OPTIMIZATION OF DHAKA'S MASS TRANSIT SERVICES FOR MINIMUM TOTAL COST.

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1. Introduction

This model has been developed almost simultaneously with its application. Therefore actual conditions of DMA's transit services is reflected here. The number of stops and stop spacings and traffic congestion have remarkable affect on the vehicle operating speed that effect vehicle travel time i.e., cycle time, which in turn affects the fleet size requirements and hence the operating cost of the service. Again, the number of stops and traffic congestion has inverse relationship with the operating speed. Therefore, there exists an optimum relationship between the number of stops and fleet size that minimizes the vehicles operating cost, capital cost and user travel time cost

User travel time cost depends on the access/egress time and modes, waiting time at stops, in-vehicle riding time and transit fare. This cost increases with increasing headway as the waiting time and boarding/alighting time increases with headway. On the other hand, fleet size is inversely related to the headway increases, thus, operating cost decreases with increasing headway. So headway makes a trade-off between the user travel time costs and fleet size requirements. Again since the fleet size and vehicle capacity could be expressed in terms of headway, we would like to optimize the headway first and then determine the corresponding fleet size and vehicle capacity for local and call-on service.

The optimization of various physical and operational aspects of public transportation systems has been the subjects of several studies. Vuchic (1966) analyzed optimal station locations for two different criteria. Byrne and Vuchic (1972) analyzed the problem of finding minimum cost line positions and headway. Lesley (1976) analyzed the bus stops spacing for minimum user cost and minimum total cost. However, his findings that the optimal spacing should be 50m during peak periods and 200m at other times are flawed in two aspects. These unrealistic results come from several incorrect assumptions like he assumed that the bus service area is defined by circles around each stops with a radius of one-half of stops sapcings.

The purpose of this study is to establish the optimum relationship between transit parameters and determine the optimum combinations of number of stops, headway and fleet size that minimizes the total cost (user cost plus system operating cost) for varieties of transit services of DMA. Where slow moving motorized vehicles and non-motorized rickshaw are playing in the same roads with transit services and causes of several up-downs of transit speed as many times it faces slow moving small transport and rickshaw on en route. This study further identifies the factors, which influence the optimum parameters.

Key Words: Mass Transit Modeling, Transit Demand, Optimization

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2. Model Development

In this study we would like to develop total cost model for varieties of transit services such as local, call-on, request stop, accelerated and express services by correlating the vehicle dynamic characteristics, en route traffic congestion, transit performance parameters, and user travel time cost and system operating cost. However, in this paper we will develop total cost model for local, call-on and request stop service and but formulate the headway model and combination of headway and number of stops model for optimization of local and call-on service to minimize total cost as described below.

(1) Cycle Time and Fleet Size

Cycle time is the mean time for a vehicle to complete the round trip including the time spent at each terminal, terminal time T_t. Assuming vehicle travel time and terminal time are same in each direction, so we could find the cycle time θ is twice the sum of vehicle travel time and terminal time, i.e.,

$$\theta = 2(T_r + T_t) \quad (1)$$

Where, T_r is the vehicle travel time for entire route length L.

Let N is the fleet size i.e., number of vehicles serve the route. So the average time headway between the vehicles $h = \theta/N$. Therefore, the fleet size,

$$N = \frac{\theta}{h} = \frac{2(T_r + T_t)}{h} \quad (2)$$

Now the vehicle travel times for local, call-on and request stop services can be formulated [7] respectively as:

$$T_r^l = n^l \xi + L/V + 2ph\mu \quad (3)$$

For $S = L/(s-1) = L/n^l > S_c$

$$T_r^c = n^c \xi + L/V + 2ph\mu \quad (4)$$

For $S = L/n^c > S_c$

$$T_r^r = n^r \sqrt{2(m+1)S_d(a+b)/ab} + 2ph\mu \quad (5)$$

For $S_d = L/n^r = Lc/2ph < S_c$

Where, $\xi = \sqrt{2(m+1)S_c(a+b)/ab} - S_c/V$; $n^l = (s-1)$;

$$n^c = (s-1)\times\left(1-e^{\frac{-2ph}{(s-1)}}\right);\ n^r = 2ph/c;$$

T_r^l, T_r^c and T_r^r are the respective vehicle travel times for local, call-on and request stop service while the vehicle faces m times traffic congestion/obstacles at equidistant within two adjacent stopping for a moment and n^l, n^c and n^r are their respective number of stopping. And, a and b = linear rate of acceleration and deceleration; s = total number of equidistant stops including terminals; V = average cruising speed of the vehicle; l = average users in-vehicle travel distance; μ = average boarding or alighting times per person; S = average spacing distances between two stops, where $S \geq S_c$, S_c is the critical distance; S_d = average spacing distances between two stops $S_d \leq S_c$; p = the mean number of trips generated per unit time; c = average number of passengers simultaneously board or alight at a single stopping for request stop service.

By using equation (2), (3), (4) and (5) we can express fleet size for local N_l, call-on N_c and request stop service N_r as under:

$N_l = 2\left(n^l\xi + L/V + 2ph\mu + T_t\right)/h$ ----------------------------(6)

$N_c = 2\left(n^c\xi + L/V + 2ph\mu + T_t\right)/h$ ----------------------------(7)

$N_r = 2\left(n^r\xi + L/V + 2ph\mu + T_t\right)/h$ ----------------------------(8)

(2) Total Cost

The total cost C_t per unit time is assumed to consists of users travel time cost per unit time C_u and the system operating cost per unit time C_o, which can be expressed by:

$C_t = C_u + C_o$ ---(10)

However, user travel time costs consists of four elements of cost-----access and egress time cost, waiting time cost, riding time cost and fare to access/egress modes and transit service. We could define the values of unit access/egress time ψ_e, waiting time ψ_w and riding time ψ_m, and the total user travel time cost per passenger per unit time could be expressed as:

$C_u = T_e\psi_e + T_w\psi_w + T_m\psi_m$ ------------------------------(11)

Where, T_e, T_w and T_m are the average user access and egress time, waiting time and in-vehicle riding time can be formulated (7) as $T_e = L(3-2x)/\{6V_a(s-1)\}$; $T_w = h/2(1+2q)$ and $T_m = l/L(n\xi + L/V + 2p\mu h)$--------(12)

For simplification we convert the all user trip time elements unit values into an equivalent uniform monetary unit value ψ_c taka per hour to calculate the average user's times value and add up the fare paid to transit and rickshaw to determine the average total user time cost per hour.

$C_u = P\psi_c(T_e + T_w + T_m) + PF_b + 0.6PF_r$

$= P\psi_c T_u + PF_b + 0.6PF_r$ --------------------------------- (13)

$$C_u = P\psi_c\begin{bmatrix} l/L(n\xi + L/V + 2p\mu h) + h/2(1+2q) \\ + L(3-2x)/\{6V_a(s-1)\} \end{bmatrix} +$$

$+ PF_b + 0.6PF_r$ ---(14)

Where, T_u is the average users travel time, P is the average passengers volume per hour, and F_b and F_r are the average individual fare paid to transit and rickshaw service respectively. We found (3) 30% passengers access/egress to and from transit service by rickshaw. Therefore, rickshaw fare is account 0.6 PF_r for access and egress.

Again, the system operation cost is defined as the cost per hour for the operation of transit services. Its consists of fixed-cost (head office cost), semi-variable cost (deports) and variable cost (fuel, crew, maintenance etc.). We added up these two variable costs and defined the operating cost as fixed cost and variable cost. The variable cost per hour is the product of fleet size and operating cost per vehicle per hour. Therefore, the total system operating cost per hour of a particular bus route is made up of fixed cost (F) per hour plus total variable cost per hour and can be expressed by,

$C_o = F + NV_c = F + 2V_c(n\xi + L/V + 2ph\mu + T_t)/h$ -----(15)

Where, V_c = average variable cost per hour per vehicle.

3. Model Formulation

In this section we would like to formulate the modes to determine the optimum conditions and interrelation among the transit factors for minimization of total cost. Since the number of stops, fleet size and headway is the very basic parameters of a transit service and others can be expressed in terms of them, so we defined models in terms of headway and number of stops and formulated as under:

(1) Headway Model

The purpose of this model is to determine the optimum headway, fleet size requirement and vehicle capacity that minimize the total cost. This optimization is performed through the minimization of objective function subject to given constraints and the model is formulated as:

Minimize total cost, i.e., $C_t = \{C_u + C_o\}$-----------------(16)

Given Parameters: P, p, L, l, a, b, V, V_a, ψ_c, V_c, $(s-1)$, μ, F, F_b, F_r, m.

Optimized parameters: headway h, fleet size N and vehicle capacity C_v.

(a) Optimization

After substituting the values of C_u and C_o from equation (14) and (15), differentiating the objective function equation (16) with respect to headway h, and setting equal to zero for optimization and solving for the optimum headway. We found the optimum headway h_l^* for local service that minimizes the total cost as:

$h_l^* = \{2V_c(n\xi + L/V + T_t)/[P\psi_c\{2p\mu l/L + (1+2q)/2\}]\}^{1/2}$--(17)

From the equation (17) we could see that the optimum headway is proportional (but not linearly) to the number of stops. It is also seen that h_l^* is inversely proportional to the square root of passenger demand p and user's time value ψ_c.

Again, by substituting the value of optimum headway into equation (6) we could find out the corresponding optimum fleet size N_l^* for local service as:

$$N_l^* = 2\left(n^l \xi + L/V + T_t + 2p\mu h_l^*\right)/h_l^* \text{ ------------------------(18)}$$

Similarly, we find out the optimum headway function for call-on service, which minimizes the total cost.

$$P\psi_c\left[\frac{l}{L}\left\{2pe^{\frac{-2ph}{(s-1)}}.\xi + 2p\mu\right\} + \frac{1}{2}(1+2q)\right] + \frac{2V_c}{h}\left\{2pe^{\frac{-2ph}{(s-1)}}\ \xi + 2p\mu\right\} - \frac{2V_c}{h^2}\left\{n^c\xi + L/V + 2ph\mu + T_t\right\} = 0 \text{ ------------------(19)}$$

This equation determines the optimum headway for call-on service that minimizes the total cost. However, this equation can not solve analytically. Therefore, we solved this equation by numerical analysis and determine the optimum headway h_c^* for call-on service. Similarly, we determined the corresponding optimum fleet size N_c^* by using equation (7).

(2) Number of Stops and Headway Model

The objectives of this model is to determine the optimum combinations of number of stop, headway, and fleet size that minimizes the total cost for a given vehicle dynamic characteristics, congestion levels and transit line for local and call-on service. The model is formulated as:

Minimize total cost, i.e., Min. $C_t = \{C_u + C_o\}$------------(20)

Where, $C_u = P\psi_c T_u$ (Number of stops, Headway)------(21)

And, $C_o = F + V_c N$ (Number of stops, Headway)------(22)

Given Parameters: P, p, L, l, a, b, V, V_a, ψ_c, V_c, μ, F, F_b, F_r, m.

Optimized parameters: number of stops $(s-1)$, headway h, and fleet size N (number of stops, headway).

(a) Optimization

After substituting the values of C_u and C_o from (21) and (22), differentiate the objective function equation (20) with respect to $(s-1)$ and h, and setting equal to zero for optimization. And solving for combination of optimum headway and number of stops we found the followings two equations for local service.

$$P\psi_c\left[l/L.\xi - L(3-2x)/\{6V_a(s-1)^2\}\right] + 2V_c\xi/h = 0 \text{ ----(23)}$$

$$P\psi_c\{2p\mu\, l/L + (1+2q)/2\} - [n\xi + L/V + T_t]2V_c/h^2 = 0 \text{ (24)}$$

Similarly, we found the equations for call-on service as:

$$\xi\left\{1 - e^{\frac{-2ph}{s-1}}\left(1 + \frac{2ph}{s-1}\right)\right\}\left(P\psi_c.\frac{l}{L} + \frac{2V_c}{h}\right) - P\psi_c.\frac{L(3-2x)}{6V_a(s-1)^2} = 0 \text{ ---------------(25)}$$

$$P\psi_c\left[\frac{l}{L}\left\{2pe^{\frac{-2ph}{(s-1)}}.\xi + 2p\mu\right\} + \frac{1}{2}(1+2q)\right] + \frac{2V_c}{h}\left\{2pe^{\frac{-2ph}{(s-1)}}\ \xi + 2p\mu\right\} - \frac{2V_c}{h^2}\left\{n^c\xi + L/V + 2ph\mu + T_t\right\} = 0 \text{ -----(26)}$$

Now, simultaneous solving of equation (23) and (24), and (24) and (25) for $(s-1)$ and h will gives the optimum combination of number of stops and headway that minimizes total cost for local and call-on service respectively. We determined those optimum values by numerical analysis and the results are represented graphically in the results and discussion section. By substituting the values of optimum headway and number of stops in equation (6) and (7) we found the corresponding optimum fleet sizes for local and call-on service.

4. Results and Discussions

The results obtained from numerical analyses are illustrated graphically to understand the interrelationship between the basic parameters and their significant influences on each other. We also analyzed the behavioral changes between the parameters at different levels of en route traffic congestion/obstacles. We performed these qualitative and quantitative analyses based on the following assumed parametric values, unless otherwise specified.

Route length $L = 20$Km; Average users travel distance $l = 12$ km; Vehicle cruising speed $V = 30$ 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 $q = 0.2$, ψ_c =250taka/hr and V_c = 20taka/hr.

(1) Headway and Number of Stops Model

The relationship between the optimum combinations of number of stops, headway, and fleet size for minimum total cost of local service at congestion levels (a) $m = 0$ and (b) $m = 2$ is shown in figure1. From this model a sets of optimum parameters (headway, number of stops and fleet size) can be determined simultaneously, as needed in design criteria for minimum cost. It is observed that the optimum headway continues to decreases gradually as demand increases. Since the optimum number of stops becomes constant for large demand, therefore, optimum headway and optimum fleet size decreases continuously with increasing demand. In comparison with figures 1(a) and 1(b) it is clear that the optimum headway and fleet size does not influenced significantly as the congestion increases. However, optimum number of stops remarkably decreases with increase congestion/obstacles. Conversely, when the optimum number of stops is specified for a fixed route transit system the optimum headway and vehicle capacity must be increases with the increasing congestion to meet up increasing demand.

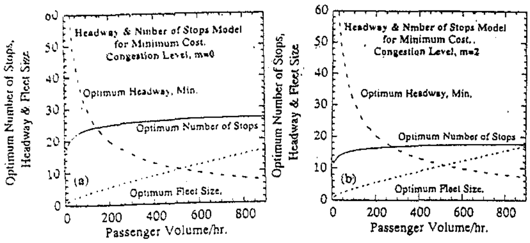

Figure Number 1. Relationship between the Optimum Combinations of Number of Stops/20km, headway, and Fleet Size for Minimum Total Cost for Local Transit Service at Congestion Levels (a) $m = 0$ and (b) $m = 2$.

(2) **Headway Model**

The relationship between the optimum headway, and fleet size and corresponding user travel time that minimizes total cost for local service at congestion levels (a) $m = 0$ and (b) $m = 2$ is shown in figure2. When the number of stops and user travel time is given for a local transit route, we could determine the optimum headway and fleet size, from this model, which minimize the total cost. It is observed that optimum user travel times decreases with increasing passenger demand as the optimum headway decreasing. Again, the optimum headway increases and fleet size decreases with increases of user travel time. In comparison with figure 2(a) and 2(b) we could see that the optimum user travel time increases with traffic congestion. So, the frequency of service has to be increased from the scheduled headway to reduce user travel time during congestion i.e., in peak periods

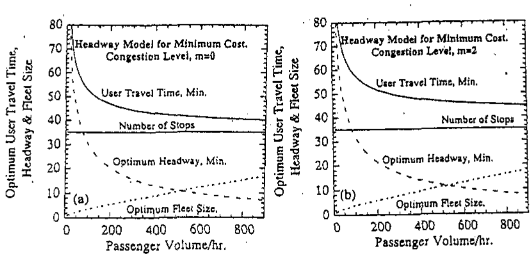

Figure Number.2 Relationship between Optimum User Travel Time, Headway, and Fleet Size for Minimum Total Cost for Local Transit Service at congestion levels (a) $m = 0$ and (b) $m = 2$.

5. Conclusions

.One of the most significant findings resulting from the numerical analysis is that the optimum headway, users travel time and optimum number of stops that minimizes total cost are quite sensitive to the vehicle dynamic characteristics, passengers generation rates, and traffic congestion for a fixed route transit system. It is found from headway model that the optimum headway is inversely proportional to the square root of passenger demands and user's time unit value for local service. And users travel time significantly increases with traffic congestion. Therefore, users travel time can be reduced during congestion, i.e., in peak periods by increasing service frequency and vehicle capacity. Again, from the headway and number of stops model its revealed that the optimum headway continues to decreases gradually as demand increases and conversely fleet size increases with demand; the optimum number of stops remarkably decreases with increases en route traffic congestion/obstacles. Further, for increasing passenger demand the number of stops increasing and become constant at some point, but the headway decreases continually with increasing demand to meet-up increasing passenger demand. On the other hand, for a small demand the number of stops practically becomes very large and it's become too sensitive towards change in passengers demand.

Although, these models have been developed under some limitations of assumptions these optimization procedures represents conceptually accurate algorithms and simulation results reflects the correct interrelation between the variables. Therefore, in practice it can be very useful and effective planning tool for solving existing problems of DMA's transit systems.

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