Spatio-Temporal Analysis Of Public Transportation System Using Static Transit Accessibility Methodological Framework

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Abstract: This paper analyses the public bus network of the valley, its service coverage, and the share of the valley population with suitable access to the network within a given distance and time. It also analyses spatial relationships to public transport access in the valley. The Spatio-temporal access with the public transport is analyzed using General Transit Feed Specification (GTFS) data set and GIS network analysis. The GTFS dataset is developed for the valley using data obtained from the survey. The result shows that 39% of the valley population can access public buses within 500m. It is found that the population-weighted average distance to the nearest bus stop is 894m and takes 16 minutes in the valley. This spatial map categorizes the area with different levels of public bus access highlighting the area needing investment in relation to the existing traffic congestion in the valley.

Keywords: accessibility, GTFS, GIS, public transport, spatial analysis, urban transport planning

1 INTRODUCTION

The transportation system of the city is associated with the development of the town. It plays a significant role in the economic growth of society and ensures the vitality of a city [1]. Public transport provides long-term sustainability, commuting a large capacity to considerable distances with less burden to the economy and environment [2]. In most of the developing cities, the distribution of public transport services is limited within a specific area, mostly in urban. In the absence of distributed road networks, the services are disseminated inequitably and confined within the limited space, increasing transport activities particularly the city area. Public transport plays two significant roles in urban systems. It provides transportation over medium-to-long distances for inhabitants that do not have any feasible alternatives – a societal equity role of transit. And an instrumental role by reducing fuel consumption and emissions. It thus plays an essential role in the urban structure by enabling the growth of other urban interactions and the economy. However, for public transport to be significant in urban structure, it needs to be easily accessible and readily available as well. Access to public transport has a significant role in its successful operation. Evaluating accessibility for proper management of the city has become inevitable in city planning. In general, accessibility is the facility that eases people to reach their destination and perform their activities [3]. However, in different disciplines, transit accessibility is analyzed from different perspectives. The transport planners analyzed by focusing on mobility (vehicle travel), land-use planners focus on geographical access, service providers emphasize on the ease with which services can be provided. Based on the evaluation measures and objectives, accessibility measures vary. Estimation of transit accessibility is primarily affected by factors like transport demand, mobility, modes, affordability, integration, management, user information, and connectivity among others [3]. In general, there are two perspectives, one is the proximity to and from public transport, and the second is the cost of travel (time or tariff) [4]. To better understand the relationship between transport infrastructures and land use patterns, often transportation projects are analyzed from both mobility and accessibility approach [5]. Recently, accessibility is even considered as a social indicator in performance evaluation of public transport and is used as an instrument in assessing the public transport system [6]. Measuring the level of accessibility is, thus, crucial to understand the public transport system. A large body of literature shows various measures of accessibility. With increasing data availability and improved measuring tools, different components of accessibility are measured. Variables like travel time, cost, the spatial distribution of activities, opportunities available based on time, socio-economic and demographic factors, service coverage, service frequency, vehicle capacity, are often used to measure accessibility. Primarily the accessibility measures are categorized into four major components: Transport component (travel time, cost, the effort of movement), Land use component (spatial distribution of activities of opportunities), Temporal component (time constraint to reach activities or opportunities) and individual component (socio-economic and demographic factors) [7, 8]. often population and service facilities are used in accessibility measurement using the approach of access to bus stops, travel time, and access to destinations [9-13]. Due to a wide range of variables, the measure of accessibility could vary with the objective of the study and data availability. The use of sophisticated tools make a difference in planning and developing accessibility measures [14]. The attempt to measure public transport accessibility started long ago, and there is still growing attention due to diversity in its measurements. [8] simplifies the measures by categorizing the wide range of measurement into three models: one is system accessibility models that represent overall accessibility but lacks actual transit accessibility. Second is the system facilitated accessibility approach that potentially measures actual transit accessibility by incorporating temporal component but cannot measures opportunities available. Third approach represents the model measuring the activities and opportunities associated with the number of possible destinations. Due to its deterministic approach, it cannot measure consumer's preference of the transit network. Thus the result of accessibility measures could vary based on the modelling approach and the purpose of use. More recent studies have shown the integration of time and space into individual mobility that has changed the place-based perspectives into people-based perspectives [15]. Recent advances in GIS widened its approach to measure aggregate accessibility in space-time geography [2, 16]. The use of General Transit Feed Specification (GTFS) data and detailed travel survey facilitated in capturing the variations in the transit network. A widely accepted standardized transit data set, also known as General Transit Feed Specification (GTFS), is used to measure the temporal dimension of the accessibility [14]. GTFS is a standard format based on text files for distribution and exchange of data about transit systems and their schedules. Introduced in 2005 to create a trip-planner in Portland [17], GTFS was later opened for general use in 2007 by Google. Most commercial route planning software can export full transit schemes (timetables) to GTFS. Google Transit distributes a GTFS file for many developed cities via data shared voluntarily by public transit agencies. Recent studies have been using General Transit Feed Specification (GTFS) together with ArcGIS Network Analyst Tools to measure the shortest path method along with travel time between the specific nodes [14, 18]. It has been used in various transit systems for locating high activity bus stops, modelling travel demand, data interaction among service providers, updating transit information, and modelling trip generation [14, 19, 20]. This study aims to explore the spatial distribution relationship between public bus access and population in relation to their location, to develop the GTFS data set for the valley bus routes, and investigate its application in network analysis and to formulate policy recommendations for public transport development. Section 2 describes the brief overview of the public transport system of the Kathmandu valley. In section 3, we describe the application of the methodology used for the case of the valley, followed by results and discussions. We conclude with a summary and insight for the public transport planners.

2 Public Transport System of Kathmandu valley

Kathmandu valley is one of the densely populated cities of Nepal with a population of 2.6 million in 2011, and an estimated 3 million in 2018 at an annual growth rate of 4.3% [21, 22]. Geographically there are three districts Bhaktapur, Kathmandu, and Lalitpur with 1136 wards [21] altogether. The current federal system of Nepal has merged wards and municipalities, reducing the total number of wards to 251 from 1136 [23]. There are over 100 bus routes in Kathmandu valley serving 27% of travel demand. But the public bus modal share is only 2% of total passenger transport [24]. The average access time to reach the nearest bus stop in an urban area is 12 minutes and in a rural area is 73 [25]. The national survey also showed that 66% of households reside within reach of 30 minutes to the nearest bus stop, 25% within 30 minutes to 3 hours, and 10% lived further than 3 hours from the nearest bus stop [25]. As per the National Planning Commission 15th approach paper, 79% of Households have access to public transport within 30 minutes of walk and is expected to reach 99% population by 2024 [26]. The rapid urbanization of the city is increasing individual motorized vehicles in Kathmandu valley. The public transport of the valley in Kathmandu dates back to 1959 with a local bus service. Later Sajha Yatayat, a cooperative started mass transport service in 1961/62, and in 1975 electric trolley bus started in Kathmandu valley along the 13km road span. However, the government-owned public bus failed due to the weak management system and external interferences. Since then, the private sector started dominating the transport service. Vehicle and Transport Management act formulated in 1992 gave route permits to private companies to operate public transport. In 2015, National Sustainable Transport Strategy (NSTS) for Nepal (2015~2040) was formulated with the vision to develop efficient, accessible, people-centric transport. And the master plan was developed in 2017 for improving the urban transport system of the valley for establishing a sustainable urban transport network. As a result, large capacity (45-55 seat capacity) city buses with some improved facilities came into operation. Studies done for Kathmandu valley has pointed out the major problem of public transport as the longer travel time, irregular operation time, longer waiting time at bus stops, overcrowding, insecurity inside the bus, overlapping routes, and poor service to passengers and consequently shifting people towards private vehicles [22, 27-29].

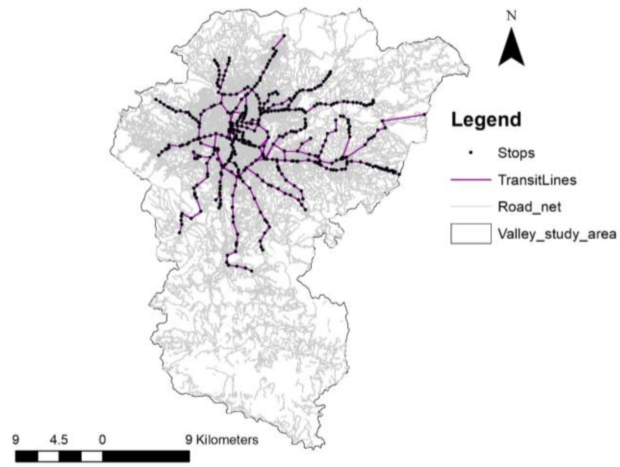

***Figure 1 Study** area showing the valley road network and bus routes*

3 Methodology

In this study, we first developed General Transit Feed Specification (GTFS) data set for the 41 public bus routes of the valley using a standard format based on text files for distribution and exchange of data about transit systems and their schedules. Most of the countries have already developed a standard GTFS data set and is openly available in a common format. The unregulated transit system of the valley is yet to develop the data set. So the first measure is to develop the GTFS data set. GTFS consists of 13 individual text files formatted in CSV file, and six mandatory txt files: agency.txt, stops.txt, routes.txt, trips.txt, stop_times.txt, and calendar.txt files. These files are related to each other in one way or another like trip in trip.txt has the same route-id as the route in route.txt, stop_id from stop.txt is used as a unique id to generate route in route.txt. The input database is developed using file format [30] to generate an entirely new GTFS data set for the public transit of the Kathmandu valley. It contains the actual street paths taken by the transit vehicles. A route planner is developed using the GTFS dataset in MS ACCESS. All the routes are provided with its unique ID. The sequential stops along the route are added and the time taken between each stop by the bus is provided. Each route is identified by its type along with the type of vehicle used. Each stop has its ID and is located using latitude and longitude. The transit operation information is given in schedule operating parameters which has attributes such as frequency of the bus service in each route, start and end of operation time, and combination of different schedules to each route. By adding a year of operation it generates output GTFS data set and is then exported to the text file format. This output data obtained is an input to GIS network analysis, which is dynamically linked by the "Add GTFS to Network dataset" toolset developed by ESRI. This tool generates transit lines and stops and connects the stops with the network. A sequential link between stops is created for each transit line. The main output from "Add GTFS to Network dataset" is a transit network with a schedule parameter: Transit Evaluator, which contains travel time and schedule timing information. It gives travel time between any stops in the network, and thus service frequency in each stop is calculated. To measure public bus accessibility in the valley, the statistical analysis units identified as the ward and the centroid of the wards with population attribute is created. The topological network connects the centroids to the street using the automated process of GIS which selects each centroid. It identifies the point on the street network closest to that centroid and generates a new network link connecting those two points. It results in a pedestrian network with population attributes. The centroids are the origin for a walking trip to the transit, and the destinations are the nearest bus stops along the bus routes. The walking network identifies the shortest path between origin and destination using Dijkstra's algorithm in the Network Analyst. When calculating the travel time, the distance between the centroid and bus stops was considered. The assumed speed of walking is 3km/hr. The methodology of the study was based on the service access at different time intervals from the ward centroids. Transit accessibility is obtained as the function of the population and the average travel time to the stops. To measure the transit accessibility between origin and destination, the destination facility at the city center i.e. Ratnapark is chosen in this case. The service coverage by public bus under the time interval of 5 min, 10 min 15 min, 20 min, 30 min, 40 min, 50 min, 60 min and 90 min from the destination is estimated. The test was performed during day time when there is lower traffic congestion. The difference in travel time along the five routes are observed for different time of day. The overall accessibility to public buses and from the city center was analyzed. The data required for the analysis are obtained from department of survey and published documents. The primary data of travel time between origin and destination for 41 routes are derived from the author's survey. The secondary data, like street network data with administrative boundaries, were obtained from the Department of the survey. OpenStreetMap (OSM) was used to obtain other data like street lines, transit facilities, and buildings, including other background data of the valley. The study area as shown in **Error! Reference source not found.** includes one ring road, 23 peripheral routes outside the ring road, and remaining inside the ring road. Among them, 21 routes have their origin or destination in Ratnapark, the heart of the city center.

4 Results and Discussions

Figure 2 depicts the share of the valley population having access to the bus stop. The figure shows the threshold distances ranging from 500m to 3km. Considering the threshold distance of 500m to reach the nearest bus stop, only 39% of the valley population has access to public transport stops. At 1500m approximately 90% population is suitably covered. Moreover, the two-third population has accessible public bus service within 1000m distance. Approximately 10% of the population lies beyond 1.5-kilometer access to the public bus. The logarithmic relationship between population coverage and access to public bus stops indicates that certain area of the valley population needs to walk substantial distance to reach the nearest bus stop. By extending threshold distance, a large share of the population could access public bus service. The population-weighted average distance to access public bus in the valley is found to be 894m. The threshold distance to public bus in the well-established public bus network is however 400m for public bus and 800m for the rail network. The longer threshold distance in the valley is due to unplanned settlements and poor land-use planning.

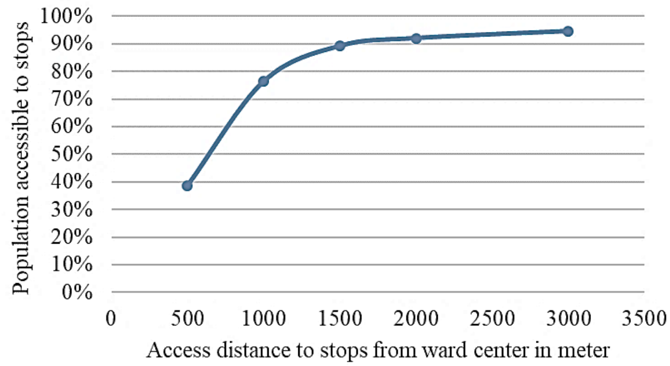

Figure 2 *Population accessible from ward center to nearest bus stops*

Evaluating service coverage based upon time to access the nearest bus stop shows that nearly 10% of the total valley area has good access within 10 min walk time **Error! Reference source not found.Error! Reference source not found.**. Almost 50% of valley area lies beyond the reach of 60 minutes' walk to/from the bus stop. However, what can be observed from the population density of the valley is that almost 95% habitation is in 50% of the valley area. The population-weighted average time to reach the nearest bus stop in the valley is found to be 16 minutes which is comparatively higher than other developed countries

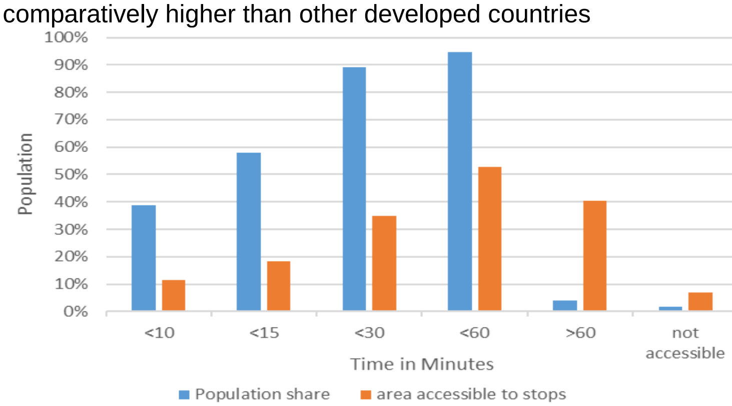

Figure 3 *Population and area accessible to the nearest transit facility*

The terrain of the valley has also led dispersed habitation in few parts of the valley and the provision of public transport coverage becomes more difficult in those regions. The spatial effect of Figure 2 is depicted in **Error! Reference source not found.** showing the spatial relationship to public transport access in the valley. The peripheral area is poorly linked to the valley bus system providing poor coverage in the area. However, most of the population providing service in this region is or around the city. Some of the rural population is unlikely to utilize public bus services. The southern part of the valley is poorly linked to the public bus network compared to other parts of the valley

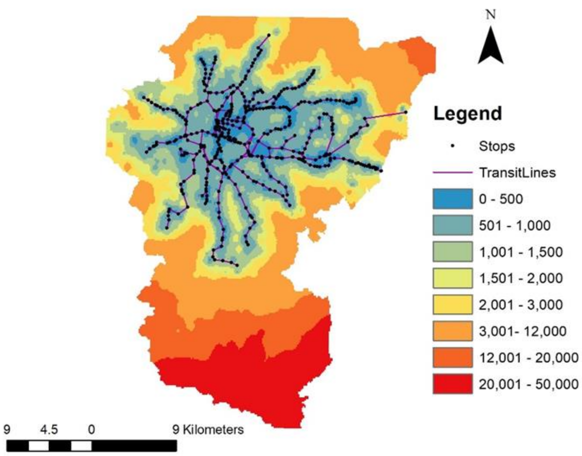

***Figure 4 Spatial** map showing distance from bus stops in meter*

Using the above-mentioned method, the service coverage by public bus from the city center is analyzed Figure 5. The colors in the figure mean interval from 0-90 minutes and distribution shows the time taken to get from all zones to the city center. Within 90 min public bus can cover 66% of the valley area and provide service to 92% of total valley population. The figure illustrates that 4% of the valley area where nearly 26% of people inhabits could be reached in 10 min from the city center. In 30 min travel time, 72% of people could access the center and 92% of people could easily access the city center in 1.5hour travel by bus. However, the area accessible within the 30 min, 60 min, and 90 min time is 23% and 54% and 66% respectively. It indicates excessive population density in the inner city areas linked directly to the public bus accessibility to the city center. The spatial map shows that the city-centric area has a well-developed bus network coverage and the coverage is poor in the periphery. It could be due to poor road infrastructure development in the outer valley area, the valley terrain, and dispersed population. The access time is estimated based on travel time at 13:00 and could significantly differ with respect to the time of day.

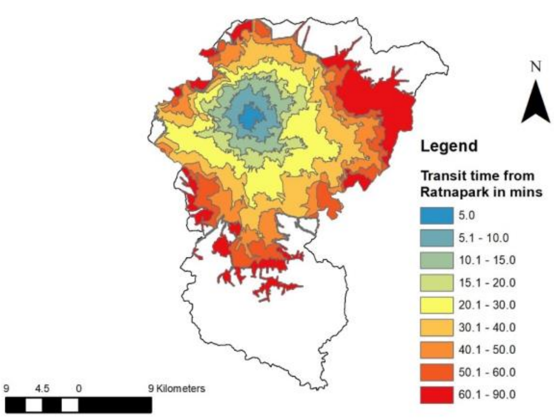

***Figure 5** Spatial map showing the time to reach the city-center from different parts of the city*

The network analysis of the five major routes was carried out to measure the public bus travel time along the route. It shows that the travel time increases in the morning rush hour and afternoon rush hour and reduces in other times of day. It takes approximately 30 minutes more time to cover the same distance at peak hours. The high frequency of the bus for peak time service and heavy traffic of private vehicles increases the travel time. The analysis indicates the traffic condition as well as the travel pattern of the valley. Travel time to reach destination has been one of the major reasons for the mode shift to private vehicles in recent years. The result shows the significant differences in the spatial distribution of travel time with the public bus. The city-centric infrastructure development of the valley could be noticed with high population density in the inner part of the city. Based on the access time and distance to transit facility and travel time from the key location to different parts of the city, different parts of the valley area could be categorized as strategically significant in terms of travel time. The public transit accessibility measures could be used to identify the populated area in terms of public bus service coverage. The spatial map also indicates the uneven distribution of infrastructure and spatially diverse patterns.

5. Conclusions

For achieving sustainable urban forms, it is crucial to ensure access to public transport. The main goal of the current study was to determine the spatiotemporal public bus accessibility in Kathmandu valley. This study shows that 39% of the population has public bus coverage within 500m and the weighted average distance to the public bus stop in the valley is 894meter and takes 16 minutes at the walking speed of 3km/hr. The spatial relationship to public transport shows that some of the population is unlikely to utilize public transport services. The inner-city area is sufficiently covered by public buses compared to the peripheral areas. The southern part of the valley has a poor bus network and also inhabits fringe population. The network analysis shows the difference in public bus service coverage in the valley. This study has identified the valley area with different levels of public bus service implying the need to improve the public bus network. The assessment of public bus travel time accessibility provides basic understanding of system functionality. The findings of the research provide insight for transport planners and policymakers in locating the area needing urgent actions. The study has highlighted the public bus service and travel pattern implying the need to manage the existing bus system for efficient service. In the present context, to improve public transportation in the valley, managing the current bus route service is crucial. The possible solution could be the integrated bus service, where the peripheral route acts as a feeder route that connects to the ring road. The interchange could be made to reach the city center along the ring road. It could considerably reduce congestion inside the ring road, and the total travel time could also be reduced without having to invest high on the infrastructure. The integrated system where all the private operators come under a single authority also decreases the unhealthy competition between operators as they do not have to compete between themselves. The schedule operation of the bus and the user information could be the potential area for improvement. The route planner developed in this study using GTFS could be used for scheduling the public bus and providing information to the users for their expected travel plan. Implementing such a system in the existing transport system is, however, a challenge. But with stringent government policy, such intervention is possible, and management of the overall public transport system is likely without needing to invest a huge amount in the infrastructures. Public transport refers to a public bus in this study. The model could be updated to incorporate all the modes of transport. The analysis is carried out within the limited available data, Hence, there exists a possibility to enhance the output with improved quality of data. This study highlights the need to improve the accessibility of the public bus at the local level by improving the current bus routes network through the integrated transport policy. Further study can be carried out to understand the differences in travel behavior and transit access to other work stations.

ACKNOWLEDGMENT

The authors would like to thank Prof. Dr. Yngve Karl Froyen, professor at Norwegian University of Science and Technology (NTNU) for his guidance in developing methodology part of the research.

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