Determining the Direction for Rapid Transportation by Maximum Cover Method: Case Study in Sydney, Australia

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Abstract— Routing for public rapid transportation is defined as determining the optimized location or position of stations and direction of route in a city. This problem can be solved as an optimization problem with target function of maximizing the cover of stations and distance of stations and length of direction as constraints. At the other hand, researchers have interested by heuristic or explorative methods due to their simplicity and fast performance in solving various problems. In the current paper, an heuristic method is represented for step by step developing of direction based on maximizing the criterion of population covered by stations and accessibility to important urban locations so that it is expected that the trip cover of direction – as target function – is maximized. The solving method is originated from two previous methods of population cover and trip cover. The population cover, trip attraction, diametric direction and length of direction are used as criteria. The proposed method is used in network of Sydney as case study. 20 answer directions with selected departure point are constituted by this method and two previous ones and the trip cover and their population are calculated and identified by comparing the results. The trip covers of directions in new method are increased compared to two previous methods. The maximum trip cover produced by one of the directions proposed by new method and by trip cover method is 58869 and 46962 trip, respectively. Comparing the new method and population cover method is showed that the population covered by the proposed method is 21.4% lower than the original method and the trip cover is 3.3 times greater than the original method. The answers of the proposed method have more trip cover than the maximum cover trip method as about 16.5%. For more precise concluding, a comparison is made between directions with same trend proposed by the presented method and the maximum trip cover method and it shows that for each of 4 same trend directions, trip cover is increased between 12 and 67%.

Index Terms— Heuristic Method, Attractive Trip Points, Trip Cover, Population Cover, Rapid Transportation, Maximum Cover Method, Sydney, New South Wales, Australia, Public Transport

1 Introduction

Use of rapid public transportation systems are rapidly growing; since these systems cause to increase in speed and decrease in rush and blockade in urban system and also reduce the increasingly problems in big cities [1-25]. Selecting the route for these systems have definitely a great effect on their function from speed, reduce in delay and increase in capacity points of view [25-39]. Determining the direction for rapid urban transportation systems is principally an optimization problem which is usually solved using non-systematic methods due to its complexity and large time consuming of the solving process [40].

Routing for rapid public transportation systems, which is named as "locating the rapid transit line" in some papers, is generally a problem for determining a direction for movement of rapid public vehicle in a city with high efficiency and low difficulty [41-67]. The recent activities for routing of rapid systems are frequently used from heuristic and meta-heuristic methods [68, 69]. No need to time consuming network analyses and performing customary optimization algorithms with massive calculations are the advantages of such methods [70, 73, 74]. In this regard, after studying these methods, a solution is presented in the current paper based on a heuristic method named as maximum cover.

Current et al. studied a route with maximum cover and minimum length by a multi-purpose research [71-77]. Thereafter, more heuristic methods were used as progress of investigations [78]. For example, Dufourd et al. proposed a method which used from new algorithm of Tabu search [79-83].

Bruno et al. proposed another model which was more real and assumed that the personal instrument mode is rival for rapid public system [84-87]. Bruno et al. proposed a new model which was a two step method for routing the metro system [88, 89]. Laporte et al. introduced the concept of trip cover of station by defining the various types of direction cover in different methods [90-93]. They solved the problem using a heuristic method and maximum length of direction as constraint [94, 95].

2 Case Study in Sydney, Australia

The interest of developing urban metropolitan regions is thoroughly related to the provision of sufficient and proper transportation services. There is a critical need to business activities, education, employment and recreational opportunities in an increasing urban population. Urban planning is based on the locating of these services and the providing of suitable transportation infrastructure including freeways, mass transit, and parking accommodation. Regional patterns of develop-

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ment, economic viability and environmental impacts are largely influenced by transportation system. However, the preserving of acceptable level of life's quality in society also depends on the transportation system. Hence, governments use more and more resources, continually, to efficiently plan and develop transportation services, as high as possible. Although there is not necessarily a clear path from policy specification to system implementation, establishing and using some processes to monitor and measure the performances and achievements are very important.

Regarding the planning for expected future growth and development in Sydney region, transportation service provision is a building block of social, economical and environmental sustainability. Specifically, ensuring about the viability of distribution of goods and services and also reasonability of social activities and networking the region are very significant. Combination of population growth and urban form make rather frightening challenges for transportation system. Moreover, some means should be established by transportation planners to evaluate and monitor the transportation system so that it can be ensure that the sustainability or achievability of short and long term goals.

Number of components involved in the transportation planning process and their complexities are rather important. The process ranges from the planning of major infrastructure projects such as interstates, freeways, bus ways and light and heavy rail systems to the regulation of pollutant emissions. A very important element of transportation planning process is getting confidence about the availability of certain modes of public transport for use. The importance of public transport services in a successful transportation system is widely recognized as the most important reason for it is assurance of long term sustainability in terms of resource consumption and the environment. Other important reasons are providing a transportation option for those without access to a motor vehicle and a travel alternative to commuters in order to decrease stress on current infrastructure. As a whole, this strongly motivates the public transport services.

To provide public transportation, two interrelated issues of access and accessibility to this mode of travel should be addressed. Access is defined as the opportunity for utilizing the system based on the proximity to the service and its cost. By increasing the distances or barriers to access a service at either the trip origin or destination, the possibility of recognizing the service as a mode of travel decreased. Similarly, the applicability of service reduced as its cost increased.

An accessible public transport system ships a passenger from its start point of trip to its destination in a reasonable time. Therefore, accessibility covers the operational functioning of a system for regional travel. However, access deeply affects the public transportation system and complements service accessibility. Accordingly, access to public transportation is clearly differs from the accessibility of the public transport system. Further, access and accessibility are mutually dependent to each other, if the public transport system is to be successful and well utilized. Although both are important, only access will be considered presently.

Evolving of metropolitan regions critically depends on the transportation planning. Parameters including trip purpose, temporal and spatial distributions of trips, modal splits of travel, and costs should be taken into account by transportation planning. These considerations will affect current and future infrastructure as well as the environment. A big picture perspective suggests influences on mobility which fits into a more general interpretation of sustainability that includes social, economic and environmental factors. The economic development can be grown on the basis of transportation systems. It also is a useful means to interact the society. An ineffective transport system and associated urban forms will limit economic and social opportunities. However, it should be pointed out that the greatest transportation implications for the sustainability of a region is due to the energy and environmental consequences of excessive traveling of single vehicle automobiles.

The implications for urban forms designed for motor vehicle transport are an inefficient use of nonrenewable resources, congestion and noise and air pollution externalities. One of the critical aspects of regional growth and prosperity is transportation planning which is closely connected to policy formulation and implementation.

The existence of some approaches for monitoring, evaluating and modeling system performance, in order to better inform and understand policies and regulations associated with transport services are very important. Associated with this has been the continued development and application of analysis approaches and models for identifying and assessing alternatives for achieving mandated reductions. This is essential to assess effects on facilities and various modes of travel resulting from the regional growth and change.

Geographical information system (GIS) is a key component to better understand of transportation processes in the emerging methods and techniques. Whether it is used to evaluate broad scale regional policies or link specific capacity, GIS is proving to be valuable for transportation management and modeling platforms. As a result, considerable investment has been made to establish transport planning approaches and relevant data to help the monitoring, evaluation and modeling processes.

Since 1960s, a program of continued road building was addressed in Australia due to the increased transportation demands associated with the rapid expansion of metropolitan areas.

However, government agencies have, recently, interested on public transport planning and provision. It is due to the interest of community to provide a transport option for those lacking a private vehicle and the increased awareness of the problems associated with automobile dependency. Therefore, public transport service provision should be included in sustainable regional development, as a component of the transportation planning process. The public transport service is an interconnected combination of bus, rail or ferry services subsidized by local, state and/or federal governments. In fact, the Clean Air Act discussed above has critically focused on the public transport provision. Numerous details including the best placement of stops and routes, the frequency of operation, and the connectivity of the transport network for regional service delivery should be classified in providing or managing this form of public assistance. The Integrated Regional Transport

Plan for Sydney aims to identify a future for transportation system so that it will meet anticipated demands without sacrificing desirable aspects of quality of life.

However, it is not desired in developing metropolitan regions to increase the percentage of private vehicle trips. Although public transport is only one of the components of a transportation system, it is expected that supporting this mode of travel lead to great advantages for urban regions, both in terms of mobility and sustainability. Monitoring the efficiency of public transportation performance, and hence, its method of implementation, is of critical importance as a tool for evaluating the policy goals as well as planning for future improvements.

Availability of public transportation is the opportunity for utilizing the system which can be interpreted in terms of proximity to the service and the its cost. The current paper is focused on the proximity to public transportation. Specifically, how does the location of public transport facilities such as bus, train or ferry stops serve the needs of the population? Motivating this interest further is the Integrated Regional Transportation Plan for Sydney. The policy goal specified by the plan for public transport in the region of at least 90% total population coverage within 400 meters of a bus, rail or ferry stop. The focus is thus on origin based access. This goal is one of the designed criteria for improving the operation of public transportation and its attractiveness, through enhanced service quality. Another important goal is ensuring the suitable service coverage due to the great influence of the time taken to reach a public transport stop on total travel time, which in turn affects the potential patronage. The reason for choosing 400 m coverage distance or threshold is that people can walk comfortably this distance under normal conditions. However, the distance criterion could be dynamic so that it suits specific circumstances or terrain. Unfortunately, many long term strategies, goals and policies, such as providing suitable coverage, are mainly based on the political desires rather than thorough and detailed analysis. However, the most important thing is the proper, rigorous and replicable assessment and monitoring of these goals and policies. Technical issues about the evaluating a policy goal like suitable access coverage are ever present. One issue is that information about the exact residence or location of individuals is not available. The census data, reported at some aggregate scale, is the most precise available geographic information. For the Sydney region, census data at the collection district level is the most disaggregate form of spatial information. Thus, this information is an aggregate representation of the actual location of individuals in the region. As the final goal is evaluating the public transportation access, use of such data could be potentially led to wrong estimates. Because of the form of obtained data that is out of control of an analyst or planner, handle of the issue is hard. However, this is an important concern which should be recognized. Evaluating access to public transport is of particular interest in policy making as well as the locational siting of specific dwelling types. For instance, good access to public transport is an interesting advantage for high occupancy buildings or perhaps public housing. How can access be estimated? If access is defined to be a specified distance (or travel time) to a public transport stop, then it is possible to identify all of the areas within the threshold distance of all stops. Knowing these areas, the total number of individuals in a region having suitable access may be determined. This does create the need for some sort of areal interpolation process, as partial coverage of spatial units is very likely. Comparing the distance from a spatial reporting unit, namely a collection district, to the distance from its nearest stop would be an alternative. If this distance is within the threshold, coverage is achieved. Although both approaches are potentially erroneous, they are contrasting perspectives and combining of them provide a means for ensuring that estimates of access are reliable and stable. It is worthwhile to note that based on the above discussion, there may be implications for the scale and aggregation issue, but further empirical analysis would be necessary.

The policy goal of providing 90% of the total population access within 400 m of a bus, rail or ferry stop in the Sydney region is actually a common transportation planning objective in Australia. According to bus, rail and ferry stop locations supplied by New South Wales Transport; the public transport access coverage in the greater Sydney region was assessed by means of a commercial GIS. Population data from 2001 and 2006 at the collection district level (the most disaggregate form available) was utilized. It is revealed, by examining the 400 m coverage criterion using the 2006 census data, that only 55.25% of the population in the region (or approximately 954,000 people) has suitable access to public transport, which is clearly lower than the stated objective of 90% total population coverage. An interesting question may be raised is regarding the sensitivity of the threshold distance in evaluating access coverage. What if the distance was 350 m or 450 m, how would this alter coverage?

In fact, 90% goal can be gained if the threshold distance is increased up to 8.8 K, which is far beyond the stated distance of 400 m.

According to the logarithmic relationship between population coverage and suitable access to a public transport stop, it can be concluded that there need considerable distance to access a public transport stop as the population is so dispersed in certain areas. In fact, this is shown that extending the acceptable threshold distance often has little net impact. For instance, approximately 83% of the population is considered suitably covered at three kilometers.

Relaxing the threshold distance to 7.5 K only provides additional regional population coverage of 6%. The ability to realistically achieve the 400 m service objective for the entire region is questionable at best. They are primarily administrative sub-regions with little political power, but the regional delineation does reflect the urban structure of the city. In 2006, about 37.8% of the total population of the region was located in Sydney sub-region. Accordingly, regional transport coverage has considerably influenced by Sydney sub-region. It is not entirely surprising that most of the total population provided service in this region is in or around the city.

This is due to the rural nature of these areas which lead to more difficulty in providing public transport coverage since their populations are dispersed. Moreover, it represents an area where many people are deciding to spend their retirement, indicating a high proportion of people with a potential

need for public transport services. Such issues should be highly considered in the planning and provision of these services at the sub-regional level. The processes such as the Integrated Regional Transport Plan for Sydney are designed to satisfy the future short and long term demands of regional transportation. However, comparing the results of 2001 and 2006 censuses about the performance of the public transport system and the planning for the region are very disappointing. Thus, little attempt or gain to improve public transport access appears to have been made in this period of time. Without a concerted and deliberated effort to improve access opportunity over periods of time, it would not seem realistic that public transport usage could be expected to increase.

It is demonstrated in the previous section that the level of public transport service in Sydney region is far from the desired level.

Improvements of regional services are examined in this section. As some people are not likely going to ever use such services, focus on that parts of people which will be possibly utilize the public transportation would be more beneficial. As an example, the inland areas away from the populated coastal sub-regions are predominantly rural in Sydney. It is difficult to envisage public transport services capable of meeting the needs and requirements of people in the rural areas at reasonable operating costs. Therefore, it makes sense to adjust the notion of service coverage to reflect the spatial, socioeconomic and demographic characteristics of potential patronage rather than attempting to set public transport goals for the entire region. In addition, when setting performance goals, it should be evaluated that how much of costs must be recovered by public transport services. Accordingly, the standards of coverage would be more realistically modified.

The main concern of public transportation services is chosen depending upon the policy objectives; it may be the improving access to areas that contain a high proportion of transport disadvantaged groups (such as the elderly, invalid pensioners, low income earners) or areas which contain a high probability of increasing public transport patronage. This approach works based on the principle of providing service access to those that would most likely use it not based on the improving of service to the entire population.

The improving of service is also followed based on the strengthening and extending the coverage of the transport system. As suggested by the Integrated Regional Transportation Plan for the greater Sydney region, many of the improvements are focused on increasing the quality of public transport such as increasing travel speed through the addition of separate bus lanes. This may potentially lead to increase of system utilizing by making existing service more efficient, and thus an attractive travel alternative. However, this approach is extremely rough and may have little net effect. Providing new public transport corridors, as an extension to the current system, over the next 25 years is considered by a few projects in the Sydney transport plan. However, it reveals, through the examining of impacts of such extensions on regional coverage in Sydney, that these corridors will provide service access to at most an additional 3% of the population. As a result, even long term strategic goals have not reach by such a myopic and uncoordinated view on service provision planning. Furthermore, the first major transportation project announcement following the Integrated Regional Transport Plan was not one of the strategic transport opportunities considered in the plan and will only enhance public transport in areas already provided relatively good public transport access. Sustainability is the major goal of improving service provision and perhaps increasing system coverage.

These aspects of sustainability are largely affected by the efficiency of the public transport system. Specifically, fuel consumption would be decreased as stops are well placed and service routes are good. Thus, it is important to examine the efficiency of transport stops and travel routes in terms of redundancy and suitability. That is, can the same level of service provision be obtained by reducing the number of stops maintained, coupled with new route design in the current service system. In Sydney, suburbs within a five kilometer radius of the central business district have been particularly well served by public transport. Routes and stops have been added incrementally through the years. This is due to the growing of population and service expansion, often implemented by separate planning agencies. However, the process is highly susceptible to inefficiencies.

The efficiency and sustainability of a public transport system would be affected by strategic decisions associated with relocating stops in order to increase the total population served by the system.

Better planning and designing of stop locations and route networks significantly improve the service coverage and system efficiency which in turn, lead to improving the performance and sustainability of the system. However, location and routing optimization model size will certainly prove to be challenging. For the Sydney region, there are 3,793 collection districts and 10,911 public transport stops; so the problem magnitude is quite significant.

However, costs of increasing the public transportation service coverage necessitate more creative options. Incorporating the personalized public transit options is an interesting alternative for improving regional coverage. This is a means of providing patrons (or potential patrons) with a range of price differentiated public transport options. For example, a person at a personalized public transit stop has numerous options including taxi, multiple fare taxi, mini-bus on a flexible route or conventional bus on an established route. A personalized system would provide the patron with real time information, showing available services and anticipated arrival times. The ability of a personalized system to provide the customers with choice and control, which makes public transit use more attractive, is one of its advantages. More importantly, numerous stops can be established for personalized service in low density areas, where scheduled public transport services are expensive and underutilized.

It is worthwhile to note that personalized systems are costly despite these appear to be an attractive solution for the provision of additional public transport services. First, need of personalized services to global positioning system (GPS) and communications technology makes these services expensive. However, such technologies are already commonplace in most taxi services, at least in Australia. Second, the fares of the alternative would have to be structured so that they were signif-

icantly lower than the cost of calling a taxi. In other words, surviving a personalized system in low density areas depends on its need to ongoing subsidies, although these subsidies may well be lower than the cost of increasing public transport access through the approaches detailed above.

High cost of transport access and weak demand for public transport services in low density areas are its main problems.

3 Results and Discussion

It should be pointed out that it is necessary to consider more practical access goals for sub-regions due to the probable failure of the targets of public transport access specified in the Integrated Regional Transportation Plan for Sydney. In a special manner, providing public transport access for people who have more interesting to utilize such services should be considered as an explicit policy objective. Such factors are including spatial location, urban and rural features, demographics, and socioeconomic status.

It should be concerned that high number of residents in the region are elderly. As the closeness to public transport services is a critical issue for this group, access goals should be more detailed rather than overly generic.

In the current analysis, access to public transport is studied as a single distance or threshold measure of proximity from populated areas to public transport stops. It may be possible to develop a greater representation of public transport access by combining more detailed spatial information such as roads and service route locations and topography, on the basis of dynamic and more realistic travel distances or times.

Another important issue which should be considered is extending the interpretation of service access. The proximity to public transport system was studied in this paper. However, this service has a temporal component as well. How often and at what times is a particular access stop visited? Does this satisfy the people that are likely to frequent this stop? Some public transport stops in the Sydney region have fewer than four services per day. The service opportunity should be included in a more accurate measure of access.

However, destination access also is a critical issue. As the travel patterns are not well understood, such analysis is difficult. For example, numerous stops may be occurred during a trip from home to work or work to home to accomplish personal or work related tasks, such as going to the bank and shopping for groceries. It, which is known as trip chaining, makes the analysis of travel behavior quite complex. As a result, more detailed travel pattern information is required than only knowing the residential locations of individuals.

Moreover, it should be pointed out that residential information is corresponded to where individuals live not where they work or often travel to and from. However, subdestinations of individuals during their travel is of critical importance in utilizing the public transport system and hence, it should be considered as more as possible, if demand for public transport is to be increased.

The effect of land use configurations is a final consideration in the planning of effective public transportation. The advantages taken from suitable access to public transport by certain land use categories (high density dwellings and public housing) are discussed previously. Urban form is closely related to land use and transportation. Therefore, it would be necessary to accomplish the efficiencies resulted from providing the better public transport through coordinated land use planning and policy development.

Reaching to regional sustainability is critically related to developing an adequate public transportation system. The proximity of public transport stops to the regional population will be very effective for the performance of a public transport system.

Altering the placement of stops and modifying route service may be useful for improving the performance of public transport system in areas with high public transport access. Combining of more dynamic proximity measures, service considerations, demographic and socioeconomic factors can improve the evaluation of public transport access. Ensuring about providing the sufficient and proper regional public transportation service can be achieved by higher efficiencies identified through advanced monitoring and evaluation processes.

4 Conclusion

The current paper tries to present a new method for determining the direction of a public urban transportation system based on the cover method. The proposed method used the maximum population cover and urban attractive trip points as criteria so that, finally, the resulted directions have high trip cover. It was clear that the average trip cover of directions resulted from the proposed method were improved comparing to previous methods. A comparison was made between the proposed method and the population cover method. Accordingly, the population cover in the proposed method is lower than the other method and conversely, a significant improvement is obtained in producing directions with higher trip cover. The answers of the proposed method have higher trip cover than the answers of the maximum trip cover method and this improvement is 16.5%. In addition, the maximum trip cover which resulted from one of the directions of proposed method is 58869 trips compared to 46962 trips resulted from the maximum trip cover method while these two directions are approximately according to each other. For more precise concluding, a comparison was made between similar directions from the proposed method and the maximum cover method. Accordingly, increase in trip cover is at least 12% in every four directions. Solving the problems with heuristic methods will not provide a guarantee to produce the best answer. However, passing the obtained direction through the populous regions and city centers provide credit for its answers and its fast running and simplicity lead to prefer this method compare to other routing methods.

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