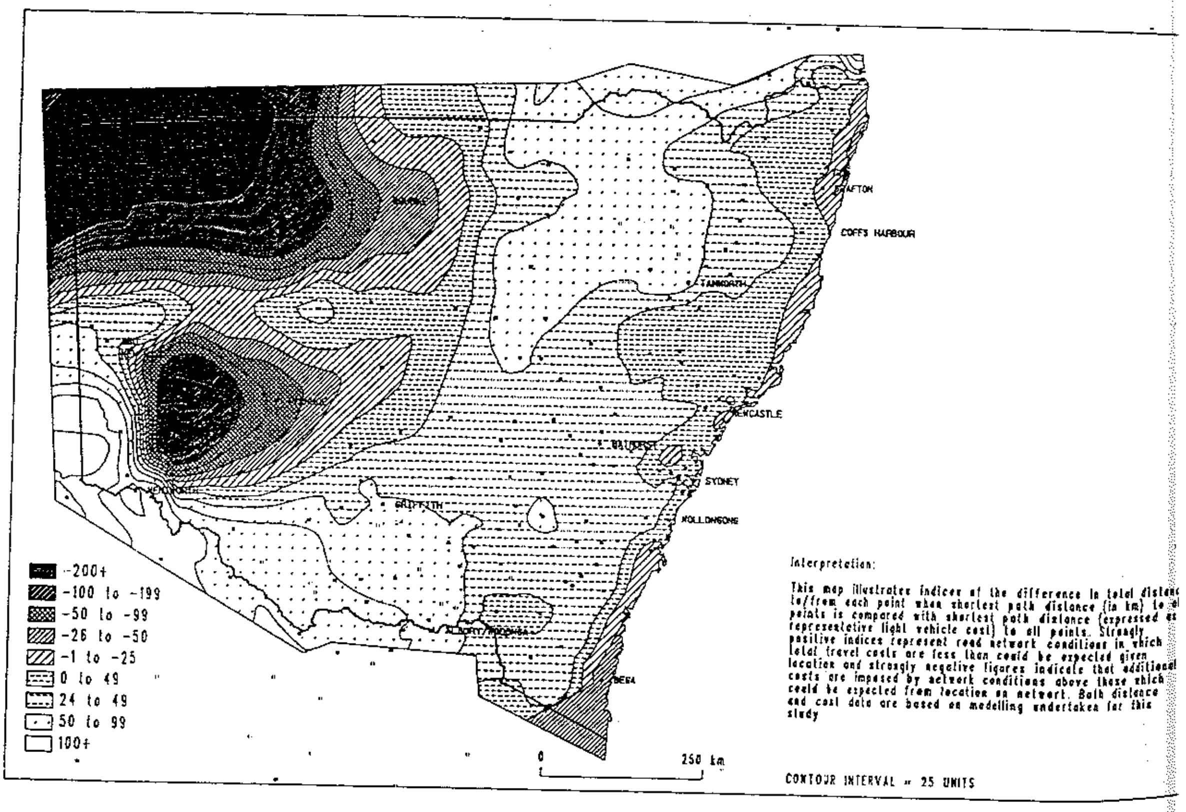

Figure 5 Network efficiency

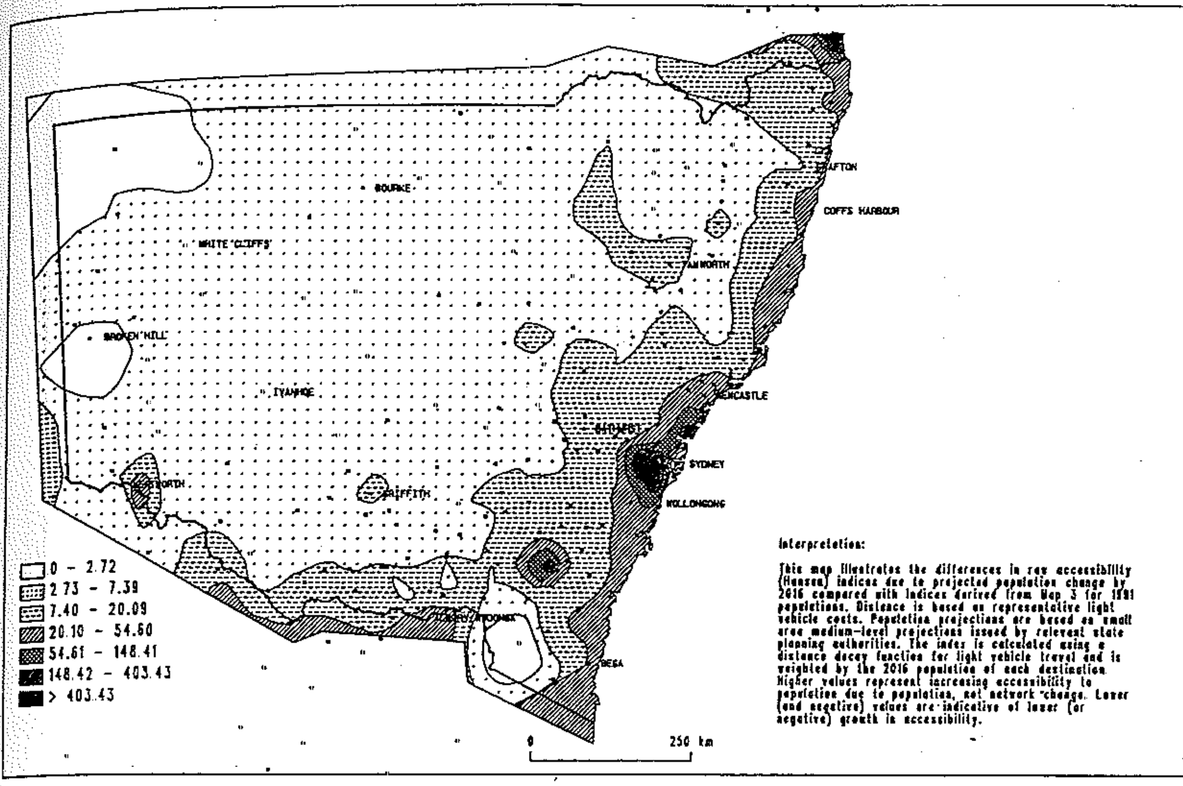

Figure 6 Difference in accessibility to population 1991 to 2016

The accessibility implications of population change underline the significance of western Sydney, the NSW Central Coast, the Canberra Region and the coastal areas of NSW for future road planning in order to maintain current levels of road accessibility.

On the other hand consideration of **Figures 7 and 8** and the simplistic analysis described in Table 1 serve to remind us that, in terms of value for dollar, smaller projects may provide greater impacts on accessibility.

The Hunter Valley Study

The issue of accessibility can be examined at several geographic scales. A study of current and future accessibility within the Hunter region of NSW was undertaken by Clarke (1993). This project addressed several research questions:

1. How efficient is the rural road network of the Hunter region of NSW as indicated by levels of accessibility to opportunities and services?

2. What changes occur in accessibility levels in the Hunter region as a result of road infrastructure improvements; for example, upgrading of the New England Highway, of the Pacific Highway, and Construction of the Motorway Pacific?

Table 1

Accessibility/Cost index - An Illustration and Comparison

Motorway Pacific

Base Network Accessibility Index (Total)	=	22039.7
Mot Pac Network Accessibility Index (Total)	=	22160.5
Increase in Accessibility Index (Total)	=	**120.8**
Dollar Cost of Motorway Pacific	=	**$5,500,000,000**
Cost per 1 Index Point of Accessibility:	=	$5,500,000,000/120.8
	=	**$45,529,000**

Sealing of Two Outback Links

Base Network Accessibility Index (Total)	=	22039.7
Sealed Network Accessibility Index (Total)	=	22042.9
Increase in Accessibility Index (Total)	=	**3.2**
Dollar Cost of Providing Seals	=	**$19,900,000**
Cost per 1 Index Point of Accessibility:	=	$19,900/3.2
	=	**$6,218,750**

On the basis of the above data the gains to accessibility (as measured by light vehicle travel costs) per dollar expended are greater for the network (i.e. throughout South East Australia) for sealing the two outback links rather than for the Motorway Pacific. The ratio of about 7.3:1 is reduced somewhat when the same analysis is conducted using projected 2016 (rather than 1991) population distributions - to about 5.4:1. Obviously further refinement of this rather crude index is warranted - using time series and discounting of costs, for example. Nevertheless such measurements are possible.

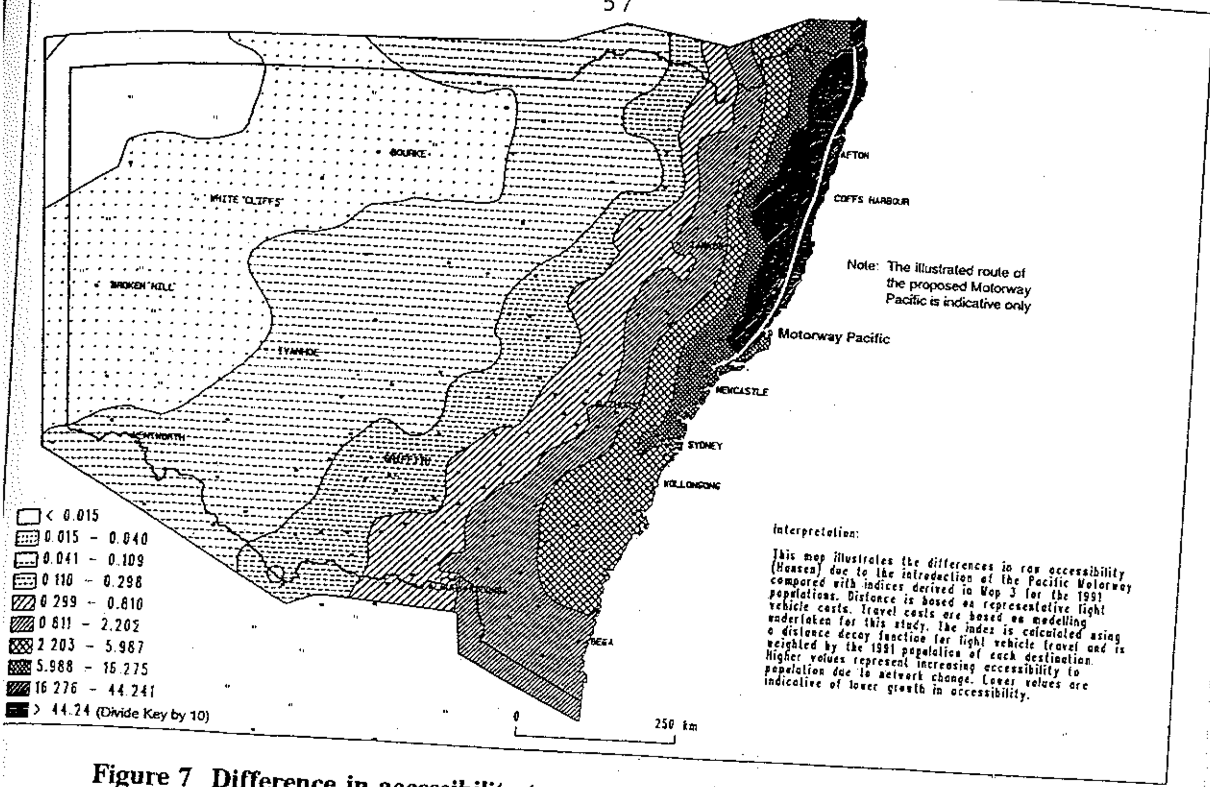

Figure 7 Difference in accessibility to population resulting from Motorway Pacific

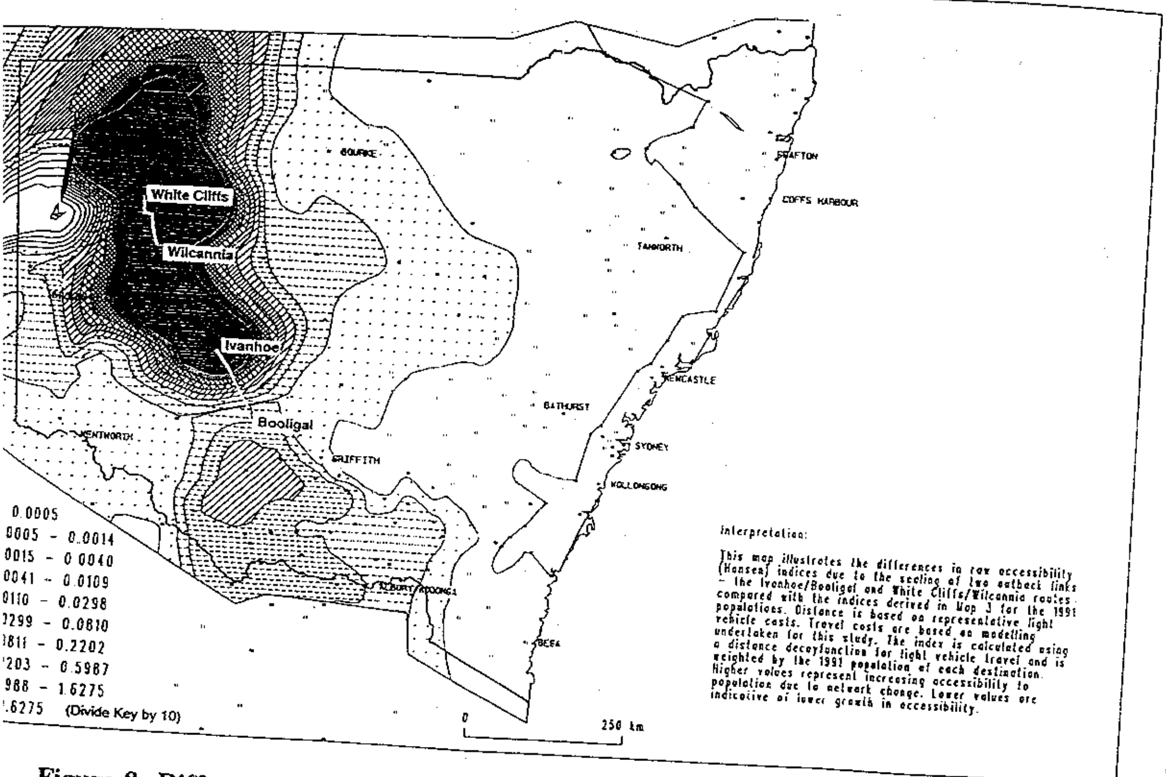

Figure 8 Difference in accessibility to population due to sealing of two outback links

3. What are the implications of any changes in levels of accessibility for rural road planning?

The study utilised ARC/INFO for data storage, retrieval, manipulation and accessibility modelling. The methodology proceeded in several stages:

1. A detailed digital road network of the Hunter region is developed using national topographic map series. The resulting network coverage is then transformed into standard Australian map grid coordinates.

2. Statistical divisions and associated census collection districts are overlaid onto the digitised road network. Key roads are extended outside the region to incorporate interstate linkages as per the study by Nichols (1993).

3. Attribute data is collected for each link of the network and includes: road classification, travel time, light vehicle cost, heavy vehicle cost, distance, speed, etc. Vehicle costs are calculated using the Simplified Cost Benefit Analysis (SIMCBA) software (RTA, 1992) where costs are based on values for a set of road characteristics.

4. Network node attributes include features such as population, employment, port facilities and rail freight sidings.

An integral accessibility measure is calculated for each origin node to all other nodes for access to ports, employment, population and rail freight facilities. Similar measures are then calculated following specified changes to the road network of the Hunter region.

The results indicate that urbanised and coastal areas have the highest levels of accessibility to opportunities irrespective of impedance measure used. Areas in the southern part of the region also experienced high levels of accessibility due to the influence of Sydney. There is a marked decline in accessibility as one moves west of the Newcastle area -- a reflection of relatively poorer road infrastructure, longer travel times, higher costs and fewer opportunities. Rural areas of the Hunter region appear to be at a locational disadvantage.

Accessibility measures were also calculated for possible upgrades to the Pacific and New England Highways, and for inclusion of the proposed Motorway Pacific (Hexham to Brisbane). Analysis indicated that highway upgrades generated higher levels of accessibility for areas identified above as already well endowed. Rural areas which experienced increases in access were mainly located adjacent to the highways. Remaining areas did not experience substantial gains in accessibility. Effects of the Motorway Pacific were very similar. **Figures 9** and **10** indicate changes in the distribution of accessibility following the above transport infrastructure changes.

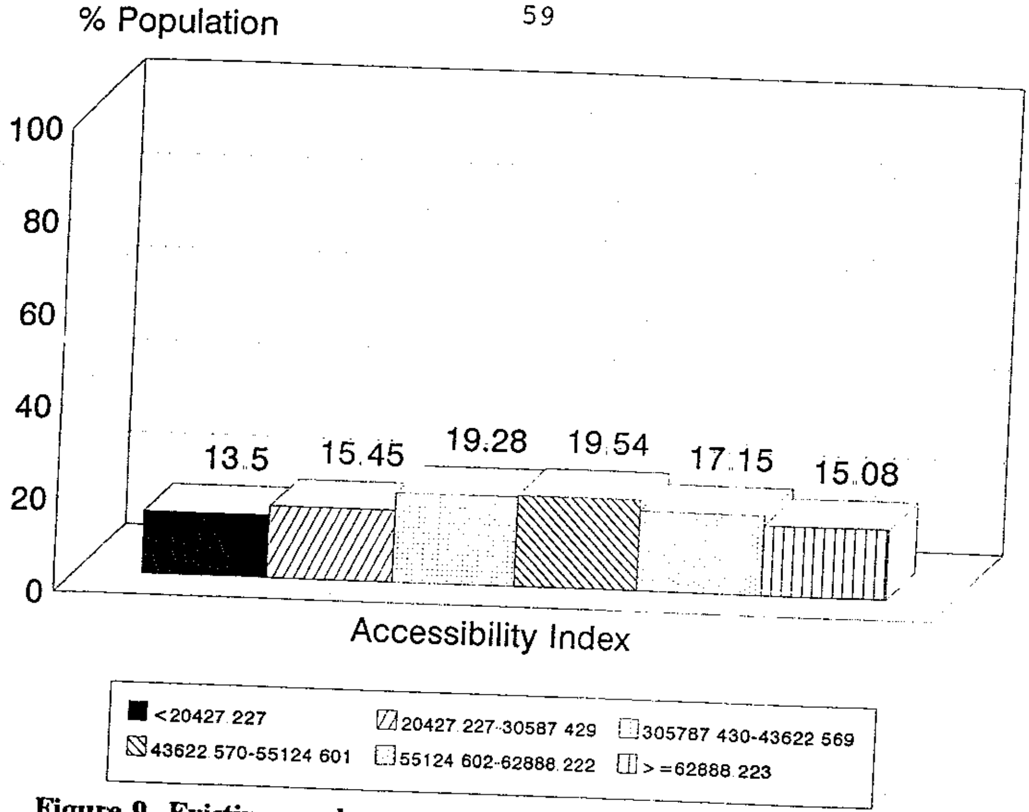

Figure 9 Existing road network of the Hunter region

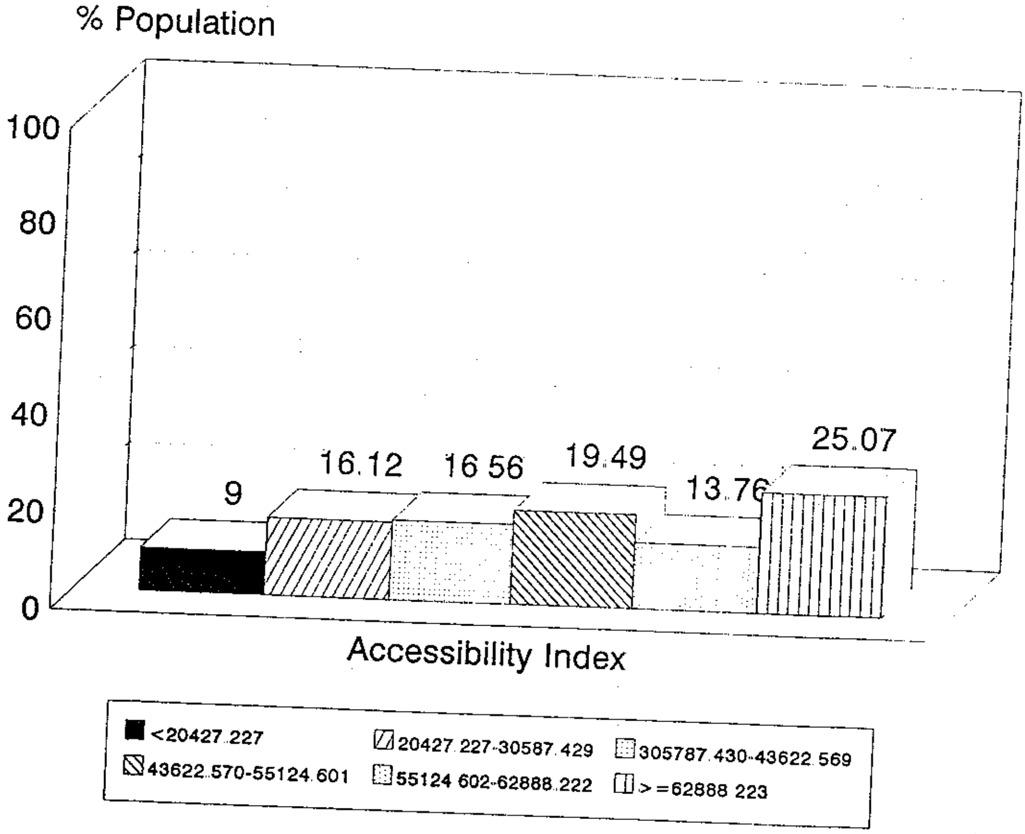

Figure 10 Upgrade of Pacific and New England Highways and Motorway Pacific

Displaying Accessibility Information

The above studies have illustrated a variety of measures of accessibility which are appropriate for different circumstances. Not only have different measures been used, but the display of these measures can be varied to suit the purpose.

For example, accessibility measures can be displayed in the following ways:

- for spatial units (polygons) such as collector districts or LGAs.
- for nodes or points on the network with the use of isolines to describe variation between points.
- as tables.

All three techniques can be used to illustrate changes over time resulting from either changes to the network or changes in the attractiveness of potential destinations. The choice of technique is user dependent.

5. CONCLUSION - DERIVING PERFORMANCE MEASURES

The derivation of accessibility measures is more than an interesting intellectual exercise. Transport authorities have demonstrated their concern to provide appropriate access.

The objective of the studies described above has been to provide an illustratiuon of techniques which can be used in the assessment of network performance in meeting accessibility objectives. This paper does not provide a series of formulated performance indicators which can be used by transport authorities.

Any such measures must have the following characteristics.

1. They must be understandable to both the public and policy decision makers.

2. They must reflect the costs of movement.

3. They must be capable of describing change over time and, hence, progress made towards achieving of increased accessibility.

The specific measures chosen (for example, light vehicle cost of access to hospitals for centres of 20,000 or more) will, no doubt, have to reflect differing expectations dependent on location and a variety of other factors.

It is hoped that this paper is a starting point for discussion, the end result of which is both the incorporation of accessibility objectives and measurement of the authorities performance in meeting those objectives.

The provision of public funds to meet increased demands for access will necessarily involve trade-offs in the allocation of the community resources. The derivation of the measures decsribed in this paper may provide an indication of what those trade-offs involve.

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