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# The Assessment of the Regional Network Vulnerability : The Case Study of The Green Triangle Region

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**Abstract**
Due to the need for a robust transportation network, researchers have put more attention on developing methods to improve transport network reliability. Given the common characteristic of rural settlements in Australia whereby most of them are sparsely distributed, the road network vulnerability can be more important than reliability study in terms of the adverse of socio-economic impact on the community. This research studies the road network vulnerability at the Green Triangle Region by assessing the changes of the Hansen Indices and ARIA indices after degrading or closing one or more links. The changes were measured by comparing the Hansen indices and ARIA indices at the full networks and the degraded networks. By assessing the changes, then the links which give the highest changes will be assigned as the most critical links in the wide road networks. The study concluded that the most critical links within the wide network are the short links which near the E and F category centres and at other cases the impact of the degraded links on the communities are quite local. In addition, this study also concluded that the ARIA indices are more appropriate in order to suggest the appropriate method in measuring the network vulnerability.

## Introduction

Due to the need for a robust transport network and the different factors that can affect the performance of the transport system, the notion of transport network reliability has been of interest for research for more than a decade, and certainly since to the Kobe earthquake of 1995. Since the network reliability studies have tended to focus more on the urban network reliability which mainly concerns terminal reliability, travel time reliability and the reliability of road network performance (Nicholson et all, 2003) then has been a lack of the assessment of the consequences of network failure. The network vulnerability method needs to be considered to make up this deficiency. Moreover, due to the negative consequences of network degradation in rural area road networks where the congestion is not the important issue, network vulnerability may be more important than the network reliability (Taylor and D' Este, 2003).

## Problems

Given the common characteristic of rural settlements in Australia whereby most of them are sparsely distributed, in this case, the transport networks become the critical lifelines in providing community accessibility. In addition, in rural areas, the road networks are sparser than in urban areas with the fewer good alternative roads. Thus, by degrading one particular links, a service centre may be completely inaccessible so that will give significant effects to the community. Therefore network vulnerability assesses the negative impact of the degraded links on Australian rural communities particularly in accessing vital services. Previous research has studied the regional network vulnerability in Western Australia and South Australia. This study considers the Green Triangle Region on the Southern end of the border between Victoria and South Australia. This case study area is different because it is located mid way between two large metropolitan cities (Adelaide and Melbourne) whereas the previous study only included one such city each.

By considering those issues, this research studies the road network vulnerability at regional level in the Green Triangle Region by using the accessibility approach including both the Hansen Accessibility index and the Accessibility/Remoteness Index of Australia.

## Objective

According to the importance of the economic growth of the Green Triangle Region and by considering the value of time in accessing the service centres in terms of using the quickest and the shortest routes to reach destinations, the road networks within the Green Triangle region should cater for the future demand by reducing the road network vulnerability.

By considering the effect of the failure of some important links, this research tries :

1. To assess the accessibility indices of cities in Green Triangle area both with Hansen Accessibility index and ARIA index
2. To suggest an appropriate method for assessing the network vulnerability in regional area
3. To identify the critical links within the road network of the Green Triangle Region

## The Transportation System Reliability

According to Wakabayashi and Iida (1992) reliability may be defined as "the probability of a device performing its purpose adequately for the period of time intended under the operating conditions encountered". This definition is very general and has given different meanings to different users. Thus, recently there are several approaches in order to measure the transport network reliability. As has been discussed in Bell (2000), the earlier studies of the transportation system reliability grouped the transport network reliability into two broad categories; connectivity reliability and road network performance reliability. Connectivity reliability relates to the successful of travel between the origin and destination in residual networks after one or more links were closed or degraded. On the other hand, road network performance reliability concerns the changes of the travel time and travel cost in order to reach destination after one or more links were degraded.

Moreover, since the transportation system is a dynamic system which is not only built by the transportation infrastructure but also the road network performance and the road user behaviour, transportation system reliability analysis should be able to handle the different level of the degradation. There are several approaches in order to increase the reliability of the transport network systems. The previous studies suggested that this can be increased by emphasising the strengthening and relocation of the infrastructure in terms of reducing the direct cost. Moreover, due to the potentially severe consequences of the degraded transportation network on the socio economic costs to community, Nicholson (1997) suggested that transport network reliability can be improving by;

1. improving the network configuration
2. having stand by components
3. monitoring critical components
4. undertaking regular preventive maintenance
5. identifying priorities for repairing degraded components to minimise the socio economic impacts

**Vulnerability**

The definition of vulnerability has not yet been generally agreed. Based on the ideas of several authors, the notion of the vulnerability focuses more on the negative events that significantly reduce the road network performance. Berdica (2002) defined the vulnerability as " a susceptibility to incidents that can result in considerable in road network serviceability". The link /route/road serviceability described the possibility to use that link/route/road during a given period of time. Furthermore, since accessibility depend on the quality of the function of the transportation system, this concept relate to the adverse of the vulnerability in terms of reducing accessibility that occurs because of the different reasons. As the idea of network vulnerability relates to the consequences of link failure and the potential for adverse socio–economic impacts on the community (Taylor and D' Este, 2006), thus the vulnerability can be defined in the following terms:

1. a node is vulnerable if loss (or substantial degradation) of a small number of links significantly diminishes the accessibility of the node, as measured by standard index of accessibility.
2. a network link is critical if loss (or substantial degradation) of the links significantly diminishes the accessibility of the network or of particular nodes, as measured by standard index of accessibility.

Therefore, it can be concluded that road vulnerability assesses the weakness of road network to incidents and what adverse impacts of the degraded road network serviceability on the community.

Recently, there are several network vulnerability concepts which have been proposed. Berdica (2002) given a notion of road vulnerability definition coherently by considering the relationship between the serviceability of the road and the incidents that occur on it and how well the transport system work in different respects (full and degraded networks).

In relation to measurement of the road network performance, Taylor et al (2006) studied the network vulnerability at the level of Australian national road network and the socio economic impact of degradable links in order to identify critical links within the road network, by using three different accessibility approaches. The first method was the measurement of the change of the generalised travel cost between the full network and the degraded one. This method was concluded that by degrading one particular link will increase the generalised travel cost, then the links which gave the highest travel cost was determined as the most important links. The second method used the changes of the Hansen integral accessibility index (Hansen 1959). It was assumed that the larger the changes after cutting one link the more critical that link was on the basis of the adverse socio-economic impacts on the community. The last approach considered the changes of the Accessibility/Remoteness index of Australia (DHAC, 2001). This method was similar with the second method which sought the critical link depending on the difference between the ARIA indices in the full network and the ARIA indices in degraded network.

Moreover, Taylor et al (2006) also studied the application of the third approach at the regional level in the state of Western Australia. This study concluded that by removing one links gave different impact on the cities, for example, by cutting one link, the impacts on the several cities were only local, in contrast other cities where there were available similarly alternative road performance did not gave significant changes of the ARIA indices.

Due to the importance of the particular link within the wide road network, Jenelius et al (2006) introduced a similar approach to Taylor et al (2006). They studied the link importance and the site exposure by measuring the increase in generalised travel cost in the road network of the Northern Sweden where the road network was more sparse and the traffic volumes were low. By assuming the incident was a single link being completely disrupted or closed so the generalised cost increases, then the most critical link of the operation of the whole system and the most vulnerable cities because of the link disruptions were determined. The study concluded that the effect of closing a link was quite local and the worst effect was in the region where the road network was sparser with fewer good alternative roads.

In addition, Taylor (2007) studied the road network vulnerability in the South Australia road network which included all the freeway, highway and major main roads at the South Australia. This research used a large complex road network and evaluated the ARIA indices changes for about 161 locality centres with populations exceeding 200 people. This study found the top ten critical links at the South Australia road networks.

Moreover, it has been concluded that the Hansen Index is more suitable to assess the network vulnerability at the national level but less applicable at the regional level or inter urban area and the rural area because of the index is a discrete measures. Therefore, the ARIA index is proper approach to measure the socio – economic impact of degraded road networks in rural area (Taylor, 2007).

**Accessibility**

Accessibility can be defined as some measure of spatial separation of human activities (Morris et al, 1978). Hansen (1959) defined accessibility as "the potential for the interaction". As accessibility can be seen as the fundamental concept in transportation planning, generally, accessibility can be defined as the ease for people to participate in activities from specific location using a transport mode thus it can be used to evaluate the performance of the transport system. In conclusion, accessibility is denoted as the ease by which activities can be reached from a given location using a specific transport system which is a measure of spatial separation of human activities.

**Hansen Indices**

An accessibility measure is the integration of accessibility indicators into a single measure. Hence, in order to measure the accessibility indicator of particular area, the most commonly method is relative accessibility. Relative accessibility measures of effort in making a trip, in this case the travel time and travel cost to the nearest health centre can be defined as a relative accessibility, it is calculated using the formula

$$A_{ij} = O_j f(C_{ij}) \qquad \text{Equation 1}$$

where $A_{ij}$ is the accessibility from zone i to j , $O_j$ is the opportunities present in j and $f(C_{ij})$ is the impedance function of generalised cost for travel from i to j.

Moreover, the integral accessibility can be measured by summing the total potential for travel opportunities at particular area. According to Hansen accessibility index, in measuring the accessibility index not only consider the generalised travel cost but also consider about the attractiveness of location which represent the size of activity such as the population, the number of theatre seats, the number of jobs, as well as the size of shopping centre (Hansen, 1959). The Hansen Integral accessibility index for location can be written as

$$A_i = \sum_j B_{ij} f(c_{ij}) \qquad \text{Equation 2}$$

where $A_j$ is the integral accessibility, $B_j$ is the attractiveness of location (city) j is the number of opportunities available at j, $B_j$ is often taken of the population of city j, $f(C_{ij})$ is the impedance function represent the separation between i and j. By giving the weight, the normalised of the equation 2 is also often used as the equation 3 below.

$$A_i = \frac{\sum_j B_{ij} f(c_{ij})}{\sum_j Bj} \qquad \text{Equation 3}$$

The impedance function $f(c_{ij})$ in the equation above can be the travel time and travel cost. This means that the higher the impedance function, the lower the accessibility index at the particular area. Taylor (2007) used the reciprocal of the distance between two cities ($x_{ij}$) as the impedance factor.

$$f(c_{ij}) = \frac{1}{x_{ij}} \qquad \text{Equation 4}$$

**ARIA Indices**

Since the Hansen index is less applicable in assessing the network vulnerability in rural areas, an alternative measure such as the Accessibility/Remoteness Index of Australia (ARIA) index should be applied (Taylor et al, 2006). ARIA (DHAC, 2001) is an index which was developed by the Department of the Health and Aged Care following concern about the difficulties faced by the rural community in accessing vital services such as health, finance and education. The index measures remoteness in terms of access along the road network between populated localities and service centres. This means that the remote localities are those that have least access to the service centres and the least remote localities are those that have most access to service centres. Since the remoteness can be interpreted as the access to a range of services, some of which are available in smaller and others only in larger centre, the remoteness of location can thus be measured in terms of how far one has to travel to centres of various sizes. The range of ARIA+ index is from 0 to 15 which means the greater the index value, the more remote the particular area.

The service centre can be defined as populated localities where the population exceeds 200 persons. There are six categories of service centres which are tabulates in table 1.

| Service Centre Category | Population |
|---|---|
| A | ≥ 250,000 |
| B | 48,000 -249,999 |
| C | 18,000 - 47,999 |
| D | 5,000 – 17,999 |
| E | 1000 – 4,999 |
| F | 200 - 999 |

Table 1 ARIA Service Centre Category (DHAC, 2001)

The distance calculation for each locality centre to service centres is performed by using the transportation network ignoring the road type. Due to small differences of the distance to access the service centre at the same locality centre, these distances were also ignored. Given the minimum distance from each populated location to the nearest service centres, thus for each category has six measurement per locality, each representing the minimum distance to nearest service centre in a particular category. When the minimum distance to larger service centre category is less than the minimum distance to lower service centre category, then the minimum distance for the higher service centre category was applied. In order to get the continuous variable with values of between 0 and 15, minimum distance to all the service centre were divided by the national mean distance for each category and then were summed up (DHAC, 2001).

Then ARIA index can be calculated by considering the distance by road from a locality to the nearest service centre in each category as below

$$ARIA_i = \sum_L \min\left\{3, \frac{x_{iL}}{\bar{x}_L}\right\} \qquad \text{Equation 5}$$

Where $\bar{x}_L$ is the mean road distance of all localities to the nearest category L service centre.

Table below lists the national mean distance for each category

| Category | Mean |
|---|---|
| A | 413 |
| B | 239 |
| C | 139 |
| D | 88 |
| E | 43 |

Table 2 Average Distance Statistic for Australia (Km) (DHAC, 2001)

**The Vulnerability Measurement**

As has been mentioned at the earlier parts, this research measures the changes of the Hansen Index and ARIA indices after cutting one particular link. The section below reviews the approach in order to measure the ARIA indices changes. According to Taylor (2007), in general the integral accessibility of object can be represent by using the formulation below

$$A_i = fn\left(N, X_i, S_{jk}, j \in J, k \in K\right)$$

Where $A_i$ is the object accessibility, *N* is the transport network in its present state, $X_i$ represents the object *i* and its location and characteristics, and $S_{jk}$ represents facility type *j* located at site *k*, which thus describes the land use distribution and intensity in the study area. This equation means that the object accessibility are affected by the of the transport network configuration, the operational state of that network, and the facilities and services accessible using the network.

By assuming that the $A_i^0$ is the accessibility object at the full network $N^0$ and the $A_i^1$ as the accessibility object at the degraded network $N^1$ , thus the relative accessibility changes can be determined as the equation below:

$$\Delta RA = 1 - \frac{A_i^1}{A_i^0} \qquad \text{Equation 6}$$

Then degraded links which give the biggest changes in the accessibility indices can be identified as the most critical links.

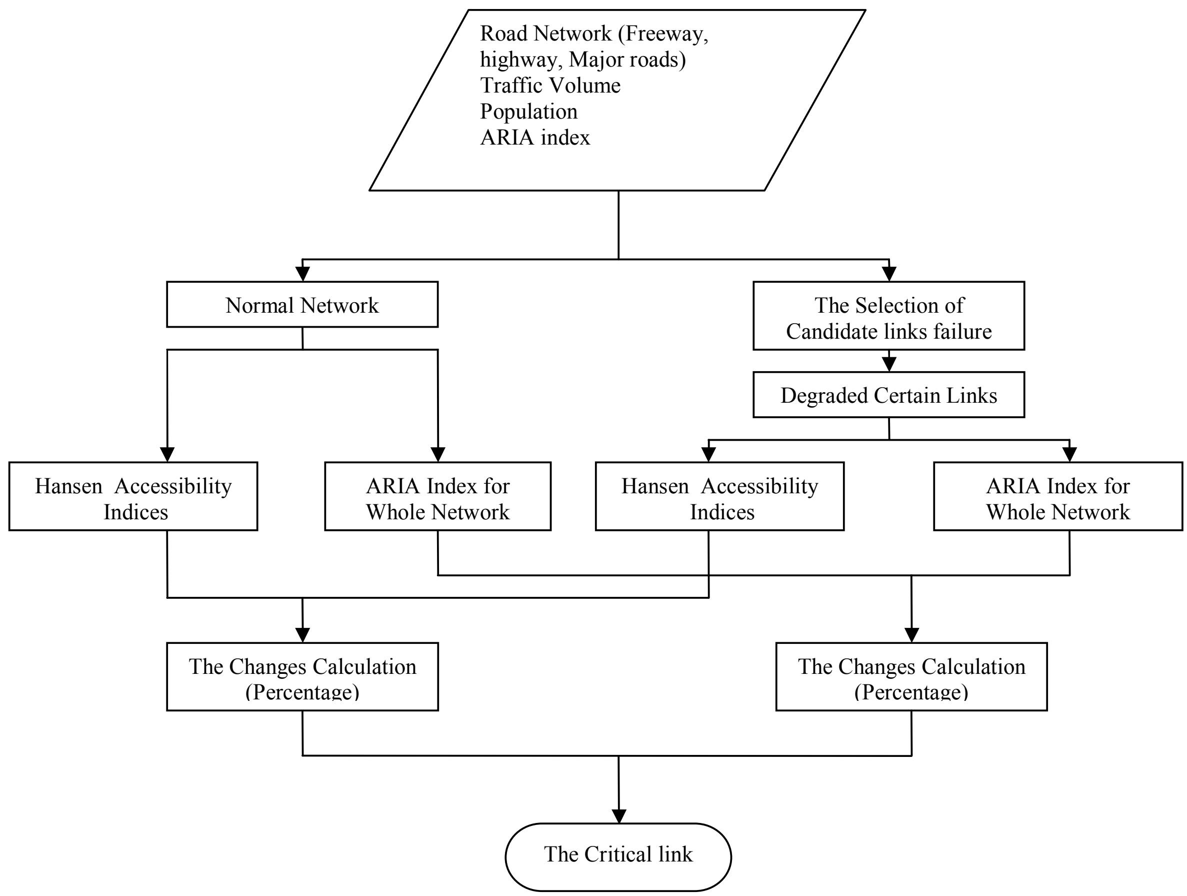
**The Methodology**

As the objectives of the study are to find out the vulnerability road network at the regional level by measuring the changes of the Hansen accessibility indices and ARIA index after degraded one or more links at the particular road network at The Green Triangle Region, thus Geographic Information system. The basic methodology are :

1. The data collection which covers road network data and its attributes especially for freeway, highway and major roads at the Green Triangle Region, locality centres population and the traffic volume.
2. The development of road network data base and revising and correcting the current road network database.
3. To extract locality centre from street pro data base based on its population which are more than 200 peoples
4. The ARIA and Hansen index calculation for the full road network

5. The selection of the candidate links by overlaying the shortest path from all locality centres to A, B, C and D service centres
6. The calculation of ARIA and Hansen index changes and the selection of the critical links
7. The development of the new method in assessing the vulnerability road network by considering the changes of the volume of surface area.
8. The development of the new method in measuring the vulnerability road network by considering the pattern of the contour and the slope change of the study area.

Research Methodology Flowchart




**Result**

**Hansen Indices and ARIA Indices at Full Network**

Based on Appendix 1, the range of the Hansen indices at the Green Triangle Region is from 2.143 to 7.608. Hence, the most accessible town is MacArthur with the population is 242 people and the less accessible city is Balmoral with the population is 202 people. The average of the Hansen Indices at the Green Triangle Region is 3.3. It can be concluded that overall the Green Triangle Region is accessible due to the availability of good topological transportation networks.

Appendix 2 tabulates the ARIA indices for all cities category at the Green Triangle region. It can be seen that, the range of the ARIA indices at the Green Triangle Region is from 1.457 to 6.254, then, the most accessible city is Warrnambool which has been categorised as C service centre with population 26669. On the other hand the least accessible town is Edenhope with the population 774 people.

In relation with the ARIA+ category which has been grouped by the DHAC, the Green Triangle Region can be classified into three classes of accessibility, namely highly accessible, accessible, and moderately accessible. In general, according to the DHAC classification the service centres in the Green Triangle Region are accessible.

**Hansen Indices at Degraded Networks**

After selecting some candidate links which would be degraded, the new shortest paths were developed. Then by using the new shortest path, the Hansen indices for all population centers were calculated for the degraded network, by using the equation 7 the changes of the Hansen indices can be measured.

Figure 1 below illustrated the four links which will be discussed in the next section.

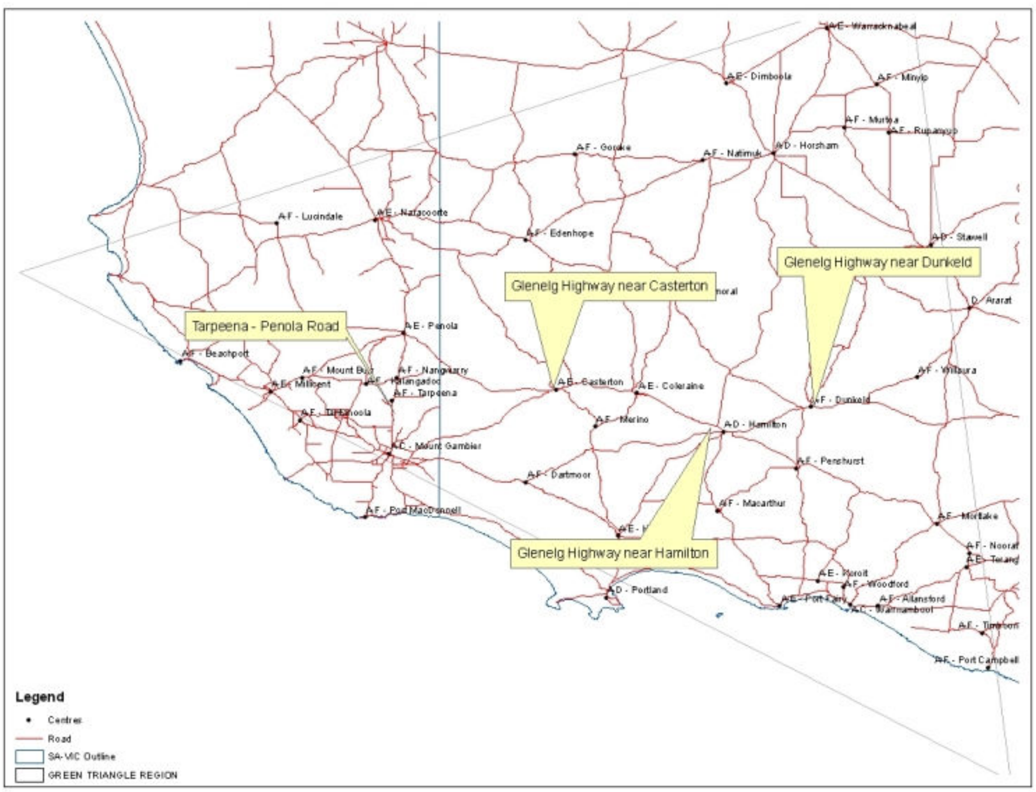



Figure 1 The Most Critical links in the Green Triangle region

Appendix 3 tabulates changes in the Hansen Indices. In general, by cutting any one link there were no significant changes in Hansen indices and the impacts are quite local. According to the network simulation, the most significant link in the Green Triangle Region is the short section of Glenelg Highway near Casterton which gives the most significant impact on the Hansen indices (19% changes). Other interesting finding were the degradation of the section of Glenelg Highway near Dunkeld and the section of Glenelg Highway near Hamilton as shown in Figure 1, which gave significant Hansen indices changes for almost all the cities at the Green Triangle region. By degrading the section of Glenelg Highway near Dunkeld, 27 adjacent population centres were affected. The most severe effect was for Balmoral with the Hansen indices changes was 6.56%. Moreover the biggest Hansen indices changes after degraded the Glenelg Highway near Hamilton was Coleraine at about 10.94% and this affected 25 adjacent population centres. Failure of the rest of candidate links slightly disrupted the performance of the road network in the region thus the Hansen indices changes were not big and did not give significant impact on the adjacent population centres. In general, it can be concluded that though the Hansen indices changes were quite small, the degraded links impacted on almost the population centres in the region as well as reducing the accessibility of the community.

For more detail all of the Hansen Indices changes for each selected link are given in the Appendix 3.

**ARIA Indices at Degraded Networks**

The Appendix 4 summarises the ARIA indices changes. The interesting finding was that by degrading one short link at the network i.e. on the Glenelg Highway near Dunkeld as shown in Figure 7, the impact on the neighbourhood population centres was quite significant, it can be seen from the indices change, there were 15 population centres were affected after degrading this link. In addition, by cutting this link the impact on the nearby city i.e. Dunkeld was very large by more than 57% of the ARIA indices changes. This big change was because of the detour from Dunkeld needed to reach the nearest C and D category service centres by more than 30km. Similarly to the changes of the Hansen index, the link section of Glenelg Highway near Hamilton and Casterton also gave big impacts to Hamilton and Casterton. The Casterton ARIA indices change by degrading Glenelg Highway near Casterton is 21.3% then other 10 population centres were also affected, though the ARIA indices changes were not too big. The degradation of the Glenelg Highway near Hamilton changed the ARIA indices of Coleraine by 29.1% and affected another 10 population centres in the Green Triangle Region.

Furthermore, in relation with the degraded or closed long road section links in the region which had heavy traffic volumes as well as being used as key road sections to connect the lower category population centres to the higher category ones in terms of reaching the better service centres on the networks, the consequences of closure or degradation of those links were not generally severe on the community. Based on the data analysis, this was due to the existence of equally attractive route in the region.

This research methodology also seeks other critical links on the network by considering the traffic volumes and the percentages of trucks, then selecting some candidate links. As for the earlier study, the candidate links were also cut and the new minimum cost path matrices were created. Based on the simulation process, the consequences of degradation or closure of some candidate links on the adjacent population centres were not significant. It was demonstrated by observation that the changes of both ARIA and Hansen indices at some scenarios were zero.

## Conclusion

Since much of the research on transportation network reliability focuses more on the urban road network problems where the big concerns are congestion and travel time variability, thus the study of road network vulnerability which analyses the social-economic consequences on the community, particularly in rural areas may be more important. In relation to the development of the road network vulnerability approach, there are different methods to measure vulnerability. Most of the methods studied the differences between a road vulnerability index in the full network and that in the degraded network. In conjunction with the previous study, one of the road network vulnerability measurements is the use of the accessibility approach. By considering the changes in accessibility using both the Hansen index and the ARIA index, this study concluded that the most critical link in the Green Triangle Region is the short link in the Glenelg Highway near Dunkeld. The closure or degradation of this link affected almost all of the centres in the region and increased the Dunkeld ARIA indices by more than 57%. In addition, the short sections of the Glenelg Highway near Hamilton and Casterton were identified as the second and the third most critical links in the region. This is due to the severe socio-economic consequences of closure or degradation of those links. In general, the other candidate links also gave large impacts for the adjacent centres but the impacts were local and quite small.

In terms of assessing the road vulnerability in the Green Triangle region, the most appropriate measurement is to use the ARIA index changes. It is due to the characteristic of the ARIA index which provides the aggregate value. Then the Hansen index is less appropriate in assessing the vulnerability road network because it is better suited to studies of large population centres. The other finding is the development of a new method for choosing the candidate links: this study suggested to overlay the shortest route to reach any C and D category service centre in terms of finding the candidate links.

## Further Research

As the network vulnerability research was only developed within the last decade, this study only focus on the accessibility indices changes under the static conditions. This means that the study only considered the changes of the minimum shortest path matrices and the serviceability of road network, however it ignores the availability of the information to road users and road user behaviour under condition of uncertainty. Additionally, this study also built on the idea that all of the road networks can cope with the increased demand due to the diverting routes. This is reasonable in uncongested networks of the type found in the Green Triangle region, but may not be so in more congested areas.

Moreover, this study did not also take account the increases of travel time when the road user can not receive sufficient information therefore the road user needs additional extra time to reverse and to find the alternative road. For further discussion, the increase of travel time and travel cost due to the different degree of the road user information can be taken into account in the measurement of the accessibility indices, for both the Hansen and the ARIA indices.

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# Appendix

Appendix 1. The Hansen Index Values at the Full Network

| Service Centre Name | Hansen Index |
|---|---|
| A - Adelaide | 1.726 |
| A - Melbourne | 4.318 |
| A-B - Ballarat | 6.843 |
| A-B - Bendigo | 5.601 |
| A-B - Geelong | 10.402 |
| A-C - Mount Gambier | 2.316 |
| A-C - Warrnambool | 3.295 |
| A-D - Hamilton | 3.072 |
| A-D - Horsham | 3.090 |
| A-D - Portland | 2.581 |
| A-D - Stawell | 3.771 |
| A-E - Casterton | 2.694 |
| A-E - Coleraine | 2.877 |
| A-E - Dimboola | 2.932 |
| A-E - Heywood | 2.708 |
| A-E - Koroit | 3.431 |
| A-E - Millicent | 2.268 |
| A-E - Naracoorte | 2.374 |
| A-E - Penola | 2.448 |
| A-E - Port Fairy | 3.200 |
| A-E - Terang | 3.982 |
| A-E - Warracknabeal | 2.911 |
| A-F - Allansford | 3.921 |
| A-F - Balmoral | 2.862 |
| A-F - Beachport | 2.143 |
| A-F - Dartmoor | 2.594 |
| A-F - Dunkeld | 3.423 |
| A-F - Edenhope | 2.561 |
| A-F - Goroke | 2.693 |
| A-F - Halls Gap | 3.532 |
| A-F - Kalangadoo | 2.352 |
| A-F - Lucindale | 2.223 |
| A-F - Macarthur | 2.950 |
| A-F - Meredith | 7.608 |
| A-F - Merino | 2.711 |
| A-F - Minyip | 3.094 |
| A-F - Mortlake | 3.919 |
| A-F - Mount Burr | 2.295 |
| A-F - Murtoa | 3.232 |
| A-F - Nangwarry | 2.380 |
| A-F - Natimuk | 2.997 |
| A-F - Noorat | 3.983 |
| A-F - Penshurst | 3.272 |
| A-F - Port Campbell | 3.733 |
| A-F - Port MacDonnell | 2.359 |
| A-F - Rupanyup | 3.269 |
| A-F - Tantanoola | 2.341 |
| A-F - Tarpeena | 2.323 |
| A-F - Timboon | 3.905 |
| A-F - Willaura | 3.686 |
| A-F - Woodford | 3.856 |

Appendix 2. The ARIA Index Values at the Full Network

| Service Centre Name | MIN A | MIN B | MIN C | MIN D | MIN E | ARIA |
|---|---|---|---|---|---|---|
| A - Adelaide | 0 | | | | | 0.000 |
| A - Melbourne | 0 | | | | | 0.000 |
| A-B - Ballarat | 121.9 | | | | | 0.294 |
| A-B - Bendigo | 147.5 | | | | | 0.355 |
| A-B - Geelong | 77 | | | | | 0.186 |
| A-C - Mount Gambier | 424.7 | 331.8 | | | | 2.479 |
| A-C - Warrnambool | 277.9 | 179.5 | | | | 1.457 |
| A-D - Hamilton | 317.8 | 195.9 | 99.6 | | | 2.374 |
| A-D - Horsham | 317.1 | 196.6 | 196.6 | | | 3.105 |
| A-D - Portland | 385.3 | 279.6 | 107.4 | | | 2.962 |
| A-D - Stawell | 249.8 | 129.3 | 129.3 | | | 2.141 |
| A-E - Casterton | 386 | 264.1 | 72.9 | 68.5 | | 3.452 |
| A-E - Coleraine | 353.5 | 231.6 | 105.3 | 36.1 | | 3.089 |
| A-E - Dimboola | 352 | 231.6 | 231.6 | 34.9 | | 4.021 |
| A-E - Heywood | 376.3 | 254.3 | 102 | 25.2 | | 3.089 |
| A-E - Koroit | 295.9 | 196.5 | 18 | 18 | | 1.924 |
| A-E - Millicent | 382.8 | 382.8 | 52.3 | 52.3 | | 3.617 |
| A-E - Naracoorte | 332 | 332 | 92.7 | 92.7 | | 4.057 |
| A-E - Penola | 378.3 | 331.2 | 46.4 | 46.4 | | 3.265 |
| A-E - Port Fairy | 308.4 | 209 | 30.5 | 30.5 | | 2.252 |
| A-E - Terang | 230.8 | 133.9 | 49.6 | 49.6 | | 2.107 |
| A-E - Warracknabeal | 345.2 | 215.2 | 215.2 | 53.1 | | 4.026 |
| A-F - Allansford | 267.5 | 173.1 | 10.4 | 10.4 | 10.4 | 1.848 |
| A-F - Balmoral | 354.5 | 232.5 | 145.9 | 61.6 | 45.9 | 4.772 |
| A-F - Beachport | 366 | 366 | 89.7 | 89.7 | 37.4 | 5.099 |
| A-F - Dartmoor | 397.9 | 276 | 55.8 | 55.8 | 55.8 | 4.551 |
| A-F - Dunkeld | 282.9 | 161 | 94.1 | 34.9 | 34.9 | 3.322 |
| A-F - Edenhope | 392.6 | 297.6 | 145.7 | 101.8 | 72.9 | 6.254 |
| A-F - Goroke | 381.9 | 271.8 | 186.7 | 76 | 60.4 | 5.826 |
| A-F - Halls Gap | 270.9 | 150.4 | 150.4 | 30.7 | 30.7 | 3.523 |
| A-F - Kalangadoo | 407.3 | 358.6 | 39.3 | 39.3 | 28.9 | 3.990 |
| A-F - Lucindale | 336.7 | 336.7 | 121.8 | 121.8 | 43.4 | 5.663 |
| A-F - Macarthur | 337.9 | 227.3 | 71.2 | 34.6 | 34.6 | 3.563 |
| A-F - Merino | 377.3 | 255.4 | 93.4 | 59.8 | 23 | 3.978 |
| A-F - Minyip | 318.4 | 196.3 | 196.3 | 51.2 | 28.5 | 4.376 |
| A-F - Mortlake | 237.3 | 128.3 | 51.2 | 51.2 | 22.2 | 2.645 |
| A-F - Mount Burr | 394.1 | 372.2 | 49.9 | 49.9 | 12.9 | 3.851 |
| A-F - Murtoa | 306.7 | 186.2 | 186.2 | 31.3 | 31.3 | 4.056 |
| A-F - Nangwarry | 395.7 | 346.7 | 29 | 29 | 17.4 | 3.442 |
| A-F - Natimuk | 343.5 | 223 | 206.6 | 27.2 | 27.2 | 4.316 |
| A-F - Noorat | 230.4 | 133.4 | 54.8 | 54.8 | 5.2 | 2.326 |
| A-F - Penshurst | 298.9 | 188.3 | 67.1 | 32.8 | 32.8 | 3.204 |
| A-F - Port Campbell | 240.2 | 159.5 | 77 | 77 | 36.6 | 3.625 |
| A-F - Port MacDonnell | 452.2 | 358.4 | 27.4 | 27.4 | 27.4 | 3.831 |
| A-F - Rupanyup | 298.2 | 177.7 | 177.7 | 49.2 | 48.5 | 4.548 |
| A-F - Tantanoola | 399 | 368.1 | 36.3 | 36.3 | 16.2 | 3.658 |
| A-F - Tarpeena | 404.5 | 350.9 | 20.2 | 20.2 | 20.2 | 3.376 |
| A-F - Timboon | 230.8 | 150.2 | 61.7 | 61.7 | 27.3 | 3.048 |
| A-F - Willaura | 254.7 | 134.2 | 134.2 | 34.8 | 34.8 | 3.435 |
| A-F - Woodford | 286.5 | 187.1 | 8.6 | 8.6 | 8.6 | 1.878 |

Appendix 3. The Hansen Indices change for several degraded links candidate

| FEATURA_NA | Penola - Tarpeena Rd | Casterton - Penola Rd | Glenelg hwy near Dunkeld | Glenelg Hwy - near Hamilton | Glenelg Hwy - near Casterton | Glenelg Hwy between Coleraine & Hamilton | Henty Hwy between Hamilton and Heywood | Princes Hwy near Kingston | Princes Hwy near Millicent | Western Hwy |
|---|---|---|---|---|---|---|---|---|---|---|
| A-C - Mount Gambier | 0.561 | | 2.366 | 0.000 | 0.042 | 0.042 | | | | 0.042 |
| A-C - Warrnambool | | | | 0.061 | | | | | | |
| A-D - Hamilton | | | 3.976 | 0.195 | | | 0.189 | | | |
| A-D - Horsham | | | | | 0.045 | 0.045 | 0.036 | | | 0.045 |
| A-D - Stawell | | | 0.243 | | | | 0.025 | | | |
| A-E - Casterton | | 0.699 | 2.826 | 3.452 | 19.937 | 3.126 | 0.067 | | | 3.126 |
| A-E - Coleraine | | | 3.228 | 10.949 | 0.162 | 0.162 | 0.106 | | | 0.162 |
| A-E - Dimboola | | | | | 0.035 | 0.035 | 0.028 | | | 0.035 |
| A-E - Heywood | 0.295 | | 1.324 | | | | 1.705 | | | |
| A-E - Koroit | | | 0.023 | 0.087 | | | | | | |
| A-E - Millicent | | 0.003 | 1.915 | | 0.003 | 0.003 | | 0.994 | 0.890 | 0.003 |
| A-E - Naracoorte | 0.463 | 0.294 | 0.012 | 0.210 | 0.294 | 0.189 | | | | 0.189 |
| A-E - Penola | 1.348 | 6.701 | 2.193 | 2.539 | 6.727 | 2.239 | | | | 2.239 |
| A-E - Port Fairy | | | 0.029 | 0.125 | | | | | | |
| A-E - Terang | | | | 0.050 | | | | | | |
| A-E - Warracknabeal | | | | 0.000 | 0.031 | 0.031 | 0.025 | | | 0.031 |
| A-F - Allansford | | | | 0.077 | 0.000 | 0 | | | | |
| A-F - Balmoral | | | 6.567 | | 0.109 | 0.109 | 0.075 | | | 0.109 |
| A-F - Dartmoor | 0.424 | | 2.844 | | | | | | | |
| A-F - Dunkeld | | | 3.524 | | | | 0.082 | | | |
| A-F - Edenhope | | | 0.202 | 0.078 | 0.196 | | 0.043 | | | |
| A-F - Goroke | | | | | | | 0.033 | | | |
| A-F - Halls Gap | | | 0.699 | | | | 0.036 | | | |
| A-F - Kalangadoo | | 1.824 | 2.05 | 1.828 | 1.824 | 1.824 | | | | 1.824 |
| A-F - Lucindale | 0.270 | 0.607 | 0.255 | 0.449 | 0.607 | 0.416 | | 0.556 | | 0.416 |
| A-F - Macarthur | | | 0.389 | 0.169 | | | 0.057 | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| A-F - Merino | | 0.491 | 2.969 | 0.406 | 0.491 | | 0.081 | | |
| A-F - Minyip | | | | | 0.030 | 0.03 | 0.024 | | 0.030 |
| A-F - Mortlake | | | | 0.026 | | | | | |
| A-F - Mount Burr | | 1.348 | 1.983 | 1.351 | 1.348 | 1.348 | | 0.928 | 1.348 |
| A-F - Murtoa | | | | | 0.033 | 0.033 | 0.026 | | 0.033 |
| A-F - Nangwarry | 3.277 | 1.915 | 2.066 | 1.953 | 1.944 | 1.944 | | | 1.944 |
| A-F - Natimuk | | | | | 0.053 | 0.038 | 0.037 | | 0.038 |
| A-F - Noorat | | | | 0.050 | | | | | |
| A-F - Penshurst | | | 0.526 | 0.092 | | | 0.025 | | |
| A-F - Port Campbell | | | | 0.027 | | | | | |
| A-F - Rupanyup | | | 0.001 | | 0.029 | 0.029 | 0.020 | | 0.029 |
| A-F - Tarpeena | 7.792 | | 1.979 | 0.040 | 0.044 | 0.044 | | | 0.044 |
| A-F - Timboon | | | | 0.026 | | | | | |
| A-F - Willaura | | | 0.754 | | | | 0.042 | | |
| A-F - Woodford | | | | 0.052 | | | | | |

# Appendix 4. The ARIA Indices change for several degraded links candidate

| Feature Name | Princes Hwy near Kingston | Princes Hwy near Millicent | Old Penola - Penola Rd | Casterton-Penola RD | Glenelg Hwy near Dunkeld | Glenelg Hwy near Hamilton | Glenelg Hwy between Casterton & Hamilton | Glenelg Hwy near Casterton | Western Hwy | Penola Rd - Tarpeena | Henty Hwy | Dartmoor - Hamilton Rd | Hamilton Hwy | Princes-Hwy Terang-Camperdown | Princes Hwy near Warrnambool |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A - Adelaide | | | | | | | | | | | | | | | |
| A - Melbourne | | | | | | | | | | | | | | | |
| A-B - Ballarat | | | | | | | | | | | | | | | |
| A-C - Mount Gambier | | | | | 4.670 | | | | | 1.020 | | 0.902 | | | |
| A-C - Warrnambool | | | | | | | | | | | | | 1.204 | | |
| A-D - Hamilton | | | | | 6.270 | | | | | | | | | | 1.520 |
| A-D - Horsham | | | | | | | | | | | | | | | |
| A-D - Portland | | | | | 0.930 | | | | | | 0.900 | | | | |
| A-D - Stawell | | | | | | | | | | | | | | | |
| A-E - Casterton | | | | | 4.310 | 21.290 | 4.670 | 21.290 | | | | | | | |
| A-E - Coleraine | | | | | 4.820 | 2.890 | 29.150 | 2.890 | | | | | | | |
| A-E - Dimboola | | | | | | | | | 16.950 | | | | | | |
| A-E - Heywood | | | | | 3.070 | | | | | | 3.270 | | | | |
| A-E - Koroit | | | | | | | | | | | | | 1.140 | | |
| A-E - Millicent | 1.180 | 5.638 | | | | | | | | | | | | | |
| A-E - Naracoorte | | | | | | | | | | 9.863 | | | | | |
| A-E - Penola | | | | 6.160 | 3.559 | 6.190 | 2.150 | 6.190 | | 12.198 | | | | | |
| A-E - Port Fairy | | | | | | | | | | | | | 0.974 | | |
| A-E - Terang | | | | | | | | | | | | | | 3.684 | |
| A-E - Warracknabeal | | | | | | | | | | | | | | | |
| A-F - Allansford | | | | | | | | | | | | | | 0.688 | |
| A-F - Balmoral | | | | | 5.345 | 2.030 | | 2.030 | | | | | | | |
| A-F - Beachport | | 3.809 | | | | | | | | | | 0.005 | | | |
| A-F - Dartmoor | | | | | 3.274 | | | | | | | 2.544 | | | |
| A-F - Dunkeld | | | | | 57.337 | | | | | | | | | | 2.489 |
| A-F - Edenhope | | | | | | 8.190 | | 8.190 | | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A-F - Goroke | | 6.227 | | | | | | | 0.387 | | | | |
| A-F - Halls Gap | | | | | | | | | | | | | |
| A-F - Kalangadoo | 0.770 | | 1.080 | 1.374 | 2.910 | 1.370 | 1.370 | 1.370 | | | | | |
| A-F - Lucindale | | | | | | | | | 7.031 | | | | |
| A-F - Macarthur | | | | | 0.185 | | | | | | 0.676 | | |
| A-F - Merino | | | | | 3.745 | 0.467 | 0.710 | 0.467 | | | | | |
| A-F - Minyip | | | | | | | | | | | | | |
| A-F - Mortlake | | | | | | | | | | | 4.352 | | |
| A-F - Mount Burr | 0.960 | | 1.070 | 1.070 | 2.490 | 1.070 | | 1.070 | | | | | |
| A-F - Murtoa | | | | | | | | | | | | | |
| A-F - Nangwarry | | | | 1.657 | 3.370 | 1.682 | 1.680 | 1.682 | 13.148 | | | | |
| A-F - Natimuk | | | | | | 2.230 | | 2.230 | | | | | |
| A-F - Noorat | | | | | 0.200 | | | | | | | 3.653 | |
| A-F - Penshurst | | | | | | | | | | | 0.752 | | 3.168 |
| A-F - Port Campbell | | | | | | | | | | | | | |
| A-F - Port MacDonnell | | | | | 3.030 | | | | 0.220 | 0.606 | | | |
| A-F - Rupanyup | | | | | | | | | | 0.000 | | | |
| A-F - Tantanoola | 1.010 | 14.430 | | | 3.170 | | | | | 0.616 | | | |
| A-F - Tarpeena | | | | | 3.442 | 0.089 | 0.040 | 0.089 | 27.370 | | | | |
| A-F - Timboon | | | | | | | | | | | | | |
| A-F - Willaura | | | | | | | | | | | | | |
| A-F - Woodford | | | | | | | | | | | 1.168 | | |
| B - Bendigo | | | | | | | | | | | | | |
| B - Geelong | | | | | | | | | | | | | |