DEVELOPING A MATHEMATICAL TOOL TO ANALYZE PUBLIC TRANSPORT CAPACITY OF ADDIS ABABA CITY

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ABSTRACT

Transportation is a crucial aspect for people living at different life standards in different areas at different times. The necessity for transportation usually is for satisfying one's life targets. The way of moving from place to place varies from rural areas to urban areas. Transportation in urban areas is too complex to that of rural once.

This study aims at developing a mathematical tool to analyze public transport capacity of Addis Ababa, the capital city of Ethiopia. Understanding the approach how to estimate the public transport capacity of the city is of great importance in planning the public transport for the future. There exist many case reports reflecting different cities suffering from insufficient transport for the habitants and visitors. Having clear understanding of existing public transport capacity, hence, is helpful to allocate options to improve its performance. There exist a variety of urban public transport service providers in Addis Ababa, such as the Light Rail of the city, Anbessa city Bus, Sheger Bus, Higer bus, Taxis, and different types of midi buses.

Keywords: Mathematical tool, Public transport, Transport capacity, Transportation.

INTRODUCTION

The probability of the public to get means of transport depends on many factors such as the population size, the number or amount of available vehicles and their capacity [1]. The capacity and efficiency of public transport differs from country to country and also city to city having better standards at developed countries and low standards at developing ones. This generally is because of the direct relation between quantity & quality of transport facilities with level of economy [2].

In developing countries, increased population growth and urbanization have led to several transport problems [5]. Mass transport in these countries is essential especially for the urban poor who have to rely on walking, cycling, and road-based public transport to meet most of their travel needs. Mainly buses provide urban mass transport and competition of service providers assures the efficient supply of mass transport services [5]. In the last decades, urban areas have experienced an increasing expansion resulting in several socio-economic problems.

These include unequal spatial urban development, a high pressure on non-refundable infrastructure, land and housing shortages, and, to high degree, lack of urban services.

These problems, in addition to low income and unemployment, eject poorer people to urban peripheries where housing costs are lower. But these peripheries are diploid of public services and increase the cost of providing urban infrastructure. Public transport, in particular, planned to operate in more density populated areas, offer a lower frequency and quality service, due in part to larger distances and unstable road system [1].

Unorganized urban expansion leads to an unorganized and irrational transport system in which superimposition of routes is one of its characteristics. In addition, municipal system if not centrally coordinated results in superimposition and low coordination of routes and irrationality of the whole system Urban expansion bring planning difficulties. But people require in each area an adequate public transport that allows easy moves to work, shopping, educational, health, and cultural centers [1].

Thus, an urban public transport system needs to assure mobility and accessibility through a fast, secure, regular, and trustable transport at a reasonable cost. Unfortunately it is not easy to assure all these characteristics due to complex institutional arrangements between state and several municipalities. Thus, a first step consists of working an agreement among all political institutions involved [1].

Transport is a catalytic force, both as an agent vital for economic growth and as an agent for economic decline where economic resources and conditions, as well as human endeavor, are insufficient. In this vein, efficient transportation should be seen as a factor that unifies the entire economy, which facilitates development [2]. A well-functioning transport system helps to maximize economic growth (progress) of cities [3]. Urban mass transport continues to be a high priority social obligation of governments throughout the world and, in some jurisdictions, it is the prime responsibility of national governments, while in other localities, it is a state or local government responsibility [4].

Mass transport in developing countries is essential for the urban poor who have to rely on walking, cycling, and road-based public transport to meet most of their travel needs. Mainly buses provide urban mass transport and competition guarantees the efficient supply of mass transport services [5].

Transport capacity deals with the movement of both people and vehicles. It is defined as the number of people that can be carried in a given time period under specified operating conditions without unreasonable delay or hazard and with reasonable certainty [6]. Capacity is a technical concept that is of considerable interest to operators, planners and service designers.

There are two useful capacity concepts stationary capacity and flow capacity. Scheduled transport services are characterized by customer waiting at boarding areas and traveling in discrete vehicles along determined paths. The waiting area and the vehicle itself each have a stationary capacity measured in persons per unit of area. Transportation services also have a flow capacity which is the number of passengers that can be transported across a point of the transportation system per unit of time. While this is usually thought of as the number of total customers per transit line per direction per hour, flow capacity can be measured for other elements of the system including corridors, fare turnstiles, stairs, elevators and escalators [7].

The key factors which influence capacity include the type of right-of-way, the number of movement channels available, the minimum possible headway or time spacing between successive transportation vehicles, obstacles to movement along the transport line such as complex street intersections and "flat" rail junctions, the maximum number of vehicles per transport unit, operating practices of the transport agency pertaining to service frequencies and passenger loading standards, and long dwell times at busy stops resulting from concentrated passenger boarding and alighting, on-vehicle fare collection and limited door space on vehicles [7].

One of the most important capacity considerations is to distinguish between maximum theoretical or crush capacity and practical operating capacity, also called schedule design capacity). A transit vehicle may have an absolute "maximum" capacity usually referred to as the crush load. This commonly is the capacity cited by vehicle manufacturers. The absolute capacity assumes that all space within the vehicle is loaded uniformly at a specified passenger density and that occupancy is uniform across all vehicles throughout the peak period, a condition that rarely happens in practice.

Similarly a rail line or a bus system operating in an exclusive right of way may have a theoretical minimum headway (time between two successive vehicles) based on station dwell times, vehicle propulsion characteristics and safety margins. From these characteristics, the theoretical maximum capacity measured as vehicles per hour per direction can be determined. However, random variations in dwell times caused by such things as diminished boarding and alighting flow rates on crowded trains, reduces the maximum or theoretical line capacity [7].

Operation at maximum capacity strains the system and should be avoided. They result in serious overcrowding and poor reliability. Therefore, scheduled design capacities should be used. This capacity metric takes into consideration spatial and temporal variation and still results in some but not all transit vehicles operating at crush capacity [7].

Further, the arriving patterns of passengers and vehicles at transit stops during peak periods may result in some vehicles having lower than capacity loads particularly if there is irregularity in the gap between successive arriving vehicles. Finally, there can be a "diversity of loading" for parts of individual vehicles (e.g., in partial low-floor LRT vehicles or buses with internal steps) and among vehicles in multi-vehicle consists such as heavy rail trains [7].

BACKGROUND

In Ethiopia, the need of public transport is highly increasing both in rural and urban areas. Many are losing their valuable time and business due to shortage of transport to jobs. This time, looking peoples making lines waiting for busses or taxis becomes somewhat familiar, especially in the capital city Addis Ababa.

The city covers total area of around 540 square kilometers. Its current population is above 4.5 million. Public transport in the city mainly consists of conventional bus services provided by the publicly owned Anbessa City Bus and Public Service Employees Transport Service Enterprises, Alliance Transport Service Share Company, Midi-buses and Taxis operated by the private sector. [8].The leading purposes of trip in the city are Work and education. The road network of Addis Ababa is limited in extent and right of way. Its capacity is low, on-street parking is prevalent, and the pavement condition is deteriorating. Despite a large volume of pedestrians, there are no walkways over a large length (63%) of the roadway network.

This is a major concern because it contributes to the increased pedestrian involvement in traffic accidents (10,189 accidents occurred in 2004 E.C. [9].

Research Questions

At the end this research paper answers the following basic questions.

1. What are the main factors on which capacity of public transportation in Addis Ababa depends?
2. How can the capacity be calculated depending on these factors?

Research Objective

Having clear knowledge about the approach how to determine the public transport capacity will help the concerned government officials and transportation professionals to apply strategies for maximizing the existing capacity and improve the service so that it will fit to the daily demand. The main goals behind this paper are:

1. To identify the different factors on which the public transport capacity of Addis Ababa depends.
2. To develop a mathematical tool that can be used to determine the operating public transport capacity for Addis Ababa.

LITERATURE REVIEW

Public Transport Generals

The basic purpose of any urban public transit system is to carry people as efficiently and effectively as possible. However, defining the aims of a transit system in more detail is not easy [11].

A public transport system has two basic objectives that it is expected to achieve simultaneously to serve the public interest and to be profitable. However, the two objectives can sometimes be in conflict.

In such cases, the policy must focus either on the public interest or on profitability [11].

The general worldwide trend has been for urban public transit systems to take the public interest approach. This has helped maintain public transit systems that offer relatively low fares and generate large networks [11]. The public transport operators always work hard to improve the status of their service in order to maximize the satisfaction of their public while satisfaction of the public depends on different factors such as: the population size, service efficiency, service quality, the number and type of available vehicles and their capacity.

The capacity and efficiency of public transport differs from country to country and also city to city having better standards at developed countries and low standards at developing ones. This generally is because of the direct relationship between quantity & quality of transport facilities and level of economy. In developing countries, increased population growth and urbanization have led to several transport problems. Mass transport in these countries is essential especially for the urban poor who have to rely on walking, cycling, and road-based public transport to meet most of their travel need. In these countries buses are the main urban mass transport providers and competition guarantees the efficient supply of mass transport services.

Public Transport Capacity

Transport capacity is different than highway capacity: it deals with the movement of both people and vehicles; depends on the size of the transport vehicles and how often they operate; and reflects the interaction between passenger traffic concentrations and vehicle flow [6].

Capacity is a technical concept that is of considerable interest to operators, planners and service designers. There are two useful capacity concepts – stationary capacity and flow capacity [7]. Scheduled transit services are characterized by customer waiting at boarding areas and traveling in discrete vehicles along predetermined paths. The waiting area and the vehicle itself each have a stationary capacity measured in persons per unit of area. Transit services also have a flow capacity which is the number of passengers that can be transported across a point of the transportation system per unit of time. While this is usually thought of as the number of total customers per transit line per direction per hour, flow capacity can be measured for other elements of the system including corridors, fare turnstiles, stairs, elevators and escalators [7].

PERSON CAPACITY

At the simplest level, transport capacity is determined by the product of transport vehicle capacity and the maximum frequency with which transit vehicles can pass a given location [6]. The person capacity or passenger-carrying capability for any given transit route can be defined as “the maximum number of people that can be carried past a given location during a given time period under specified operating conditions without unreasonable delay, hazard, or restriction, and with reasonable certainty [6].

More specifically, person capacity depends on the mix of vehicles in the traffic stream, including the number and occupancy of each type of vehicle that can reasonably be expected to pass a point on a transit route. It is a function of vehicle size, type, occupancy, and headway. The number of transit vehicles along a route reflects the degree of scheduled service [6].

TRANSPORT LINE CAPACITY

The passenger capacity of a transport line is the product of the number of vehicles per hour (usually past the busiest stop) and the number of passengers that each vehicle can carry [6].The following four basic factors determines the maximum passenger capacity [6]: Maximum number of vehicles per transport unit (bus, car, train);

Passenger capacity of individual vehicles; the minimum possible headway or time spacing between individual vehicles; and, The number of lanes or passenger loading positions available.

Factors that affect Transport Capacity

The key factors which determine transport capacity are the following [7]:

- ✓ The type of right-of-way (interrupted flows vs. uninterrupted flows),
- ✓ The number of movement channels available (lanes, tracks, loading positions, etc.),
- ✓ The minimum possible headway or time spacing between successive vehicles,
- ✓ Impediments to movement along the transport line such as complex street intersections and “flat” rail junctions,
- ✓ The maximum number of vehicles per transport unit (buses or rail cars),
- ✓ Operating practices of the transport agency pertaining to service frequencies and passenger loading standards, and
- ✓ Long dwell times at busy stops resulting from concentrated passenger boarding and alighting, on-vehicle fare collection and limited door space on vehicles.

Here under are factors determining transport capacity [6]:

Vehicle Characteristics

Right-of-Way Characteristics

Stop Characteristics

Operating Characteristics

Passenger Traffic Characteristics

Street Traffic Characteristics

Method of Headway Control

Procedures to Determine Transport Capacity

Procedures to determine capacity of an existing and operating bus transport system [7]:

Step 1: Data Collection for Critical Stop

Step 2: Data Collection for Critical Intersection

Step 3: Data Analysis

Step 4: Estimate Future Volumes

Step 5: Capacity Expansion Estimate

Step 6: Assess Capacity Expansion Alternatives for Stops

Step 7: Assess Capacity Alternatives for Intersections (curbside bus lane)

Step 8: Assess Capacity Alternative for Running Ways

Factors about Addis Ababa City Transport

Buses provide 40 percent of the public transport in the city; taxis account for 60 percent [9]. The city is currently experiencing horizontal growth, but the bus service has not exhibited growth proportionate enough to accommodate this increase. Analysis results of the transit availability indices show that only the city center is being served by the existing bus networks while urban expansion areas have low transit availability [10].

Taxis experience many operating constraints, including bad driver behavior, excessive fares, and high accident rates. This study examines the existing situation as an input for future public transport development and improvement programs [10]. The absence of an up-to-date structure in the bus company, shortage of finance, and reduction of the subsidy from the government are the biggest challenges for the service [10]. The lack of well-defined performance parameters to evaluate the operational efficiency of the bus company is also a constraint for development.

The prospects are the year-to-year increase in the number of bus users [10]. Among the 14,083 taxis operating in Addis Ababa in 2005, 12,283 had 12 seats and 1800 were small taxis with 4 seats. Of the total number of taxis, only 11,806 were inspected and registered by the Addis Ababa Transport Authority through March 005. Public transport service is highly dependent on taxis as a mode despite high fares (taxis are an expensive means of transportation when compared to buses), which are not affordable, particularly for the low-income group (i.e., the urban poor). Taxis, which are operated by the private sector, usually run on fixed routes even if they are not highly enforced by the government (unlike that of the bus).Taxi speeds are affected by frequent stopping for loading and unloading [10]. In the city of Addis Ababa, the dominant public transportation modes are city buses and taxis. Although buses have 30 seats each, they have a carrying capacity of 100 people in a crowded situation. Taxis have a carrying capacity from four (small taxis) to 12 persons (large taxis).

Car ownership among residents is very low, so the majority depends on buses and taxis for their day-to-day mobility. Walking is the main means of transportation for a number of residents. Unlike other cities in the country, bicycle use is insignificant because of topographic inconveniences. [10].

Anbessa City Bus Service, Sheger mass transport, the light rail transit, mini bus taxis, midi buses and other buses like Public Service Employees Transport Service Enterprise (PSETSE) are operating in the city currently.

The companies are mandated to provide public transport services to the city and the surrounding areas. They provide scheduled services along different routes. The basic bus service has a system of flat fares for the route with a range varying according to distance.

METHODOLOGY

The passenger capacity of a transport line is the product of the number of vehicles per hour (usually past the busiest stop) and the number of passengers that each vehicle can carry [6]. Since the aim of the paper is to develop a mathematical tool for determining the daily capacity of the operating transport system in the city, all factors will be used in their daily basis.

The daily capacity of a single service provider can be determined as a multiple of number of vehicles, capacity of a vehicle and number of trips made per day.

$$C_i = (N_V * C_V * N_t)_i \quad (3.1)$$

Where: C_i = Average daily capacity of service provider i.

N_V = Average daily operating number of vehicles of service provider i.

C_V = Average Operating capacity of a vehicle of service provider i.

N_t = Average number of trips travelled by a vehicle of service provider i per day.

After determining the individual capacities of each serving company, the total capacity can be given as the sum of all.

$$C_d = \sum_{i=1}^{n} C_i \quad (3.2)$$

Where:

C_d = Total daily capacity of the public transport.

To do so, value of Nt for all providers must be determined. It can be determined by using the following equality. The average total distance covered by a vehicle in a day is the multiple of the average length of routes and number of trips made. This in other ways is equal to the multiple of the average speed of the vehicle and effective time of the vehicle in a day.

$$(S_t)_i = (l_t * N_t)_i = (V_V * t_e)_i \quad (3.3)$$

Where:

$\boldsymbol{S_t}$ = total distance covered by a vehicle of service provider i in a day (km)

$\boldsymbol{l_t}$ = Average length of trip for service provider i, (km)

$\boldsymbol{N_t}$ = Total number of trips travelled by a vehicle of service provider i.

$\boldsymbol{V_V}$ = Average speed of vehicles of service provider i, (km/hr)

$\boldsymbol{t_e}$ = Effective time of a vehicle of service provider i in a day (hrs) .

The effective time of a vehicle in turn is calculated as a difference between the total working time in a day and the sum of all times spent at origins, stations, and destinations, time of brake for drivers and daily down times.

$$(t_e)_i = (t_d - T_S * (N_s * N_t) - t_b - d_t)_i \quad (3.4)$$

Where:

$\boldsymbol{t_e}$ = Average effective time of a vehicle of service provider i in a day (hrs)

$\boldsymbol{t_d}$ = Average total working time of a vehicle of service provider i per day, (hrs)

$\boldsymbol{T_s}$ = Average loading/unloading time at stations for a vehicle of service provider i, (hrs)

$\boldsymbol{N_s}$ = Average number of stations on a route of service provider i.

$\boldsymbol{N_t}$ = Total number of trips travelled by a vehicle of service provider I per day.

$\boldsymbol{T_b}$ = sum of all average breaking times for a vehicle of service provider I per day, (hr)

= lunch **b**reak + sum of **s**toppages at **o**rigin and **d**estination + **T**ea **b**reak.

$$= \boldsymbol{l_b + N_t * T_{od} + T_b} \quad (3.5)$$

Where:

$\boldsymbol{l_b}$ = Lunch break per day per vehicle.

$\boldsymbol{T_{od}}$ = Average time spent at origins and destinations per day

T_b = Tea break per day per vehicle (hrs)

d_t = Average down time per day for a vehicle of service provider i, (hr)

From the above two equations, equation 3.3 and 3.4, **Nt** can be given as below.

$$N_t = \frac{V_V(t_d - t_b - d_t)}{l_t + T_S V_v N_S} \quad (3.6)$$

Substituting equation 3.4 for t_b will give us:

$$N_t = \frac{V_v(t_d - l_b - T_b - d_t)}{l_t + V_v(T_S N_S + T_{od})} \quad (3.7)$$

The total of all daily passenger trips that can be served by all set of the public transport providers in the city can, hence, be determined by summing up the total daily passenger trip capacity of each service provider (look at equation 3.2.). It can also be expressed as under.

$$(TDPT)_{\text{city}} = \sum_{i=1}^{n} (TDPT)_{\text{i}} \quad (3.8)$$

Where:

(TDPT) $_{\text{city}}$ = Total daily passenger trip capacity of all public transport providers in the city

(TDPT)$_{\text{i}}$ = Total daily passenger trip capacity of public transport provider i.

The total daily passenger trip capacity of each service provider, on the other hand, can be determined by multiplying its total daily trips, ***Nt***, with the capacity of its vehicle (look at equation 3.1.). It can also be given as hereunder.

$$(TDPT)_i = (\text{Nt})_{\text{i}} * (\text{Nv})_{\text{i}} * C_{\text{i}} \quad (3.9)$$

Where:

(TDPT)$_{\text{i}}$ = Total daily passenger trip capacity of public transport provider i.

N_t = Average number of trips travelled by a vehicle of service provider i per day.

N_v = Average daily operating number of vehicles of service provider i.

C_i = Average Operating capacity of a vehicle of service provider i.

Substituting equation (3.7) for (***Nt)*** results in the following form.

$$(TDPT)_{\text{i}} = \left[\frac{V_v*(t_d-l_b-T_b-d_t)}{l_t+V_v*(T_S N_S+T_{od})}\right]_i * (N_v)_i * C_i \quad (3.10)$$

Now, equation 3.10 can be substituted for $(TDPT)$i in equation 3.8. Doing so, the total daily passenger trip capacity in the city can be estimated using this formula.

$$(TDPT)_{\text{city}} = \sum_{i=1}^{n} \left[\frac{V_v * (t_d - l_b - T_b - d_t)}{l_t + V_v * (T_s N_s + T_{od})}\right]_i * (N_v)_i * C_i \quad (3.11)$$

CONCLUSIONS

1. Public transport capacity of Addis Ababa City can be determined by using this equation.

$$(TDPT)_{\text{city}} = \sum_{i=1}^{n} \left[\frac{V_v * (t_d - l_b - T_b - d_t)}{l_t + V_v * (T_s N_s + T_{od})}\right]_i * (N_v)_i * C_i$$

2. Public transport capacity is dependent on a range of factors such as road geometry, transport planning, driver behavior, vehicular characteristics and traffic stream characteristics. As shown in the last formula this paper comes up with, there is no variable representing the road geometry. This can be justified as since the speed of the vehicles is counted, the effect of the geometry can be well revealed through the operating speed. Because as the geometry gets somewhat

inadequacy, it usually causes traffic congestion which in turn reduces the operating speed in the traffic stream and the vice versa holds true.

3. Different consequences of transport system planning affect the public transport capacity. In Addis Ababa almost all public transport providers have fixed routes to which they are assigned. At some routes and terminals a number of vehicles may spend more time until they will get their turn to load. On the other hand, peoples may be obliged to make lines looking for a means of transport on other routes. So, to maximize the daily capacity of existing public transport, it is a mandatory to have an efficient citywide transport planning.

4. Drivers' behavior affects the public transport capacity in many ways. Some drivers may prefer to start working early and get back home late so that serving the community for longer time while some others favor the opposite. A number of drivers devote long period of time when taking tea breaks and lunch breaks while some others prefer to use their time wisely so that they will have maximum working hours.

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