Accessibility Development by Shifting From Monocentric Structure to Polycentric Structure: A Comparison of Riyadh, Saudi Arabia and Melbourne, Australia

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Abstract—Land use and transport interaction is widely recognized as essential to achievement of better understanding of urban development. The concept of accessibility may provide a useful conceptual framework for this interaction. Focus on urban transport planning from catering for mobility to catering for accessibility helps to understand how more transport options can within certain land use conditions, provide a competitive degree of accessibility that matches less sustainable options. The authors have used the concept of accessibility as a framework for assessing land use and transport changes by shifting from monocentric to polycentric structure. The developed accessibility incorporated transport cost and opportunities at the end of the trip to quantify accessibility. This study takes employment, school and shopping and recreation trip purposes in account by three modes including car, public transport (PT) and walking. Melbourne and Riyadh were analysed as a case studies. The finding of the study pointed that combined and coordinated of activity and residences redistribution into polycentric structure for Melbourne and Riyadh will bring about significant benefits and will play a key role in achieving a more sustainable transport outcome.

Index Terms—Monocentric, Polycentric, Accessibility measurement, Riyadh, Melbourne.

I. INTRODUCTION

Since the end of World War II, economic growth and advancement in transport technologies have resulted in rapid urbanization. This rapid urbanization has promoted the shift from compact monocentric cities to urban sprawl, which has caused traffic congestion problems, longer trip distances, increased trip times and affected accessibility level[1].

Planning for accessibility rather than mobility may create benefits by decreasing travel distance, giving options to use more sustainable modes for example PT, walk and bicycle, and reducing the need to use the private mode [2].

By assessing the accessibility can be examined transport services to address issues of equity and transport disadvantages [3].

Decentralization of employment can be made possible by re-organization of the suburban structure, by shifting from a single core city center to multiple suburban Activity Centers (ACs) (e.g., employment, shopping, education and recreation) located at the periphery of the city. Increase employment density within Transport Oriented Development (TOD) areas will contribute towards increasing accessibility [3].

These suburban ACs become strong alternatives to the CBD, potentially combining the advantage of sprawl locations (low density, lower land price, less traffic congestion) with the advantages of sub-centre locations (economy, urbanization, personal interaction) that are connected by a good transport system [4], [5].

In Australia, there is much interest in encouraging a change in urban structure because it delivers significant transport improvements, particularly for PT. All major cities in Australia have developed spatial plans that encourage transit-oriented development (TOD) and in-fill development (so-called ‘urban consolidation’)[6].

These transport and land use policies look to bring residences closer to PT and to key AC, in an attempt to improve PT share and to respond to concerns about traffic congestion [7]. However, there are other approaches to the mix of activity, transport and land use, and interest in employment decentralization has been encouraged in Melbourne and Riyadh by future master plans until 2030.

Riyadh and Melbourne have been selected as case studies. Riyadh and Melbourne are similar in urban form and population number, yet different in transport systems. The private mode is predominantly used in Riyadh and Melbourne. However, Melbourne has a good PT system,
while Riyadh is constrained by the limited scale of its PT network currently. Yet, Riyadh future master plan adopted a PT mode such as rapid bus and train.

The objective of this chapter is to quantify the impact of polycentric urban structure policy in Melbourne and Riyadh, on accessibility improvement. This chapter organized into five sections. The first section displayed the outline of study. The second section shows the previous study. The section three displays the data and method. The section four explores the accessibility measurement result. Section five concludes the findings of study and the summary of the outcomes of study.

II. LITERATURE REVIEW

Accessibility is an alternative basis for sustainability with respect to the built environment. Accessibility to various aspects of daily life, such as employment, schools, clinical centers, shops and airports is highly valued [8].

Geurs and Van Wee (2004) have explained that, accessibility contains of four main components. The transport component is considered some indicators such as travel time, cost and effort of movement in space. The land use component measures the spatial distribution of activities or opportunities such as living, working and so on, and contains an assessment of the competitive nature of demand for activities at destinations, and of supply of potential users. The temporal component tests the time constraints users experience for their activity patterns, and the availability of activities or opportunities according to the time of the day, week or year. The individual component examines the needs, abilities and opportunities of transport users and also takes socio-economic and demographic factors in account[9].

Transportation plays a crucial role in accessibility via mobility, which may affect the land use of developments. This implies that poor levels of accessibility have significant drawbacks in terms of the potential for economic and social interactions between people and the delivery of key services [10].

Johnson (2007) found that in Australia transport problems affect 17 per cent of the surveyed job seekers, and the difficulties were more problematic in outer metropolitan areas (28 per cent of respondents) than in inner metropolitan areas (6 per cent of respondents). The importance of transportation reflects that the shortage of problems with transportation create the most difficult constraints users experience for their activity patterns, and the availability of activities or opportunities according to the time of the day, week or year. The individual component examines the needs, abilities and opportunities of transport users and also takes socio-economic and demographic factors in account[9].

To promote economic participation, social interaction and delivery of services, society must offer various options to people. The more accessibility options are available to people, the more they benefit. The likelihood that a person can find a job that is commensurate with their qualifications and interests increases if that person can conveniently access more potential employment opportunities. Increased transport options also improves ease of access, in that people are able to choose their destination and the corresponding cost of the travel according to the transport mode, and thus the amount spent on travel can be reduced. For example, an individual who has access to various retail centers may satisfy their needs easily and at low cost. When more options are available to individuals in their neighborhoods, there is less need for long-distance travel, and the amount of travel can be reduced. This scenario can help to reduce traffic congestion and benefit society [11].

The main goal of a transport system is to provide more options to society. This goal can be quantified using various measures of accessibility. Two aspects by which the transport system can contribute positively towards improving accessibility are (i) mobility and (ii) land development. The former aspect can expand the geographic scope for people to allow them to travel to many destinations. More investment in transport systems can expand the land available for development, which will increase opportunities and services close to people [2].

There are a number of approaches to accessibility measurement and they include the following:

Different approaches have used to measure the accessibility summarized into main four approaches [11]:

- Opportunity-based accessibility metrics are the sum of opportunities assumed by a measure of impedance such as the travel cost or travel time of moving to the opportunity.
- Origin-destination (OD)-based accessibility metrics measures accessibility is assumed from the spread and proximity of chosen destinations, such as the entropy based approach and the place-rank approach.
- Travel time-based approaches; it highlights the mobility aspect of accessibility, for instance, average travel time weighted by opportunities at destinations and travel time to the closest centre.
- Utility-based approaches; it considers accessibility as the benefit of the activity at the end of the trip, less the cost of moving there.
- Constraint-based approaches; it determines accessibility based on the number of opportunities that can be viably accessed within the travel time budget.

Accessibility can be measured or used in transportation planning, in which measures have often been car-based in the past [12]. Preston and Rajé (2007) state that the emphasis on employment accessibility is understandable, given its link to other important aspects of urban structure, such as choice of residential location, and also to outcomes hypothesized to be related to urban structure, such as social exclusion [8]. However, access to other types of destinations, such as retail shops, is important because it strongly influences various dimensions of travel behavior such as trip frequency [13], destination choice [12], and mode choice and trip complexity [14]. Better access to activities such as shopping and recreation is also thought to improve the general quality of life. On the other hand, accessibility has been used in addition to types of destination, and non-motorized modes such as
walking and cycling have been proposed previously as an objective worthy of further study in the land use-transportation field [12].

III. DATA AND METHODS

One of the major tasks in this study was to collect the data used to develop a land use/transport model. Data collection was divided into two groups; land use and demographic information, and transport data. In Riyadh, the demographic and population data was collected by the Ministry of Riyadh (MOR) in 2008 [15]; however, the land use data was collected by the Arriyadh Development Authority (ADA) in 2002[16].

In Melbourne, the demographic and population data was collected by the Department of Transport (DOT) of Victoria in 2008[17], however, the land use data was collected by the Local Municipalities Councils (LMC)[18].

The explanatory variables applied to the model are based on data availability. The variables were formed in relation to the socioeconomic characteristics of households, demographic data, land use and urban form. The data for Riyadh was sourced from the 2008 survey dataset, created by the MOR, and for Melbourne the data was sourced from the DOT, Melbourne, Victoria. The data was within the city’s traffic area zones (TAZs), with Riyadh featuring 2,166 of these, and Melbourne having 2,253 TAZs.

Trip distance was calculated as the shortest distance between two centroid points, which were sourced by the MOR and DOT in 2008 in Riyadh and Melbourne, respectively. At present, Riyadh has no tram and train service but it has been designed for these to be operative in the future. PT data was collected from the MOR (2008). The data for walking trip distances were extracted from Koushki’s (1988) study and used to predict the walk trip mode share in Riyadh [19].

Socioeconomic data for Melbourne was applied at the TAZ level, and used an independent variable for the models in this study, and the socioeconomic variables included the number of employed residents, the number of households, age group (0–17, 18–64, 65+), the number of jobs and the number of students.

The interaction of spatial settlement is created by the attractiveness of the spatial cells. The interaction between the spatial model and the transport network can be calculated by the accessibility indices, which describe the accessibility of different regions in the city, in turn representing access to employment, shopping, school and recreational facilities. GIS was used for this purpose.

This study developed a model through re-organize the distribution of residential and activities in 5 new sub-centers with the existing CBD area in both cities (see Fig. 1).

- Scenario 0 exhibits monocentric structure (existing structure) without change in structure and network.
- Scenario 1 has 5 new sub-centres with redistribution of both population and employment around the new sub-centres.

Additionally, different transport network structures and their impact on the traffic congestion as well as spatial fragmentation, trip times and distances was analyzed.

Scenario 0 is maternal after historical growth from 2008 year conditions while Scenarios 1 was formulated based on varying redistribution patterns. The base year was set as 2008 and the future analysis year was set as 2030. For redistributing activity or residence, it was assumed 7.5% at the incremental in activity/residence will add to the CBD, while the remaining 92.5% will be shared amongst the new subcentres. The area outside the CBD or Subcentres will remain as 2008

The growth in total population or activity was based on historical trends as sourced from ADA in Riyadh and the Australia Bureau of Statistics (ABS) in Melbourne.

A. Accessibility Measurement

Accessibility is widely measured as the number of choices or opportunities within reach. Opportunities are represented by an appropriate index, for example opportunities to access job are measured by the number of employment. The feasibility of these opportunities to a person is dependent on the transport impedance of moving there. Transport impedance is the generalised cost of moving to the location of the opportunity, which could include travel time, cost, convenience, safety, etc. Opportunities that have lower transport impedance will contribute more to accessibility than opportunities that have higher transport impedance [11].

The accessibility of a zone can be generally expressed by an isochronic equation (Koenig 1980), which is a function of weighted sum of opportunities, where the weights are based on transport impedance.

\[ A_i = \sum_j X_i f(C_{ij}) \]

where:

- \( A_i \) is the accessibility metric of zone \( i \).
- \( X_i \) is the opportunity index at destination zone \( j \).
- \( C_{ij} \) is the impedance between zone \( i \) and \( j \).

In this class of approach, there are many variants of the function form of the weighting factor based on transport impedance \( f(C_{ij}) \). Included in this class of accessibility measures are gravity-based measures and isochronic-based measures, which are used in this study, as listed below.
Gravity-based with power for impedance.

\[ f(C) = \frac{1}{C^d} \]

Gravity-based with exponential function for impedance.

\[ f(C) = \begin{cases} 1 & \text{if } C \leq K \\ \exp(-C) & \text{otherwise} \end{cases} \]

Isochronic or cumulative opportunity, K is a user-specified threshold.

Accessibility calculated by either the isochronic or the gravity approach is measured from the trip origin, typically from homes (e.g., number of schools within 30 minutes from home). Another approach is the destination-based approach, which measures accessibility from the destination point (e.g., number of households within 30 minutes from a school) [11].

In this study, an extensive literature review was performed, following Espeda’s (2011) study, which helped to establish the trip time limits shown in Table I below [11].

**IV. ACCESSIBILITY RESULTS**

Table II shows the accessibility level results for Melbourne for Scenarios 0 and 1. Work accessibility is improved in Scenario 1 compared to Scenario 0 for travel by all modes. The rate of accessibility by car is higher in Scenario 1 than in Scenario 0, and this is also the case for the PT and walk modes. In addition, the average accessibility by all modes is improved in Scenario 1 compared to Scenario 0. However, the lowest rate of accessibility by car and walk modes is 0 in all scenarios. The exception is the PT mode, the result of which is higher in Scenario 1 than Scenario 0.

In Scenario 1, the highest and average rate of primary and secondary school accessibility improve for all transport modes. For example, the highest rate of accessibility by car is 245,829, which is higher in Scenario 1 than Scenario 0, at 167,829. The average rate of accessibility, at 55,821, is also slightly higher in Scenario 1 compared to Scenario 0, at 55,786. Furthermore, the highest and average rates of accessibility are greater for the PT and walk modes in Scenario 1.

Tertiary study and shopping center accessibilities are improved for all modes in Scenario 1. For tertiary study trips, the highest level of accessibility by car is 465,668 in Scenario 1 compared to 355,668 in Scenario 0. Further, for shopping trips, the highest level of accessibility by car is 92,564 in Scenario 1, which is than the 85,307 seen in Scenario 0. The average level of accessibility is also higher in Scenario 1 than Scenario 0.

**TABLE II. MELBOURNE ACCESSIBILITY MEASUREMENTS BASED ON SCENARIOS 0 AND 1**

<table>
<thead>
<tr>
<th>Trip purpose</th>
<th>Accessibility level</th>
<th>Mode</th>
<th>S0</th>
<th>S1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary and secondary school</td>
<td>Highest</td>
<td>1,250,741</td>
<td>1,399,370</td>
<td>2,641,363</td>
</tr>
<tr>
<td></td>
<td>Lowest</td>
<td>2,619</td>
<td>3,002</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>341,472</td>
<td>354,157</td>
<td>68,983</td>
</tr>
<tr>
<td>Tertiary school</td>
<td>Highest</td>
<td>167,829</td>
<td>245,829</td>
<td>654,038</td>
</tr>
<tr>
<td></td>
<td>Lowest</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>55,786</td>
<td>55,821</td>
<td>17,052</td>
</tr>
<tr>
<td>Shopping and recreation</td>
<td>Highest</td>
<td>85,807</td>
<td>92,564</td>
<td>255,535</td>
</tr>
<tr>
<td></td>
<td>Lowest</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>26,885</td>
<td>27,349</td>
<td>6,864</td>
</tr>
</tbody>
</table>

Table III shows the accessibility level results for Riyadh for Scenarios 0 and 1. Work trip accessibility by all transport modes is improved in Scenario 1 compared to Scenario 0. The highest rate of accessibility by car is higher in Scenario 1 than Scenario 0 and this is also higher for the PT and walk modes. The average accessibility by all modes is also improved in Scenario 1. However, the lowest rate of accessibility is 0 by the PT and walk modes in all scenarios; here, the exception is for the car mode, which is higher in Scenario 3 compared to Scenario 0.

In Scenario 1, both the highest and average rates for primary and secondary school trip accessibility are improved for all transport modes. For example, the highest rate of accessibility by car is 3,394,953 in Scenario 1, compared to 2,495,713 in Scenario 0. The average rate of accessibility is also slightly higher in Scenario 3, at 1,616,156, compared to the 1,494,571 for Scenario 0. Further, the highest and average rates of accessibility are higher by the PT and walk modes in Scenario 1. However, the lowest rate of accessibility is 0 in all scenarios by the PT and walk modes, again with the exception of the car mode, which is higher in Scenario 0 compared to Scenario 1.

Tertiary study and shopping trip accessibility levels are improved by all transport modes in Scenario 1. For tertiary study trips, the highest level of accessibility by car is 1,611,052 in Scenario 1, compared to 1,451,277 in Scenario 0. For shopping trips, the highest level of accessibility by car is 2,702,453, higher in S3 than the
1,473,481 seen in Scenario 0. Overall, the average level of accessibility is higher in Scenario 1 than Scenario 0 for all transport modes.

**TABLE III. RYADH ACCESSIBILITY MEASUREMENTS BASED ON SCENARIOS 0 AND 1**

<table>
<thead>
<tr>
<th>Trip purpose</th>
<th>Accessibility level</th>
<th>Mode</th>
<th>S0</th>
<th>S1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Car</td>
<td>PT</td>
<td>Walk</td>
<td>Car</td>
</tr>
<tr>
<td>Week</td>
<td>Highest</td>
<td>5,204,791</td>
<td>5,302,942</td>
<td>5,386,966</td>
</tr>
<tr>
<td></td>
<td>Lowest</td>
<td>7,855</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>3,629,115</td>
<td>3,554,822</td>
<td>3,358,577</td>
</tr>
<tr>
<td>Primary and secondary school</td>
<td>Highest</td>
<td>2,495,713</td>
<td>4,094,276</td>
<td>184,353</td>
</tr>
<tr>
<td></td>
<td>Lowest</td>
<td>160</td>
<td>-</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>1,494,571</td>
<td>1,964,769</td>
<td>26,609</td>
</tr>
<tr>
<td>Tertiary school</td>
<td>Highest</td>
<td>1,451,277</td>
<td>1,473,481</td>
<td>1,334,083</td>
</tr>
<tr>
<td></td>
<td>Lowest</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>590,695</td>
<td>780,162</td>
<td>4,608</td>
</tr>
<tr>
<td>Shopping and recreation</td>
<td>Highest</td>
<td>113,461</td>
<td>216,378</td>
<td>9,286</td>
</tr>
<tr>
<td></td>
<td>Lowest</td>
<td>18</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>63,384</td>
<td>99,757</td>
<td>977</td>
</tr>
</tbody>
</table>

Overall, the accessibility levels are improved by the polycentric structure. In both Riyadh and Melbourne, the accessibility level is higher in Scenario 3 than Scenario 0 due to the fact that self-containment reduces the distances between housing and other activity centers, which leads to a reduction in trip costs.

V. CONCLUSION

In this paper, we have reported on comparative analysis through measuring accessibility that investigated the shift from monocentric to polycentric structure, for Riyadh and Melbourne. The results indicate that planned and concentrated employment and population in key activity centres may deliver significant benefits to improving the accessibility of car and sustainable modes (i.e. PT and walk). The findings of the combined and coordinated redistribution of activity and residences would achieve the best possible transport outcome, with regards to increased car accessibility trip. It also reduced travel consumption in general, including PT accessibility travel. It also promoted walk accessibility trips.

The finding of the study pointed that combined and coordinated of activity and residences redistribution into polycentric structure for Melbourne and Riyadh will bring about significant benefits and will play a key role in achieving a more sustainable transport outcome.

It is recommended that urban restructure polices should focus on both activity and residence re-alignment.

REFERENCES


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