MODELING OF TRANSIT VEHICLE SERVICES AND STOP SPACINGS FOR DHAKA METROPOLITAN AREA (DMA).

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ABSTRACT

In this study we developed theoretical but practically usable models for varieties of transit services namely local, call-on, request stop, accelerated and express service in considering en route traffic congestion or obstacles and their stopping criteria for DMA. We formulated the relationships between interstop spacing with various travel-time, fleet sizes, headway, passenger volume, waiting time, vehicles dynamic characteristics and en route congestion. And determined the number and locations of stops for varieties of services and their stopping criteria as per passenger generation rate so that the average travel time of maximum passengers—from their origins to destination—is minimized. The analyses showed that the performance parameters are highly interdependence on each other and remarkably influenced by en route congestion/obstacles. It showed with the increasing of congestion/obstacles the users travel times and stops spacing always increases in all transit services.

1. INTRODUCTION

The types of operation and the number and locations of stops, headway, fleet size, traffic congestion and vehicle dynamic characteristics and other related operational aspects of transit services play very significant role for the operation and performance of transit system. The number of stops makes a tradeoff between users access/egress times to and from the bus stops and operating speed of the vehicle. The operating speed of the vehicle and access/egress time of passengers increases with spacing. Therefore, there must be an optimum number of stops, which minimize the access/egress time, and vehicle travel time. However, when the vehicle faces traffic congestion or any obstacles on en route it has to slow-down its speed which changes the spacing distance between adjacent stopping and must have effect on operating speed, fleet size and travel time.

In Dhaka Metropolitan Area (DMA), bus and minibus are only the mass transit modes and around 1500 buses and minibuses of private and public sectors are providing transit services for a population of 8 million. It is clear that bus services are extremely inadequate and overcrowded. Bus stops and spacings are not designated as per transport service and transport demand. Most of the stops are undesignated, uninformative, and difficult to identify by unknown passenger. Bus and passenger arrives at random at stops because passengers have no information regarding bus arrivals, as buses are plying based on "first return first start" instead of any specific scheduled headway. So, drivers and conductors decide on en route where and how long to stop, and when and which stops to skip as per their expected maximum revenue, i.e., maximum passengers' board.

Besides these buses are not given any special priority rather plying with mixed motorized and non-motorized traffic in the same road and sometimes in the same lane. So, bus faces many obstacles with non-motorized rickshaw and slow moving three wheeler vehicles, including traffic congestion, signals and pedestrian crossing on en route. And driver has to slow-down the vehicle for each obstacle, which changes the stopping distances between adjacent stops which in turn affect operating speed and travel time of the vehicle as well as fleet size for a given passenger generation rate and headway. Therefore, in derivation of the model we consider three cases based on the spacing distance between two adjacent stops to estimate the effects of these unexpected slow-downs and traffic congestion on transit service parameters as follows:

Case1: When the spacing distance between two consecutive stops is less than the critical stop spacing so that the vehicle has to decelerate before attain to its maximum speed V.
Case2: When the spacing distance between two consecutive stops is equal to critical stop spacing so that the vehicle can attain its maximum speed V for a moment and immediately begin to decelerate to stop.
Case3: When the spacing distance between two consecutive stops is more than the critical distance so that the vehicle can attain its maximum speed V and begin decelerate after moving some distance at constant speed V.

There have been number of studies on the problem related to stops spacing, fleet size and headway and travel times. Among them areVuchic (1966), Byrne (1971), Chapman (1977), and Wirasinghe (1976, 1981). Most models are optimized the number of stops under a given headway or for an optimum headway for given number of stops. Hauer (1971) first determined the relationship between headway and number of stops for optimum fleet size. Wirasinghe (1977) analyzed number of stops and headway for a radial commuter rail transit. Byrne (1971) examined the space and time availability of transit service from a line-spacing standpoint. None of the models considered the congestion effects on transit performance parameters. However, congestion/obstacle on en route has a significant influence on travel time, fleet size and stops spacing. In DMA, buses move in mixed motorized and non-motorized traffic, therefore, the situation is completely different from other cities. There have been some studies on DMA's mass transit, among them Ahsan (1993), DITS (1993), and Zahir (1997) are mentionable. These studies did not focus on bus stops or stops spacing or congestion rather they focused on overall existing problems of DMA's transit system.

It is obvious that Dhaka's transit services are extremely inadequate, irregular, unreliable in terms of schedule and punctuality, long queues and waiting time, access/egress, number and locations of stops and overloading. So, there is an acute need for a theoretical based and practically usable comprehensive model for analyses of Dhaka's transit system performance characteristics and service parameters that are interrelated in a complicated manner, and which will use to determine the impacts of parameters on each other. The main purpose of this study is to develop ideal models for varieties of mass transit system of DMA by correlating transit performance parameters, vehicle dynamic characteristics and traffic congestion. And find out the best possible combinations of transit parameters through analyses of models by assumed parametric values, and which will use to reduces the users travel time for maximum number of passengers by reducing in-vehicle travel time, waiting time and access/egress time. We also determine which type of service is suitable during peak i.e. high demand and off-peak periods i.e., low demand to meet up passengers' demand and operator benefits.

2. MODEL DEVELOPMENT

In this section we developed models for varieties of transit services by correlating transit performance parameters and vehicles dynamic characteristics. Since the user travel times is a function of stop spacing, user in-vehicle travel time, access time and waiting time, so, we define and formulate each parameters before development of users travel time model in the following sections.

2.1 Access and Egress Time

The time required from origin to stops and stops to destinations is access/egress time, which depends on speed and distance to and from bus stops. In DMA, walking and rickshaw are the main access/egress modes but their contributions are different in terms of service and speed. DITS study revealed about 70% passengers' access/egress by walking and 30% by rickshaw [4]. The rickshaw is 3 times faster than pedestrian [5], i.e., $V_r = 3V_a$. Where, V_a and V_r are walking and rickshaw's speed respectively. The access and egress path patterns depend on the locations of residences of individual passenger and bus stops and route network. A number of access/egress patterns are conceivable. Since the perpendicular component is independent on the locations of stops, here we considered only the parallel access/egress travel components to the transit line.

A passenger would like to have bus stop near origins and destinations, and a nonstop service between these two stops. Since all the passengers presumably feel this way, the objective from a collective point of view should be minimize the sum of the access and egress time. The average access and egress time T_e, to and from the closest bus stops in terms of pedestrian and rickshaw speed are respectively as under:

$$T_e = L(3-2x)/\{6V_a(s-1)\} \quad (1)$$

and, $$T_e = L(3-2x)/\{2V_r(s-1)\} \quad (2)$$

Where, s is the number of stops including terminals, L is route length and x is the portion of passengers' access to and egress from stops by walking.

2.2 Waiting Time

The waiting time experienced by transit users is one of the most important element of the levels of service provided by a transit system. The waiting time of passengers at stops depends on headway, period of operation, congestion, bus and passengers arrival pattern at stops and loading condition of buses, etc. The commonly used model which asserts that average wait time is one-half the headway when the passengers arrivals at random and the buses arrives at perfectly regular. This situation does not meet with Dhaka's bus transit system. Here, bus and passenger both arrives at stops at random. The passengers have no information regarding bus arrivals. Therefore, they have to wait till the bus come. Moreover, during peak periods bus becomes overloaded at the beginning of journey and carries more passengers than its capacity. There is no empty place for boarding. So, driver stops buses only at major stops and skips unless there is demand for alighting. Usually, old and female and children are avoided to board on those buses. That results an increase of average expected waiting time of passengers. Under such condition and when the probability of occurrence of two consecutive full vehicles in the stream is small at most points of the routes, Ezra Hauer [6] express the expected waiting time at some point of bus route is $T_w \cong h/2(1+2q)$. Where, (3)

h = Mean headway between vehicles, and q = probability of vehicle to full capacity.

2.3 Travel Time between Two Consecutive Stops

As per the definitions of case1 and case2, spacing distance between two adjacent stops is less or equal to the critical stop spacing. So, here the vehicle possesses only two states of motions, acceleration and deceleration. Therefore, the travel time between two adjacent stops T_1 for case1, is the sum of the acceleration time t_a, deceleration time t_b, and a stopping time t_s for boarding and alighting passengers, i.e.:

$$T_1 = t_a + t_b + t_s = \sqrt{2S_d(a+b)/ab} + t_s \quad \text{Where,} \tag{4}$$

S_d is stop spacing for case 1, and a and b are linear rate of acceleration and deceleration.

Whenever, the vehicle faces traffic congestion or any obstacle within any stop spacing, it has to slow-down its speed before reach to V_1, the maximum speed that could be attained without face any congestion or obstacles within S_d, here $V_1 < V$. In practice, the vehicle may or may not face congestion or obstacles in each of stop spacing. In some spacing it might face one or two or more congestion/obstacles and in some they may not face any. The frequencies of such slow-down will depend on the level and frequencies of congestion or obstacles that the vehicle will face within S_d. Since the spacing distance between two stops are very short we assumed that the vehicle will face m number of obstacles at equidistant that causes the vehicle slow-down to zero for a moment at each time. In this intermediate slow-down the vehicles does not board or alight any passenger, so, its intermediate stopping duration does not depends on passengers volume rather it completely depend on level of congestion/ obstacle that the vehicle will face. Therefore, travel time between two adjacent stops with m times such obstacles T_1^m, is the sum of the acceleration and deceleration time for m slow-down and stopping time t_s is expressed by:

$$T_1^m = \sqrt{2(m+1)S_d(a+b)/ab} + t_s \tag{5}$$

Similarly, we can get the interstop travel time for case 2, T_2^m;

$$T_2^m = \sqrt{2(m+1)S_c(a+b)/ab} + t_s \tag{6}$$

Where, S_c is the critical stop spacing distance.

Again, the interstop travel time for case 3, T_3^m is equal to the travel time for case2, defined by equation (6), plus the time for constant speed state for $S - S_c$ distance.

$$T_3^m = \sqrt{2(m+1)S_c(a+b)/ab} + t_s + (S - S_c)/V; \qquad \text{for } S \geq S_c \tag{7}$$

2.4 Vehicle Travel Time

Vehicle travel time is the time required for making one way trip from one terminal to another. It consists of vehicle running time, time losses incurred by stopping for boarding and alighting passengers, and time loss associated with traffic congestion, signals or any obstacles. The running time depends on the speed of vehicle, which is directly influenced by stop spacings, traffic congestion and traffic signals on en route.

The stopping time at stop is a function of the number of passengers boarding and alighting at the stop and their boarding and alighting rate, which depend on the design of doors, fare collection system, and passengers characteristics. Assume p is the mean number of trips generated per unit time along the route, and θ is the cycle time and N is the fleet size. So, average time headway between the vehicles, $h = \theta/N$. Total trip generated for one way trip is equal to ph. Therefore, total number of boarding and alighting passengers for one way trip is twice the total trips generated within average time headway along the route i.e., $2ph$. It is assumed that boarding and alighting time for all passengers are same and the average sum of boarding and alighting passengers is same at all stop. Therefore, the total stopping time for boarding and alighting passengers is $nt_s = 2ph\mu$. Where, μ is the average boarding or alighting time per passenger and n is average number of stopping.

The vehicle travel time for the entire route length L is the sum of all interstop travel times between adjacent stops within L. Since s is the total number of equidistant stops including terminals. And, the start terminal is used for boarding and end terminal for alighting, we considered two terminals as a single stop. So, the total number of stop is equal to $(s-1)$, and there exist $(s-1)$ number of equidistant route section of length $L/(s-1)$. Therefore, from equation (5), (6) and (7) we could drive the vehicle travel times for case1, T_{r1}; case2, T_{r2} and case3, T_{r3} over the entire route are respectively as:

$$T_{r1} = n\sqrt{2(m+1)S_d(a+b)/ab} + 2ph\mu; \qquad \text{for, } S_d = L/n < S_c. \tag{8}$$

$$T_{r2} = n\sqrt{2(\mathrm{m}+1)\mathrm{S_c}(a+b)/ab} + 2ph\mu; \qquad \text{for } S_c = L/n. \tag{9}$$

$$T_{r3} = n\sqrt{2(m+1)S_c(a+b)/ab} + 2ph\mu + n(S - S_c)/V; \text{ for } S = L/n > S_c; \tag{10}$$

3. VEHICLE TRAVEL TIME FOR VARIETIES OF TRANSIT SERVICES

DMA's bus service does not have any regulated or controlled timetable and no specific guideline for bus stopping at stops. Whereas stop spacing and stopping policies for transit service play a very important role on transit travel time, waiting time, operating speed, reliability and comfort are prominent. Hence, we considered five types of transit services and defined their stopping characteristics in order to meet the existing peak and off-peak demands. In the following sections we derived users travel time models for each service.

3.1 Local Service

Under this service the vehicle stops at all prefixed stops whether there is passenger demand or not. So, the number of stopping is equal to the number of stop provided, i.e., $n = (s-1)$. By putting these values in equation (8), (9) and (10) we can get the vehicle travel time for local service of case1, T_{r1}^{l}; case2, T_{r2}^{l} and case3, T_{r3}^{l} over the route are respectively as:

$$T_{r1}^{l} = n\sqrt{2(m+1)S_d(a+b)/ab} + 2ph\mu; \quad \text{for } S_d = L/(s-1) = L/n < S_c. \quad (11)$$

$$T_{r2}^{l} = n\sqrt{2(\mathrm{m}+1)\mathrm{S_c}(a+b)/ab} + 2ph\mu; \quad \text{for } S_c = L/(s-1) = L/n. \quad (12)$$

$$T_{r3}^{l} = n\sqrt{2(m+1)S_c(a+b)/ab} + 2ph\mu + n(S-S_c)/V; \quad \text{for } S = L/(s-1) = L/n > S_c. \quad (13)$$

3.2 Call-on Service

Under this service vehicle stops at prefixed stop only where the passenger demands for boarding or alighting, otherwise by-pass or skip. So the number of stopping is less than the number of stops provided. However, if the number of passengers using this service is large, the number of stopping increases eventually and become equal to number of stops. As we know the Poisson distribution is a limiting approximation of Binomial distribution, when the probability of occurrence an event gets smaller and sample size very large. So, we assumed passenger arrival at bus stops and boarding and alighting demand follows the Poisson distribution and bus arrival at stop follows Binomial distribution. Therefore, the total number of stoppings will follow a binomial distribution and the probability of stopping a bus at n^c times within $(s-1)$ stops, $P(s)_{n^c/(s-1)}$ is can be expressed by:

$$P(s)_{n^c/(s-1)} = \binom{s-1}{n^c} p^{n^c}(1-p)^{(s-1)-n^c} \quad (14)$$

where, p is the probability of stopping a vehicle at the stop and $1-p$ is the probability of bypassing or skipping a bus stop.

The mean number of passengers using a stop for boarding and alighting is $m = 2p\theta/N(s-1)$. This m number of passengers' can not use all buses if the bus does not stop in some bus stops. So, the probability of r passengers boarding and alighting at a stop $P(r)$,

$$P(r) = e^{-m}\frac{m^r}{r!} = e^{\frac{-2p\theta}{N(s-1)}}\frac{\left\{\dfrac{2p\theta}{N(s-1)}\right\}^r}{r!} = e^{\frac{-2ph}{(s-1)}}\frac{\left\{\dfrac{2ph}{(s-1)}\right\}^r}{r!} \quad (15)$$

It is also seldom happen that a stop is skipped because the vehicle is full and nobody wishes to alight. When the bus has skipped, it means the number of boarding and alighting is zero. The probability of skipping a bus stop $P(0)$ is obtained by substituting $r = 0$ in equation (15), which is equal to $P(0) = e^{\frac{-2ph}{(s-1)}}$. Hence, the probability of stopping a bus at a stop, $P(s) = 1 - P(0) = 1 - e^{\frac{-p2h}{(s-1)}}$. (16)

Therefore, the average number of stopping for a one way trip, $n^c(s)$ = Total number of stops in one way trip $\times$ the probability of stopping a bus at a stop.

$$n^c(s) = (s-1) \times P(s) = (s-1) \times \left\{1 - e^{\frac{-2ph}{(s-1)}}\right\}. \tag{17}$$

From this equation we could see that the average number of stopping for a one-way trip under call-on service depends on the number of stops $(s-1)$, average headway and passenger generation rate. When the passengers volume is very large i.e., $p \to \infty$.

Then the number of stopping, $\lim\limits_{p \to \infty} n^c(s) = \lim\limits_{p \to \infty} (s-1) \times \left\{1 - e^{\frac{-2ph}{(s-1)}}\right\} = (s-1)$. (18)

Therefore, for large number of passengers the vehicles stop at all stops, i.e., local service. So, from equations (8), (9) and (10) we can get the vehicle travel time for call-on service of case1, T^c_{r1}; case2, T^c_{r2} and case3, T^c_{r3} over the route are respectively as:

$$T^c_{r1} = n^c \sqrt{2(m+1)S_d(a+b)/ab} + 2ph\mu; \qquad \text{for } S_d = L/n^c < S_c. \tag{19}$$

$$T^c_{r2} = n^c \sqrt{2(\mathrm{m}+1)\mathrm{S_c}(a+b)/ab} + 2ph\mu; \qquad \text{for } S_c = L/n^c. \tag{20}$$

$$T^c_{r3} = n^c \sqrt{2(m+1)S_c(a+b)/ab} + 2ph\mu + n^c(S - S_c)/V; \qquad \text{for } S = L/n^c > S_c. \tag{21}$$

3.3 Request Stop Service

Under request stop service the vehicle stops anywhere at the passenger's origins and destinations along the route whenever passenger request for boarding or alighting. So, the access/egress time is equals to zero. Theoretically, the number of stopping is infinite, however, each stopping is for the purpose of at least for a single boarding or alighting i.e., maximum number of stopping is twice the number of total trips generated along the for one-way trip, i.e., $2p\theta/N$. Moreover, there is a possibility of simultaneous boarding and alighting and also more than one passenger may board or alight in a single stopping. So, the number of stopping will be less than the maximum number of stopping $2p\theta/N$. In that case, the number of stopping for request service, $n^r = 2p\theta/Nc$, where, c is the average number of passengers board or alight simultaneously during a single stopping. So the average spacing distance between two stoppings equals to $= Lc/2ph$.

Similarly, by putting the values of number of stopping in equation (8), (9) and (10) we can get the vehicle travel time for request service of case1, T^r_{r1}; case2, T^r_{r2} and case3, T^r_{r3} over the route are respectively as:

$$T^r_{r1} = n^r \sqrt{2(m+1)S_d(a+b)/ab} + 2ph\mu; \qquad \text{for } S_d = L/n^r = Lc/2ph < S_c. \tag{22}$$

$$T^r_{r2} = n^r \sqrt{2(\mathrm{m}+1)\mathrm{S_c}(a+b)/ab} + 2ph\mu; \qquad \text{for } S_c = L/n^r = Lc/2ph. \tag{23}$$

$$T^r_{r3} = n^r \sqrt{2(m+1)S_c(a+b)/ab} + 2ph\mu + n^r(S - S_c)/V; \text{ for } S = L/n^r = Lc/2ph > S_c \tag{24}$$

3.4 Accelerated Service

In this case successive transit unit skips different sets of predetermined stops. The vehicle will stops mostly at major stops where passenger demand is high. Stopping criteria of this service is same as local service, and only difference in stop spacing distance, so, we could use the same model we derived in case 3 for local service. Here, the number of stopping is equal to the number of prefixed stop but less in comparison with local service. For longer stop spacing the operating speed of the vehicle will increases and users travel time will be reduced, specially, for long distance passengers and peak period service.

3.5 Express Service

This is faster or non-stop service usually for long distance passenger. It will stop at the transfer point or maximum loading point of the route. It will stop at its prefixed stop. The number of stop is very limited and must be less than any other services. This service will be faster in comparison with accelerated service. It will be suitable for long distance travelers. We could also use the same model of case 3 for local service with longer spacing distance as per planning.

4. USERS TRAVEL TIME FOR TRANSIT SERVICES

Users travel time T_u consists of users in-vehicle riding time T_m, access/egress time T_e, and waiting time T_w. Therefore, the users travel time, $T_u = T_m + T_e + T_w$. (25)

Now, users riding time or in-vehicle travel time T_m, is the travelling time for users average travel distance l, at overall operating speed, V_0, i.e., $T_m = l/V_0$. Where, the overall operating speed is the ratio of entire route length and vehicle travel time i.e., $V_0 = L/T_r$. So, the in-vehicle riding time in terms of vehicle travel time can be expressed as:

$$T_m = l/V_0 = lT_r/L \tag{26}$$

By using equations (1), (3), (11), (12), (13), (25) and (26) we derive users travel time for local service for case 1, T_{u1}^l; case 2, T_{u2}^l and case 3, T_{u3}^l respectively as under:

$$T_{u1}^l = l/L\{n\ \sqrt{2(m+1)S_d(a+b)/ab} + 2ph\mu\ \ + L(3-2x)/\{6V_a(s-1)\} + h/2(1+2q) \tag{27}$$

$$\text{for } S_d = L/(s-1)\ = L/n\ < S_c.$$

$$T_{u2}^l = l/L\{n\ \sqrt{2(\mathrm{m}+1)\mathrm{S_c}(a+b)/ab} + 2ph\mu\} + L(3-2x)/\{6V_a(s-1)\} + h/2(1+2q) \tag{28}$$

$$\text{for } S_c = L/(s-1)\ = L/n.$$

$$T_{u3}^l = l/L\{n\sqrt{2(m+1)S_c(a+b)/ab} + 2ph\mu + n(S-S_c)/V\ + L(3-2x)/\{6V_a(s-1)\}$$
$$+\ h/2(1+2q); \qquad \text{for } S = L/(s-1) = L/n > S_c. \tag{29}$$

Similarly, from equations (1), (3), (19), (20), (21), (25) and (26) we can have users travel time for call-on service for case1, T_{u1}^c; case2, T_{u2}^c and case3, T_{u3}^c respectively are follows:

$$T_{u1}^c = l/L\{n^c\sqrt{2(m+1)S_d(a+b)/ab} + 2ph\mu\ + L(3-2x)/\{6V_a(s-1)\} + h/2(1+2q) \tag{30}$$

$$\text{for } S_d = L/n^c < S_c.$$

$$T_{u2}^c = l/L\{n^c\sqrt{2(\mathrm{m}+1)\mathrm{S_c}(a+b)/ab} + 2ph\mu\} + L(3-2x)/\{6V_a(s-1)\} + h/2(1+2q) \tag{31}$$

$$\text{for } S_c = L/n^c;$$

$$T_{u3}^c = l/L\left\{n^c\sqrt{2(m+1)S_c(a+b)/ab} + 2ph\mu + n^c(S-S_c)/V\right\} + L(3-2x)/\{6V_a(s-1)\} + h/2(1+2q); \qquad \text{for } S = L/n^c > S_c. \tag{32}$$

Again, similarly, by using equation (1), (3), (22), (23), (24), (25) and (26) to get users travel time for request stop service for case1, T_{u1}^r; case2, T_{u2}^r case3, T_{u3}^r respectively are follows:

$$T_{u1}^r = l/L\left\{n^r\sqrt{2(m+1)S_d(a+b)/ab} + 2ph\mu\right\} + h/2(1+2q) \tag{33}$$

$$\text{for } S_d = L/n^r = Lc/2ph < S_c$$

$$T_{u2}^r = l/L\left\{n^r\sqrt{2(\mathrm{m}+1)\mathrm{S_c}(a+b)/ab} + 2ph\mu\right. + h/2(1+2q); \text{ for } S_c = L/n^r = Lc/2ph. \tag{34}$$

$$T_{u3}^r = l/L\left\{n^r\sqrt{2(m+1)S_c(a+b)/ab} + 2ph\mu + n^r(S-S_c)/V\right. + h/2(1+2q) \text{---------------(35)}$$

$$\text{for } S = L/n^r = Lc/2ph > S_c.$$

5. RESULTS AND DISCUSSIONS

This section discussed the results and relevant findings through graphically illustrate the relationships among the parameters such as users travel time, headway, number of stops, fleet size passenger demand, access speed and traffic congestion both qualitatively and quantitatively based on the following assumed parametric values, unless otherwise specified.

Route length L =20Km; Average users travel distance $l = 12$ km; Vehicle cruising speed V = 40 km/hr; Walking speed V_a =4.5 km/sec; Acceleration rate $a = 1.0$ m/sec^2 and Deceleration rate $b = 1.2$ m/sec^2; Percentage of passenger access to and egress from stops by walking x =70%; Passenger generation rates per unit time $p = 5$ persons/sec; Average time headway $h =$ 5 min, Average boarding or alighting times per passenger $\mu = 3$ sec/per; and Probability of two successive vehicles full to capacity q =0.2.

Here we would like to detail investigate the dependence and effects of transit parameters on each other for local and call-on service, and illustrate their relationship graphically in brief in the following sections:

5.1 Relation between User Travel Times and Number of Stops and Headways for Local Service.

The relationships between average user travel times and headway and number of stops for local service are respectively shown in figure1 and figure2. Figure1 shows that the average users travel time increases linearly with headway. And figure2 shows users travel time first decreases with increases of number of stops to a minimum point and further increases with number of stops. Again from figures 2(a), (b) and (c), it is observed that the minimum users travel time on congested route is always more in comparison with the minimum travel time of without congestion. And the minimum travel time point shifted towards left with the increasing of congestion. It's revealed that the optimum stop spacing increases with traffic congestion. From figure1 and figure2, it is clear that there exist various combination of headway and number of stops for same users travel time. Therefore, isochronal lines for T_u (a) 30 min.; (b) 40 min and (c) 50 min are plotted in figure3 as a function of average headway and number of stops. Any combinations of headway and number of stops on isochronal lines gives the same respective user travel time.

Figures 3(a), (b) and (c) show that firstly headway sharply increases with number of stops and reaches to maximum and gradually decreases with increases of number of stops. The headway is increases with user travel for a given number of stops. It is also found that as the congestion on en route increases headway is decreases for a given number of stops and users travel time. So, while the user travel time is given for a fixed route transit system its frequency should be increased during traffic congestion to meet-up passengers demand.

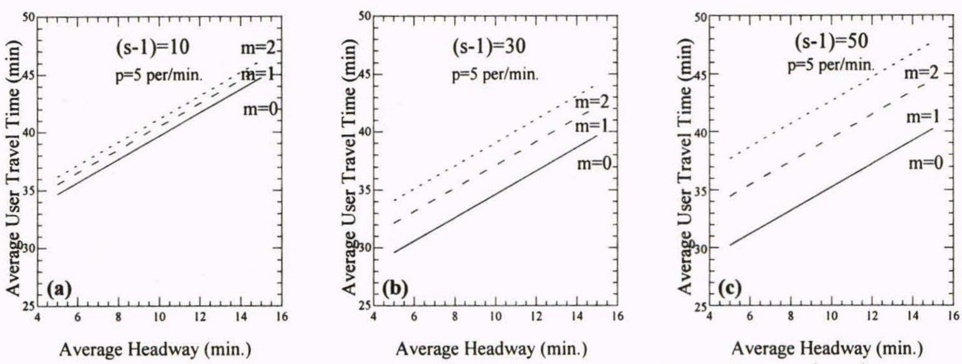

Figure 1. Relation between User Travel Times and Headway for (a) $(s-1)=10$; (b) $(s-1)=30$ and (c) $(s-1)=50$ per 20 km at Different Congestion Levels for Local Service.

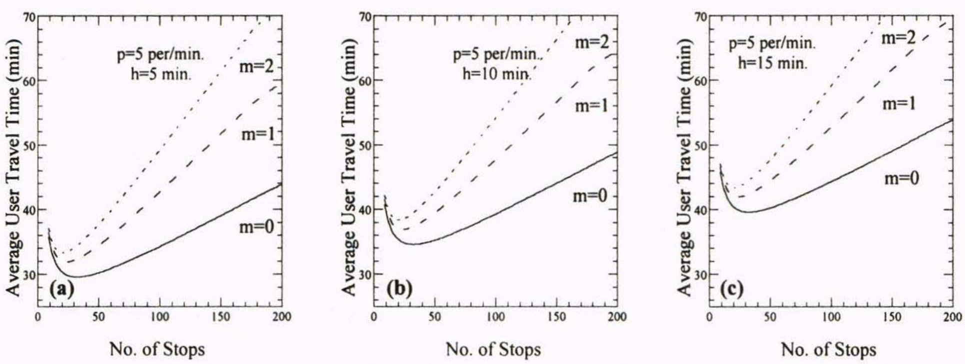

Figure 2. Relation between User Travel Times and Number of Stops/20 km for (a) $h=5$ min; (b) $h=10$ min and (c) $h=15$ min at Different Congestion Levels for Local Service.

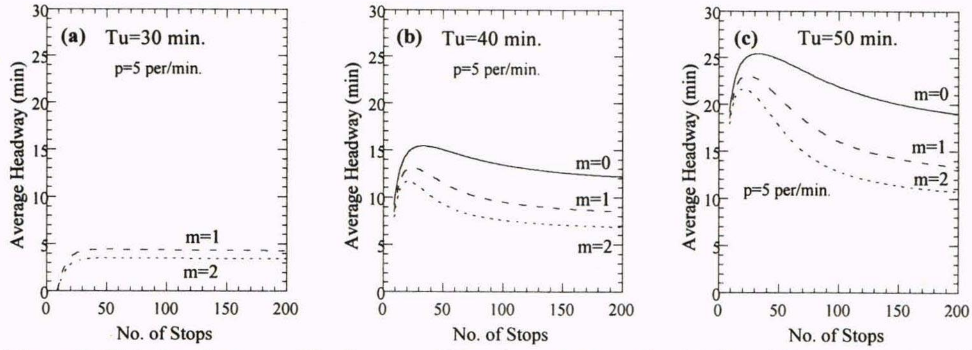

Figure 3. Relation between Headway and Number of Stops for (a) $T_u = 30$ min; (b) $T_u = 40$ min and (c) $T_u = 50$ min at Different Congestion levels for Local Service.

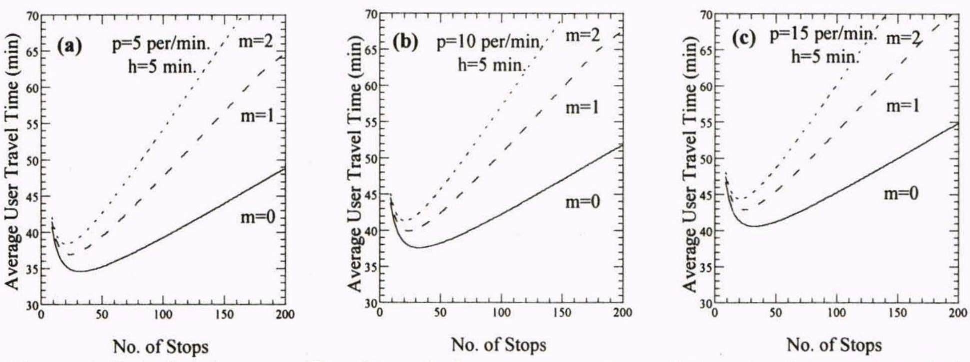

Figure 4. Relation between User Travel Times and Number of Stops for (a) $p = 5$ pers/min; (b) $p = 10$ pers/min and (c) $p = 15$ pers/min at Different Congestion Levels for Local Service.

5.2 Relation between User Travel Times and Number of Stops and Headways for Call-on Service.

The relationships between the average users travel times, headway and number of stops for call-on service is shown in figure 6 and figure 7. Figure 6 (a) shows that for short headway ($h = 5$ min) and without congestion ($m = 0$) the users travel times asymptotically diminishing without a minimum point, which is different from local service. However, when the vehicle faces traffic congestion or ply on long headway the users travel times function behaves similar as local service. Because when the number of stops becomes very large the passenger's access/egress time reduces but the probability of stopping eventually increases, which increases the vehicle travel time. In comparison with figure 4 and figure 7 we could easily seen that users travel time increase more sharply with number of stops for local service than call-on service for every combination of p and h. Again, figures 6 (a), (b) and (c) shows that the optimum number of stops becomes greater for minimum travel time with shorter headway. And figure 7 also shows the number of stops, which minimizes the user travel time, varies with passenger volume. It shows that as the passenger generation rate decreases the number of stops, which minimizes travel time increases. The congestion effects on call-on service also found similar as local service.

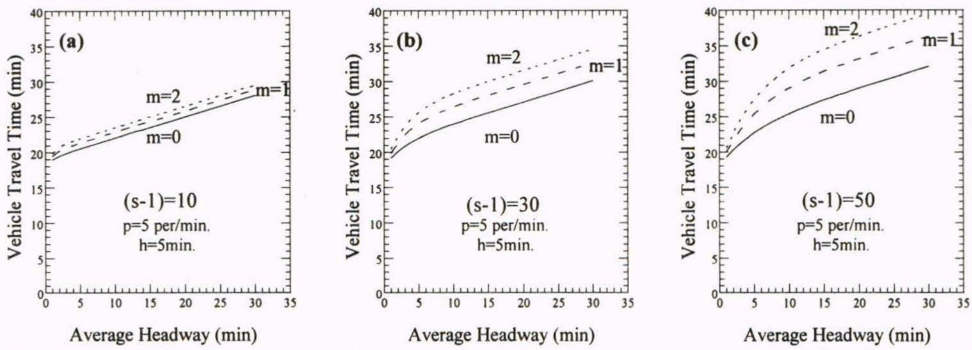

Figure 5. The Relation between Vehicle Travel Times and Headway for (a) $(s-1)=10$; (b) $(s-1)=30$ and (c) $(s-1)=50$ per 20 km at Different Congestion Level for Call-on Service.

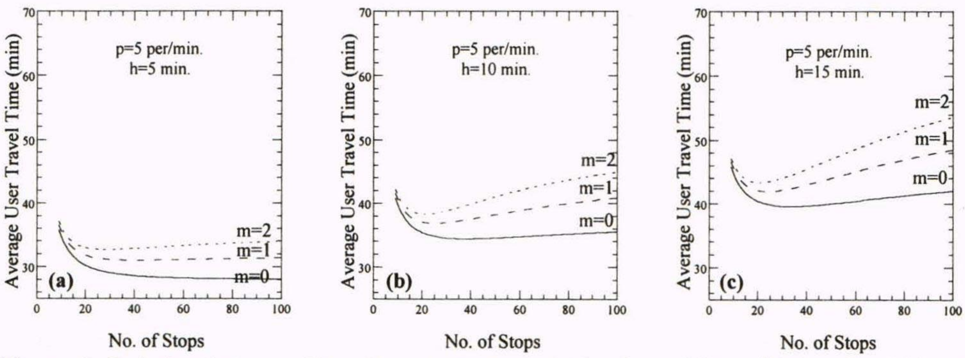

Figure 6. Relation between User Travel Times and Number of Stops/20 km for (a) $h=5$ min; (b) $h=10$ min and (c) $h=15$ min at Different Congestion Level for Call-On Service.

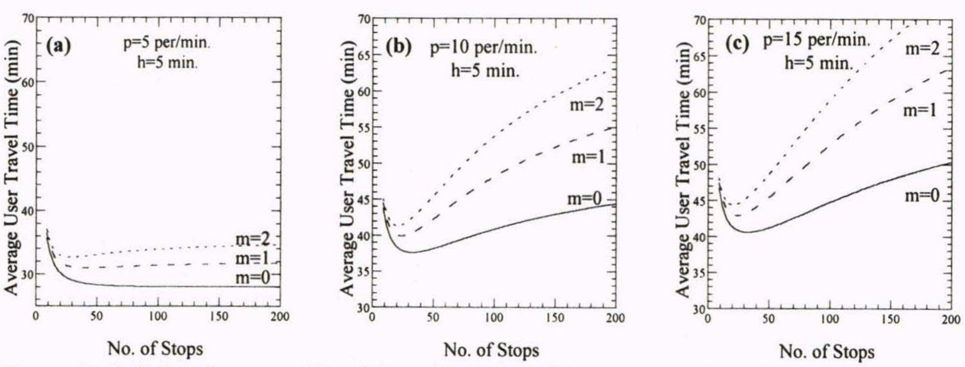

Figure 7. Relation between User Travel Times and Number of Stops/20 km for (a) $p=5$ pers/min; (b) $p=10$ pers/min and (c) $p=15$ pers/min at Different Congestion Levels for Call-on Service.

5.3. Relation between Number of Stops, Headway and Fleet Size.

The relationships between the number of stops and headway, and fleet sizes for local and call-on service are shown in figure 8 and figure 9 respectively. From figure 8, it is seen that for a given fleet size headway increases with number of stops in either congested or without congestion route. And as congestion levels increases the slope of curves becomes more stepper with increases of number of stops. It means headway increases more sharply with congestion in comparison with without congestion. So, the passenger generation also increases with congestion level as the headway increases. Therefore, to serve a transit route with a constant fleet size the capacity of the vehicle must be increases with the number of stops as well as with the level of congestion. In comparison within figures 9 (a), (b) and (c) it is observed that with increases of fleet size the slope of curves diminishes and the effect on headway become very small for large number of stops. It means, as larger the fleet size the effect of headway on number of stops and congestion becomes small for call-on service.

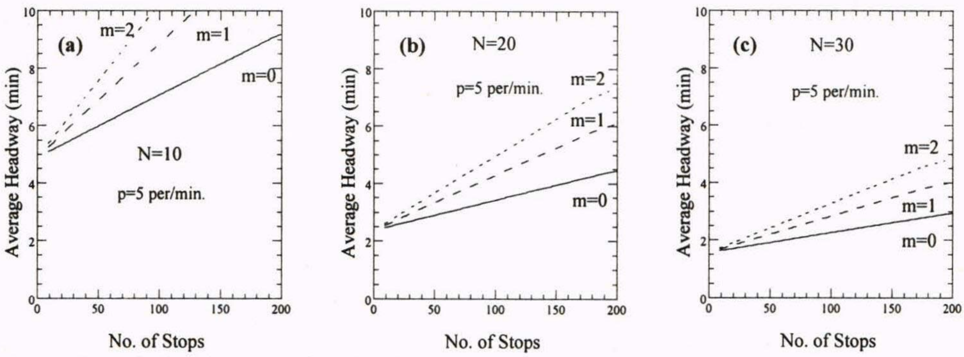

Figure 8. Relation between the Number of Stops and Headway for Fleet Sizes (a) $N = 10$; (b) $N = 20$ and (c) $N = 30$ at Different Congestion Levels for Local Service.

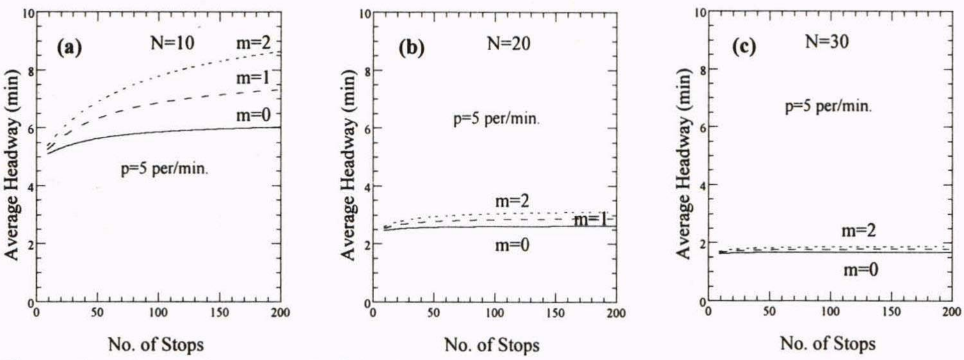

Figure 9. Relation between the Number of Stops and Headway for Fleet Sizes (a) $N = 10$; (b) $N = 20$ and (c) $N = 30$ at Different Congestion Levels for Call-on Service.

6. CONCLUSIONS

In this study we defined five types of transit services namely local, call-on, request stop, accelerated and express services based on their stopping criteria for DMA and developed their users travel time models in considering en route traffic congestion or obstacles. We performed detailed analysis for local and call-on services and showed parametric interrelationship and interdependency in graphical form.

The described model proved to be efficient in the sense that the results obtained in the simulation reflect correctly the interrelation between the variables. It means that for different cases and situations the model was able to represent the dynamic behavior of the characteristics involved in the DMA services. This can be observed according to the following aspects detected in our simulation:

1. The minimum user travel time with congestion is always more in comparison with the minimum travel time of without congestion, and it increases more with more traffic congestion/obstacle. So, the optimum stop spacing increases with congestion.
2. Headway decreases with the increasing congestion for a fixed route transit system where number of stop and travel time is fixed. Therefore, its service frequency should be increased with traffic congestion in order to meet-up the passengers' demand.
3. Again, headway increases with the traffic congestion and number of stops for a given fleet size. So, the number of passenger generation for one-way trip also increases with congestion and number of stops. So, the capacity of the vehicle should be increased with the increasing of traffic congestion and number of stops for local service.
4. For short headway and without congestion/obstacle the user travel time asymptotically diminishing without a minimum point for call on service. However, while vehicle faces traffic congestion or ply on long headway the users travel time increases with number of stops as like local service.
5. For a large number of stops the user travel time increases with the increasing of number of stops for local service but diminishes after at some point for call-on service. It means the effect of number of stop after some point becomes negligible for call-on service.
6. For a small passenger volume i.e., in off-peak period the request stop and call-on services are suitable as the number of stops related with travel time.
7. With the increasing of passenger volume the number of stopping eventually increases for call-on service and become equal to number of stops, i.e., local service. So, the local service is suitable for increasing demand. However, to provide a fast and peak demand service express and accelerated service is suitable along with local service, specially, for long distance passengers.
8. With the increasing of headway and passenger volume the optimum number of stops that minimizes user travel time decreases for local and call-on service. Optimum number of stops for minimum user travel times decreases with the increasing of en route congestion/obstacles levels i.e. increasing stops spacing.

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