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Calibration of Transit Operations Planning Model and Evaluation of Bus Transit Route Performance in Riyadh

P.A.Koushki[#], G. A. Ali[*], and Y. A. Al-Nuaim[+]

[#]Department of Civil Engineering, Kuwait University, P.O. Box 5969 Safat, Kuwait 13060: [*]Department of Civil Engineering, College of Engineering, Sultan Qaboos University, P.O.Box 33, Al-Khod 123, Muscat, Sultanate of Oman; and [+]Planning Department, Municipality of Riyadh, Riyadh, Saudi Arabia

تحديد دالات تشغيل شبكة النقل العام وتقييم أدائها في الرياض

بارفيس أمير كوشكي ، وجلال عبدالله علي ، ويوسف عبدالله النعيم

خلاصة : توفر نظم النقل العام حرية الحركة لقطاع كبير من مواطني الحضر بادنى تكلفة ، وأقل اثر سلبي على البيئة وبالرغم من أهمية هذا النظام الخدمي فإن معظم شبكات ونظم النقل الجماعي تعاني عالميا من نقص مادي لتواجه الاعتماد بدرجة كبيرة على الدعم الحكومي لاستمراريته وكرد فعل للقصور الواضح ، وشح الموارد المالية ، وقلة الدعم فقد اضطرت إدارات النقل العام للتفكير في السبل الكفيلة لرفع كفاءته التشغيلية والخدمية ، وليست إدارات النقل العام في المملكة العربية السعودية بمعزل عن هذه المنظومة . وتهدف هذه الدراسة إلى تقويم أداء عينة من قطاع النقل العام الخدمي في مدينة الرياض بالسعودية ، وقد تم استخدام برامج الحاسوب لتحليل الدالات التشغيلية لنظام النقل العام والمتعلقة بخطوط السير ، وسعة الحافلات ، والجدول الزمني للرحلات ، وتعرفة النقل . ولكي يتضمن النموذج التحليلي المتغيرات الاجتماعية والاقتصادية والثقافية لمستخدمي النقل العام في مدينة الرياض بالمملكة العربية السعودية ، تم تحديد متغير نسبة الزمن إلى التكلفة والمتعلقة بالطلب على النقل العام بالإضافة إلى زمن الرحلة بالحافلة والسير على الأقدام . وقد توصل البحث ودراسة تقويم اثر المتغيرات في نظم تشغيل النقل العام إلى ان تغير عوامل التشغيل لم يؤد إلى تحسين الوضع ، ويمكن رفع كفاءة الشبكة بإدراج العوامل ذات الصلة بالتكلفة والزمن : كالاستعانة بحافلات صغيرة الحجم والتعديل في برنامج التشغيل .

ABSTRACT: Public transit systems provide mobility for a large percentage of urban residents very cost-effectively and with minimum negative impact on the environment. In spite of their vital and indispensable services, however, the majority of transit systems worldwide suffer from financial neglect and are forced to rely heavily on government subsidies for survival. In response to the rapidly shrinking funds and subsidy levels, transit managements have to focus attention on ways to improve service operations. The management of public transit systems in Saudi Arabia is no exception to this trend. This study is aimed at evaluating the service performance of a sample of regular (fixed-route, fixed-schedule) bus transit routes in Riyadh, Saudi Arabia. Utilizing a microcomputer-based program, the bus transit service operational measures of fare, headway, vehicle size and routing were analyzed. To account for the socio-economic and cultural differences of transit ridership in Riyadh, time/cost elasticities of demand as well as walk time and bus travel time parameters of the model were calibrated. Evaluation of the impact of changes in service operational measures suggested that no change in operational variables could improve the very low productivity of one of the sample study routes. A cost-reduction strategy which includes the use of smaller vehicles and less-frequent service runs should improve the low productivity of this route. Findings also indicated that a small increase in fare would pay for the total operation and maintenance costs of the other routes. The authors, however, do not recommend an increase in fare for a variety of reasons: the low income level of the captive riderships, the enormous financial resources of the country, and the multi-dimentional role of transit systems in providing urban mobility with minimum negative impacts on the environment.

This paper presents the result of a research study designed to evaluate the impact of changes in service attributes on the productivity of a sample of bus transit routes in Riyadh, Saudi Arabia. The evaluation of service measures was performed utilizing a microcomputer-based evaluation program.

In spite of the positive impact of public transit systems on urban land use development (Vuchic 1991), quality of life (Pucher 1988), and its importance in providing mobility and accessibility to employment opportunities (Newsom et al. 1991), urban public transportation modes are now threatened with complex financial difficulties (Pickrell 1983, Technology Sharing 1985). The majority of urban transit systems worldwide rely heavily on government subsidies for survival (Koushki and Barry 1989, Talley 1991). The causes of current transit system problems in the western developed nations were addressed in a meeting of transport and transit specialists in the U.S. (Transportation Research Board, TRB 1983). Transit problems were categorized into three broad classes: societal conditions and trends, government policy and subsidy, and management shortcomings. The first category of societal conditions and trend-related factors included: rising income and decentralization of urban activities; recession, fuel, and other price increases; skewing of government policies relating to land development in favor of the auto and highway use; and lack of interrelationship between transit and planning for related activities such as land use control, traffic controls, and community facilities. Factors in the second category included the creation of a large-scale operating subsidy program with little attention to productivity, and rapid increase in the number and complexity of government requirements. Management shortcomings, the third category, included such factors as ineffectiveness of management/skilled employees training programs; emphasis on satisfying political constituencies by expanding service without demand justification; insufficient attention to new markets and new forms of complementary services; and lack of attention to the potential of various forms of paratransit systems. Of these factors, those in the third category, are the ones most commonly observed in the management of transit systems in developing nations. Curtailing transit services to minimize costs may provide for a simple short term solution alternative. However, in the long run, this alternative usually results in a further decline of ridership and loss of revenues. Operational changes aimed at improving service productivity and efficiency, on the other hand, are emerging as one of the most promising policy alternatives for the improvement of cost effectiveness of public transportation systems (Obeng et al. 1986, MacDorman 1988).

A number of policy variables are available to transit managements for service operation improvements. These include service frequency, number and spacing of bus stops, routing, fare (Guenthner and Jea 1985), marketing (Walb and Booth 1985), management and administration (Turnquist et al. 1983), and technology (Stephanedes 1980). The development of microcomputer-based programs in recent years has also facilitated the search for, and evaluation of, these service operating strategies. The Transit Operations Planning (TOP) model used in this study represents one such model system (Turnquist *et al.* 1983).

In Saudi Arabia, enormous revenues from oil over the last two decades have brought rapid and unprecedented change and development in socio-economic infrastructures. The first (heavily government-subsidized) public transport company, SAPTCO, for example, was only established in 1979 (SAPTCO 1987). The availability of historical information and data on the performance and productivity of the public transit systems in Saudi Arabia is, therefore, very limited (Al-Nuaim 1989). With the depletion of financial reserves due to the recent wars of the Arabian Gulf, combined with the sudden drop in oil revenues worldwide, Saudi Arabia's bus transit system company is now suffering from downsizing and cutbacks in its budget.

In contrast to the public transit system, the individual driver-owned and operated minibus paratransit system in Riyadh has been enjoying long-term financial success. This positive phenomenon has been found to be a function of a number of factors. Chief among them are the system's tailoring of its service to meet the needs of the demand, the expansion in the seat capacity of its vehicles, the individual ownership/operation of its vehicles by the drivers, and the system's service operation type: flexible-route, flexible-stop, and flexible-schedule (Koushki 1984).

In another recent unpublished study dealing with a comprehensive survey of demographic, transportation, land-use, and economic characteristics of Riyadh, data were also collected on ridership traits of the SAPTCO urban transit system (RDA 1987). Important findings of the study included the following: a) less than 3.5 percent of daily trips in Riyadh were made by public transit systems, and b) more passengers were carried by the mini-bus paratransit than by SAPTCO bus transit (38,000 versus 34,000) per day.

The productivity of a selected number of SAPTCO bus transit routes in Riyadh was also evaluated in a recent study. Findings of the study indicated that the application of life-cycle route cost and revenue analysis may clearly distinguish the efficient and inefficient transit routes (Koushki and Barry 1989). Life-cycle analysis was recommended as a mechanism which could play an important and useful role in long-range planning, budgeting and policy analysis of a bus transit system, especially those with fluctuating levels of costs and revenues, which is the case in most rapidly developing countries.

Operational Characteristics

SAPTCO provides both inter-city and intra-city bus transportation in ten urban areas. These include: Jeddah, Riyadh, Makkah, Madinah, Dammam, Taif, Qasim, Hofouf, Abha, and Yanboa. The system operates a fleet of 1,100 buses (291 buses in Riyadh) and has manpower of 3,431 (made up of at least 16 nationalities). There are a total of 106 bus routes, 19 of which serve the capital city of Riyadh (SAPTCO 1988). An analysis of the annual kilometers of operation (supply), and riderships (demand), for the system's inter-city (public transit) services nationwide pointed to the lack of adjustment between demanded riderships and the supply of transit services. For example, while the number of passengers, both

TABLE 1

Summary of Route Data Surveys for the Study Routes

Route Characteristics	Route Name		
	Batha-Naseem	Atigah-Sulimania	Batha-Ulayyah
Length, km (Round Trip)	52	28	18
Route Fare (SR)[a]	3.0	2.0	2.0
No. of traffic signals	30	16	19
Population density[b]	Med - Low	High - Med	Low - Med
Area income level[b]	Low - Med	Med	High
Mean No. of buses	9	6	14
Mean daily service round trips	6	9	5
Mean passengers per round trip[c]	39.2	27.9	20.3
Mean headway (min)	19.0	18.5	14.5
Mean daily passengers[c]	2,118	1,519	1,399

[a] US $ 1.0 = SR 3.5

[b] RDA (1987)

[c] SAPTCO (1987, 1988)

nationwide and in Riyadh, declined rather significantly between 1985 and 1990, the vehicle-kilometers of operation increased over the same time period. The successful service completion of the paratransit systems in urban areas has been cited as the main cause for the ridership decline of the bus transit system (RDA 1987). Further analysis of the data also showed that while the number of passengers declined by 9.1% and the system's total revenue decreased by 5.9%, the kilometers of operation and the peak hour fleet size, both increased by 6.3% and 7%, respectively (SAPTCO 1988).

Evaluation of Alternative Services Strategies

A number of bus routes in Riyadh were evaluated to examine alternative service strategies such as fare, frequency of service (headway), and rerouting, as well as their effects on cost, ridership, and revenues. The analysis was performed utilizing the TOP model program. A set of criteria was established to facilitate the selection of sample bus routes. These included the general socioeconomic status of ridership (income levels, marital status, expatriate/Saudi, etc.), the population density of the transit corridor (high, medium, low) and the length of the route (long, medium, short). Using these criteria, in conjunction with an analysis of SAPTCO's route structure and discussions with its managerial staff, the following representative bus routes were selected for the study: Al-Batha/Al-Naseem (long, medium density, low income), Al-Atigah/Al-Sulimania (medium length, high density, medium-high income), and Al-Batha/Al-Ulayyah (short, low density, and high income). Table 1 presents the locational, operational, area socioeconomic, and ridership characteristics of these study routes.

The Data

Utilization of microcomputer-based TOP model program requires a number of input data files. These include route data (sequence of stops, the seating and standing capacity of vehicles, route segment length, speed limit, number of signalized intersections, number of stops, and the number of boardings and deboardings per bus per segment); the x-y coordinates for each stop; basic unit costs; and finally the choice of demand model. Route-related data were collected via field surveys of each selected bus route. Data concerning unit capital and maintenance/operation costs were obtained from the files of SAPTCO in Riyadh. Revenue information was computed from annual riderships and route fare levels.

To account for hourly, daily, and monthly variations in demand (ridership), each sample route was field-visited during morning peak period (7:00 a.m.-9:00 a.m.), evening peak period (6:00 p.m.-8:00 p.m.), and off-peak period (3:00 p.m.-5:00 p.m.), each repeated three times on three different days of the week. For each route, field-visits covered the six working days of the week - Saturday through Thursday. The data collection was stretched over time to cover an eight-month period. At each field visit, a randomly arriving bus was selected at the route origin stop. Riding in the bus, the required data were recorded until the route destination stop was reached. At least two random buses were monitored during each time period. The operating travel speed for each origin-destination trip was computed from the measured travel time and route length. The data were then averaged to represent the service operational characteristics of a route for a given time period. Table 2 presents the summary result of route data surveys for the sample routes.

TABLE 2

Summary of Route Data Surveys for the Study Routes

Physical and Operational Characteristics	Morning Peak			Afternoon Peak			Off-Peak		
	Batha - Nas.	Atigah - Suli.	Batha - Ulay.	Batha - Nas.	Atigah - Suli.	Batha - Ulay.	Batha - Nas.	Atigah - Suli.	Batha - Ulay.
Route length (km) - one-way	26.0	14.0	9.0	26.0	14.0	9.0	26.0	14.0	9.0
No. of bus stops	21.0	20.0	11.0	24.0	21.0	12.0	22.0	20.0	11.0
No. of signalized intersections	30.0	16.0	19.0	30.0	16.0	19.0	30.0	16.0	19.0
Average travel time (min) - one-way	69.3	36.2	29.8	62.4	43.1	28.7	64.2	36.7	24.7
Average travel speed (km/hr)	22.5	23.2	18.1	25.0	19.5	18.8	24.3	22.9	21.9

The Model

The TOP model has been developed to guide bus transit managements in the search for, and evaluation of, operating strategies that meet local transit service objectives. The model is primarily intended for use on single routes or in transit corridors including a number of serial or parallel routes (Turnquist et al. 1983). A distinctive feature of the TOP model lies in its ability to link the demand and supply components in an equilibrium structure so that the effect of change in any service measure will be reflected in the ridership of the transit route.

The basic components of the TOP model include models of demand, supply, costs and evaluation measures. Six service elements are specified, namely the bus fare, headway, vehicle size, routing, walk time and bus travel time. Specification of these elements determines the initial values for the four basic performance measures (supply model). These performance measures influence, and are influenced by ridership (demand model). This interaction determines the equilibrium between supply and demand for the transit route.

TOP Model Modifications: A review of the model parameter files indicated that a number of parameter values require modification if the characteristics of the area/route under study are to be reflected in the demand and supply models. The default model parameters are based on mean transit system characteristics in several cities in the United States. Model parameter modifications included the following:

a) **Walking characteristics** - The door-to-door travel time for a given transit trip is a function of several time components including access time, wait time, in-vehicle travel time, transfer time, and egress time. In a recent study concerning walking characteristics in central Riyadh, the mean walking speed and the maximum walking distance were found to be 1.1 m/s and 0.54 km, respectively (Koushki 1989). The model default values (1.3 m/s and 0.4 km) were, therefore, modified accordingly.

The mean distance of walk to bus stops also depend upon stop spacings and the density distribution of walk trips originating from, and destined to, the transit market area surrounding each bus stop. Based on the assumption of uniform distribution of trip-end densities over the market area, the expected walking distance to a bus stop may be computed as follows (Turnquist et al. 1983):

$$E[WD] = \frac{12\,WD_{\max}^{2} - S^{2}}{24\,WD_{\max} - 6S} \qquad \text{for } S < 2\,WD_{\max} \qquad (1)$$

and

$$E[WD] = \frac{2}{3}WD_{\max} \qquad \text{for } S \geq 2\,WD_{\max} \qquad (2)$$

where WDmax = Maximum walking distance; S = Bus-stop spacing and E[WD] = Expected walking distance.

b) In-vehicle (bus) travel time - The multiple regression equation for the computation of bus travel time on a given route segment took the following form:

$$T_i = T_i^o + 0.11\, I_i + 1.0\, L_i + 0.22\, N_i + 0.04\, P_i - 2.3 \quad (3)$$

where:

T_i = Mean travel time for segment i (min)
T^o_i = Free-flow travel time on segment i (min)
I_i = Number of signalized intersections on segment i
L_i = Length of segment i (km)
P_i = Mean number of boardings and deboardings on segment i
N_i = Number of stops on segment i

However, since variables such as signal timing, number of stops and passenger loading/unloading characteristics vary rather significantly in Saudi Arabia from those of the United States, the spatial transferability of the parameters of the equation required examination. Using the data collected for the sample routes in Riyadh on segment length, number of signalized intersections, number of loading/unloading stops, and the number of boardings and deboardings, a least square multiple regression model was calibrated and evaluated. The model demonstrated a high predictive ability and was, then, chosen to replace the model-recommended equation for bus travel time. The calibrated regression equation for Riyadh had the following form:

$$T_i = T_i^o + 0.2545\, I_i + 0.01\, L_i + 1.5392\, N_i + 0.06\, P_i - 3.82 \quad (4)$$

where the variables are as defined above.

The resulting t-statistic values for the parameters of the model were as follows:

Variable	Parameter β	t-Statistic
No. of signalized intersections on segment i:	0.2545	18.25
Mean no. of stops on segment i:	1.5392	53.16
Length of segment i:	0.0123	29.51
Mean no. of boarding/deboarding on segment i:	0.0611	6.94

R-square = 0.912; F-Statistic = 54, $p < 0.001$

The coefficient of determination, R^2, for the model was 91.2 % indicating an excellent goodness of fit for the model.

c) Cost parameters - Basic unit cost coefficients are the input requirements of the Cost Model. These include: capital cost per vehicle-km, fuel and maintenance cost per vehicle-km and driver cost per vehicle-km of operation. These data were taken from the files of SAPTCO as input to the model. Utilizing these data and route-level operational data, the program computes the total cost for each route. The total cost is the sum of labour, maintenance, fuel and capital costs. The cost model estimates the short-run incremental costs of service changes, without including overhead costs (administration, insurance, etc.), which would not be expected to change on the short run. The capital cost is expressed as equivalent annual costs over the life of the vehicle (14 years with an engine overhaul during the 9th year of service). There is no parameter calibration in the cost model, since actual transit system-related costs and operational data are input to the model.

d) Other modifications - Two other modifications were also made to the parameter values of the TOP model system. These included modifications to the distributional split of daily trips (by trip purpose) and to demand elasticities.

The prohibition against women driving in Saudi Arabia and the nonavailability of school bus transportation for a large number of school-age children affect the distributional split of these trips significantly (trip chaining). When a father leaves home for work, with an intermediate stop to drop his children, the home-based work trip will change to a home-based nonwork (school) trip. It was therefore, necessary to modify the percent split of home based work, as well as home-based nonwork, trips for Riyadh. Utilizing the data from a recent regional study (MOMRA 1985), the TOP model system parameters were then modified, as shown in Table 3.

TABLE 3

Time/Cost Elasticitis and Distributional Split of Daily Trips

Variable	Parameter Value	
	Model	Riyadh
Split of Daily Trips:		
Home-based work	0.65	0.56
Home-based nonwork	0.38	0.47
Transit Demand Elasticities:		
In-veh. travel time	-0.27	-0.15
Out-of-veh. travel time	-0.54	-0.25
Fare	-0.15	-0.39

The other necessary modification involved is that of the demand elasticity parameters. The model system incorporates three elasticity-related parameters: in-vehicle travel time elasticity, out-of-vehicle travel time elasticity, and out-of-pocket fare elasticity. General knowledge concerning the characteristics of bus ridership in Riyadh indicates that lower elasticities should be employed for the first two elasticity parameters, since the great majority of the bus transit ridership in Riyadh includes low-income expatriate individuals. In general, expatriate low-income bus travelers in Riyadh are found to be less sensitive to both the in-vehicle and the out-of-vehicle travel times, and more sensitive to the fare (cost). Based on a number of lengthy team-work discussions with bus transit consultants in SAPTCO, and members of the Al-Riyadh Development Authority (RDA) transport planning team, a set of travel time and fare elasticities for Riyadh were developed, and the model-recommended elasticity parameters were modified for Riyadh, as presented in Table 3.

MODEL APPLICATION: The goal of the TOP model is to provide the management of bus transit systems with information concerning the impact of changes in service strategies on the system's ridership, costs, and revenues. Important decision variables with likely impacts on service operations, therefore, include fare, headway (frequency), and rerouting. Specific findings as a result of model application are summarized in the conclusions.

a) **Fare:** In general, transit ridership worldwide is sensitive to fare. An increase in fare is usually accompanied by a decrease in ridership. The ridership decrease, however, depends on a number of factors which may include the economic and choice traits of the ridership, the purpose of the trip and, to a lesser extent, the level of service characteristics of the transit system. Due to their very low income levels, the transit ridership in the oil-rich countries of the Arabian Gulf are most sensitive to fare increases and basically insensitive to service characteristics. This is the case in spite of the fact that the majority of transit users in these and other developing nations are captives.

The impact of a fare increase on the system's revenue, therefore, depends on the point-elasticity of the demand curve and the resulting shift in equilibrium flow (lesser ridership paying a higher fare). Typical results of the effect of a fare change on the revenue-cost ratio for Al-Batha/Al-Naseem, Al-Batha/Al-Ulayyah, and Al-Atigah/Sulimania routes are presented in Figures 1, 2 and 3, respectively. The model changes the fare level until the route's cost reaches an equilibrium with the route's revenue. Results indicated that the Al-Batha/Al-Naseem route pays for more than its cost during peak hour operations (figure not shown) and for 88 % of its cost during off-peak hours (Figure 1). Off-peak hour revenues will match the route's cost only with a small fare increase of SR 0.55 - 0.60 (SR3.5 = $1.0), from the existing SR3.00 to SR3.55 or 3.60 (Figure 1). However, due to the impracticability of SR 3.60 in fare collection, a SR 3.50 would be recommended if such an equilibrium achievement is desired.

To achieve revenue-to-cost equilibrium ratios for the Al-Batha/Al-Ulayyah route, a fare increase of SR 8.00 (from the current SR 2.00 to SR 10.00) per ride is required (Figure 2). With the current fare level of SR 2.00, the route's revenue pays less than 30% of its cost,

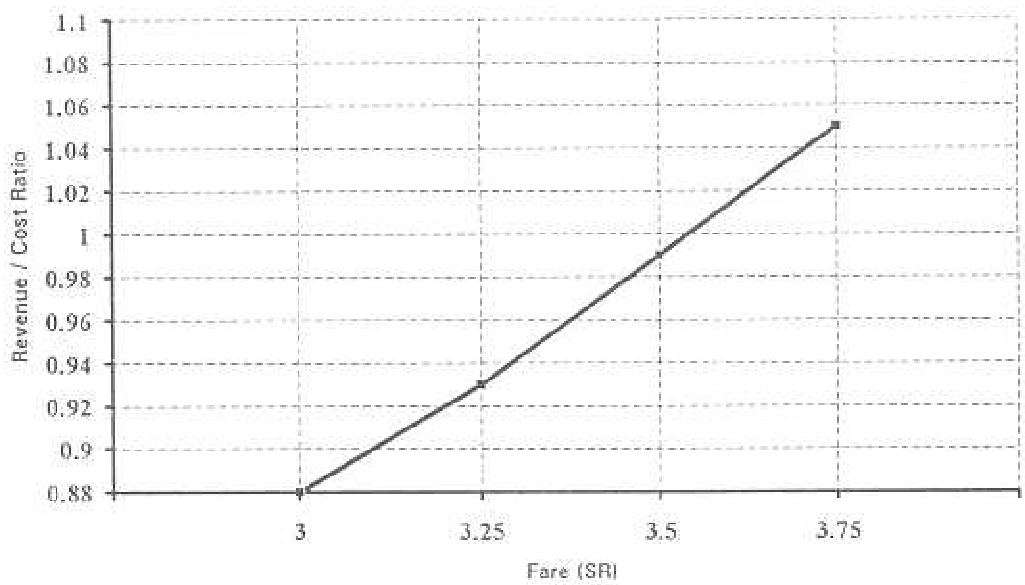

Figure 1. Fare Change and Revenue/Cost Ratio (Batha-Naseem Route, Off-Peak).

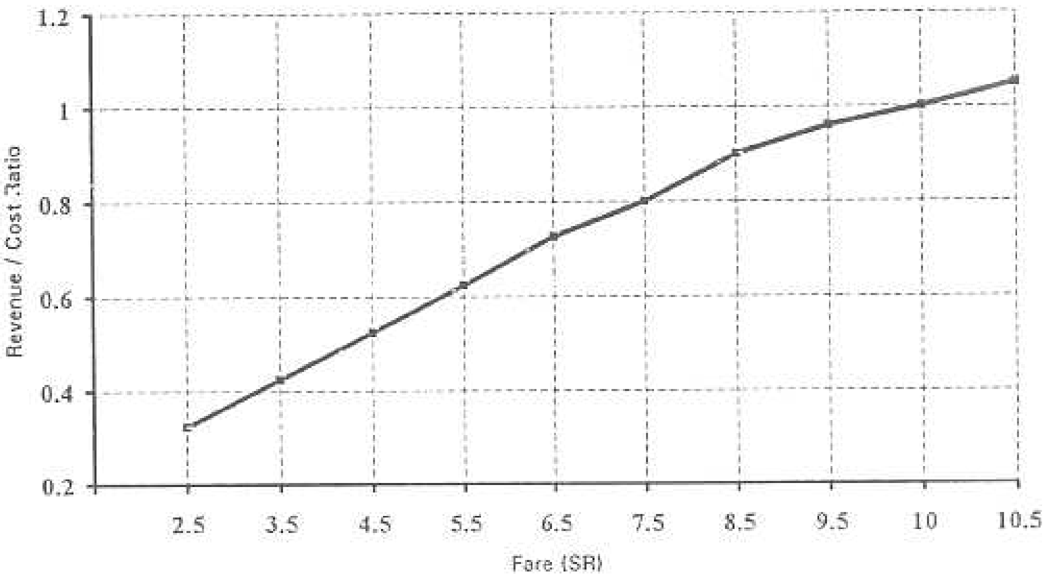

Figure 2. Fare Change and Revenue/Cost Ratio (Batha-Ulayya, Morning Peak).

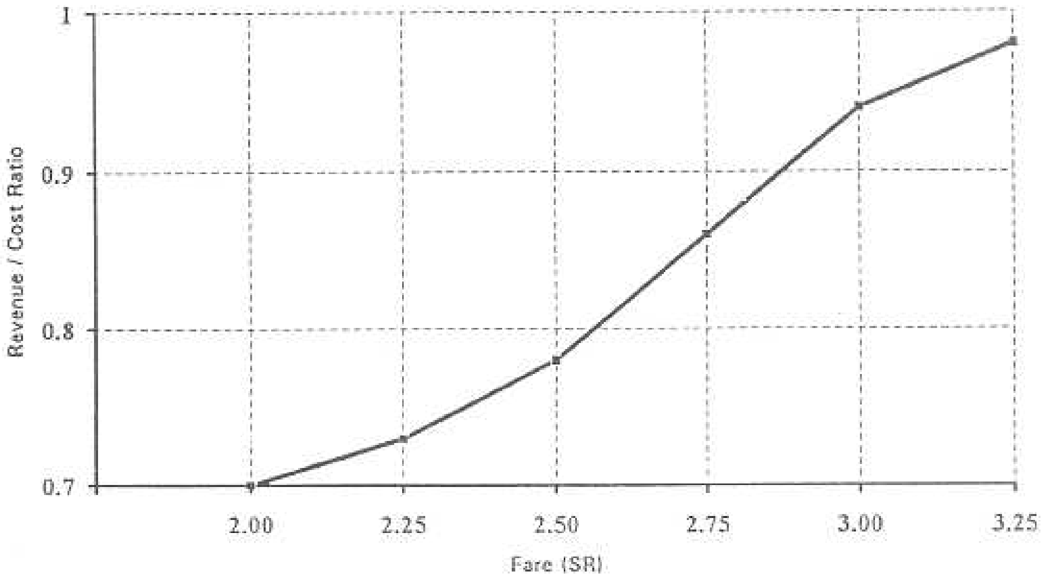

Figure 3. Fare Change and Revenue/Cost Ratio (Atigha-Sulimania, Afternoon Peak).

even during peak hours, The Al-Atigah/Al-Sulimania route, which currently pays for 70% of its cost during peak hours, will require a fare increase of SR 1.25 (from SR 2.00 to SR 3.25) to pay for its cost (Figure 3).

The impact of a change in fare on ridership and revenue per passenger-km were also evaluated for the study routes. An increase in fare was accompanied by a decrease in transit ridership, as well as an increase in the revenue per passenger-km for all routes, as expected. However, the rate of change (increase) in revenue per passenger-kilometer, with respect to a given fare level, was higher than that of the ridership level (decrease), as presented in Figure 4 for the Al-Atigah/Al-Sulimania route. Under such a condition, an increase in fare more than offsets the decrease in ridership and results in an increase in revenues. This was the case for all the study routes.

b) Headway: An increase in headway (reduction in service frequency) is usually accompanied by an increase in passenger waiting time and, consequently, an increase in the overall route travel time. In the urban areas of the developed industrialized nations, transit ridership, in general, is very sensitive to transit travel

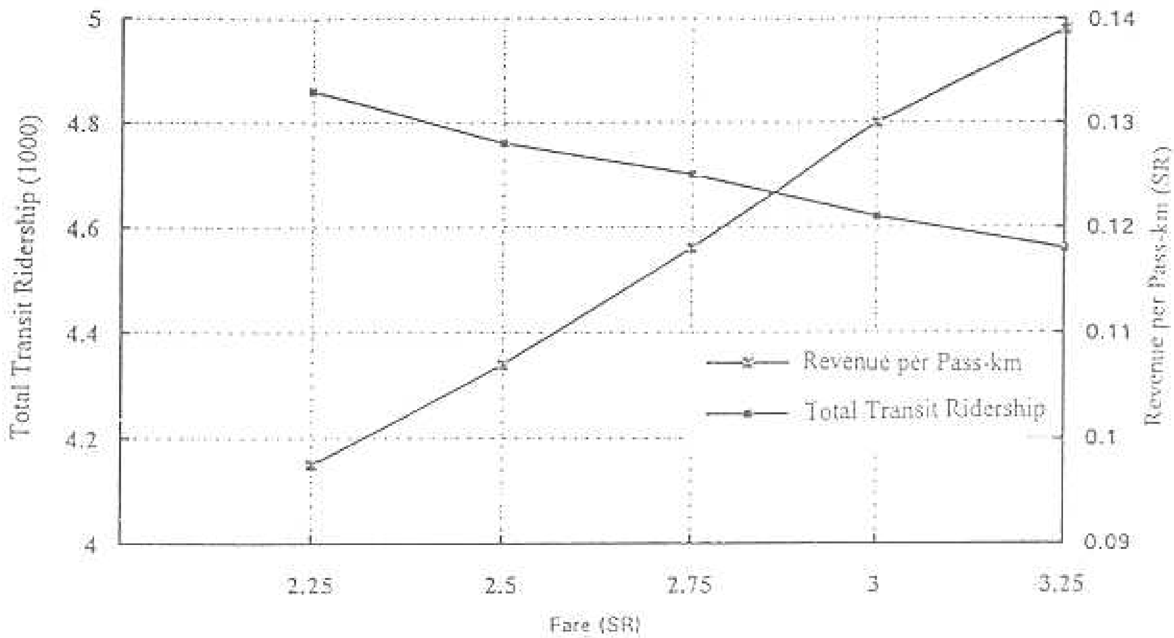

Figure 4. Fare Change, Total Ridership and Revenue per Pass-km (Atigha-Sulimania, Off-Peak).

TABLE 4

Effect of Headway Change on Bus Transit Ridership for the Study Routes (Off-Peak)

Headway (min)	Number of Daily Passengers		
	Batha-Naseem	Batha-Ulayyah	Batha-Sulimaniyah
10	6585	4920	4920
14	6469	4808	4808
17	6373	4650	4650
20	6293	5750	4750

time. An increase in headway is usually accompanied by a decrease in ridership. For the low-income riders of mass transit systems in urban areas of developing nations, however, this is not the case.

As presented in Table 4, the result of the analysis of the effect of change in headway on bus ridership indicated that an increase in bus headway from 10 to 20 minutes during off-peak hours resulted in a decrease of nearly 300 person-trips per day in the Al-Batha/Al-Naseem route, about 90 person-trips in the Al-Batha/Al-Al-Ulayyah route, and 170 person-trips in the Al-Batha/Al-Sulimania route. During the peak period (mostly home-work/work-home trips), the impacts of headway change on bus riderships were even smaller than those observed during the off-peak hour, as expected.

The evaluation of the impact of increasing headway on route's overall travel speed between origin and destination (O-D) indicated that while the reduction in travel speed due to an increase in headway (which increases the out-of-vehicle waiting time, thereby increasing the total travel time) was rather small during the peak hours, that of the off-peak hours was generally significant. As presented in Figure 5, increasing headway from 5 to 12 minutes resulted in 0.2 km/hr reduction in overall travel speed during the peak and 0.7 km/hr during the off-peak hours at the Al-Batha/Al-Naseem route. This was basically due to higher in-vehicle waiting time resulting from more frequent bus stops to satisfy ridership demand. Similar trends were also observed in the other study routes. A major impact of headway increase, however, is the reduction in the running costs of transit routes. The operation and maintenance (O&M) costs are strongly affected by changes in bus headways. The capital cost, on the other hand, is slightly influenced by the change in headways while revenues are not affected (Figure 6), as might be expected.

c) **Re-Routing:** Rerouting is the change introduced in the original path followed by the bus transit. In general, the rerouting of a bus transit route is periodically undertaken to match the supply, and due to likely changes which may occur in urban land-use and the consequential shift in the location of ridership demand

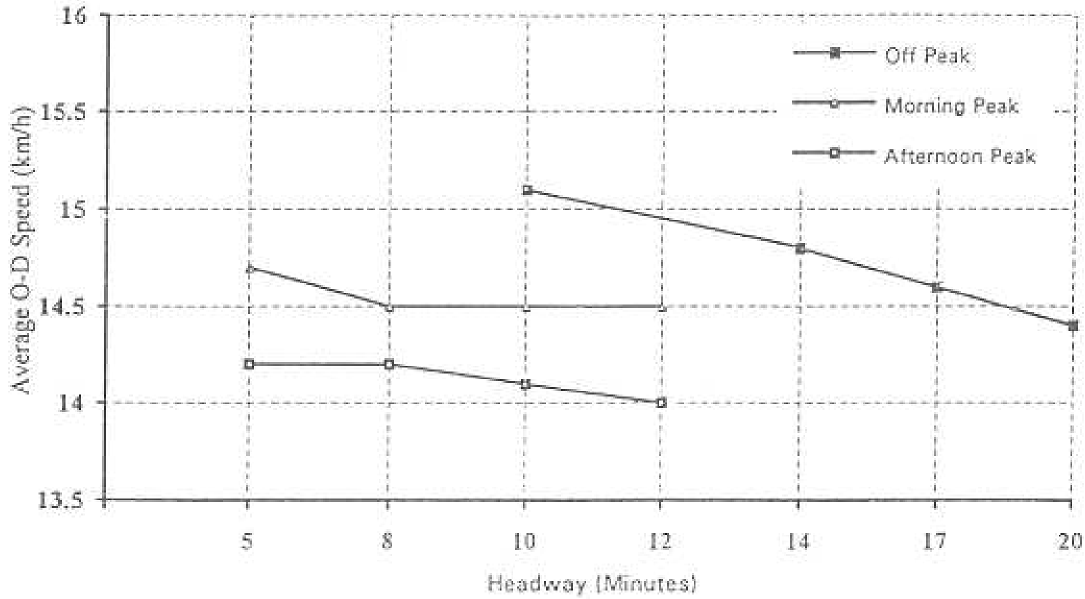

Figure 5. Headway and Mean Travel Speed (Batha-Naseem).

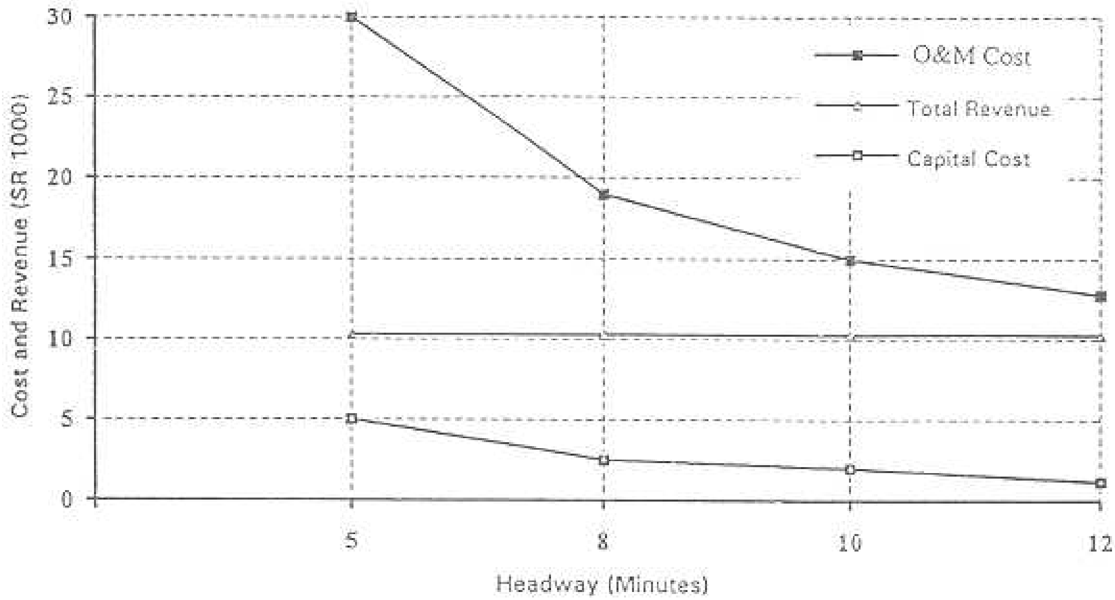

Figure 6. Headway Change, Cost and Revenue (Atigha-Sulimania, Morning Peak).

for bus transit. The TOP model also provides the transit management with the rerouting option. Inputs to the model are the characteristics of the new route segment including length, number of stops, number of signalized intersections and operating speed limits.

The application of rerouting was performed by adding a new segment to the Al-Batha/Al-Ulayyah route (Figure 7). Selection of this route for the analysis was based on its very poor productivity, with a revenue/cost ratio of only 0.32, in an attempt to improve its performance.

The Re-Routing of Al-Batha/Al-Ulayyah resulted in slight improvements in overall travel speed (Figure 8). The slight increase in speed was mainly due to the lower traffic volumes of the re-routed segment. Due to the low land-use density, generally high-income nature of residents in this area, and low level of bus riderships, no change in the transit service characteristics could significantly increase its ridership and improve the very low productivity of this route.

Analysis of the data (not shown) resulting from

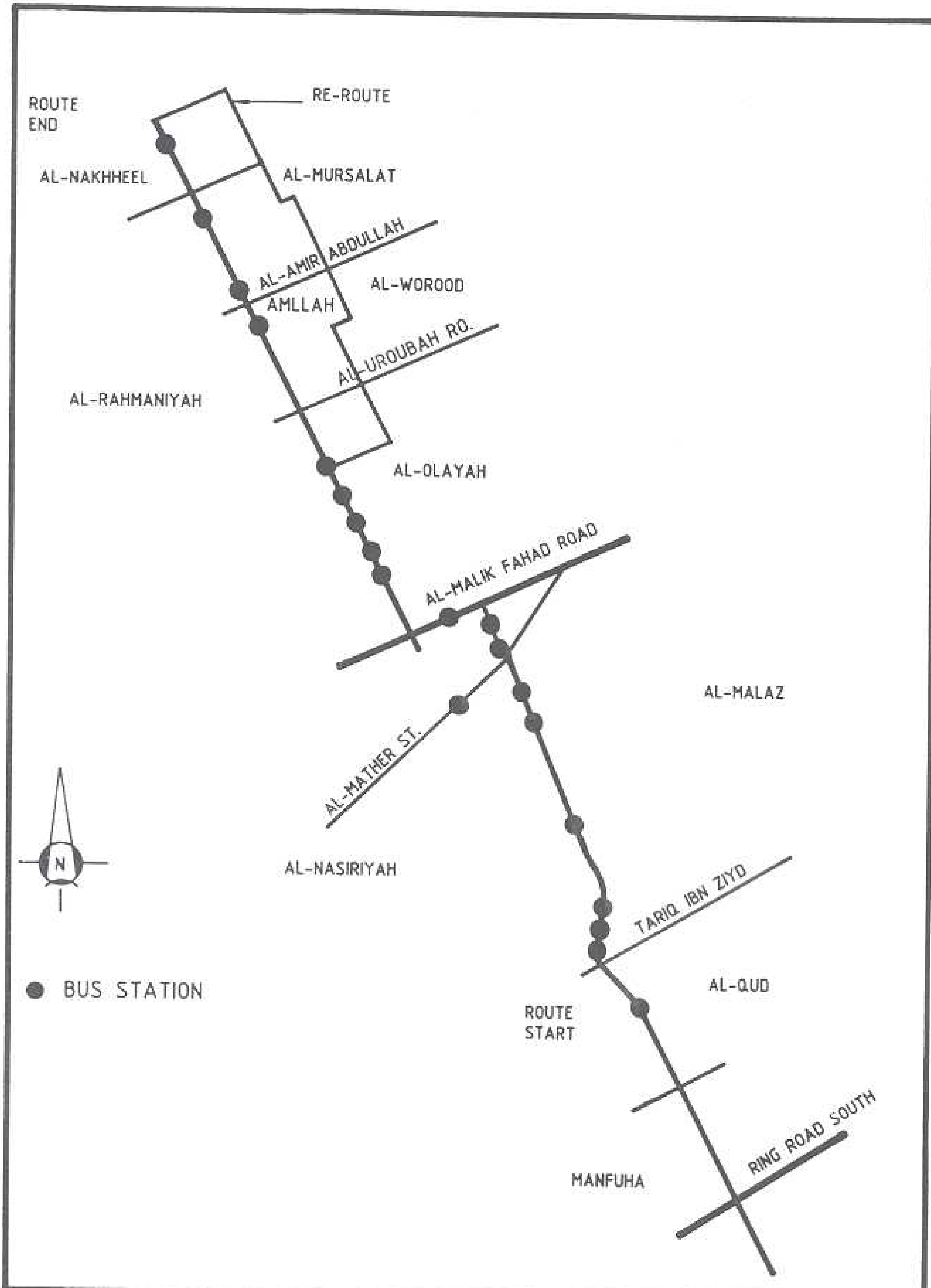

Figure 7. Batha-Ulayya Re-Route.

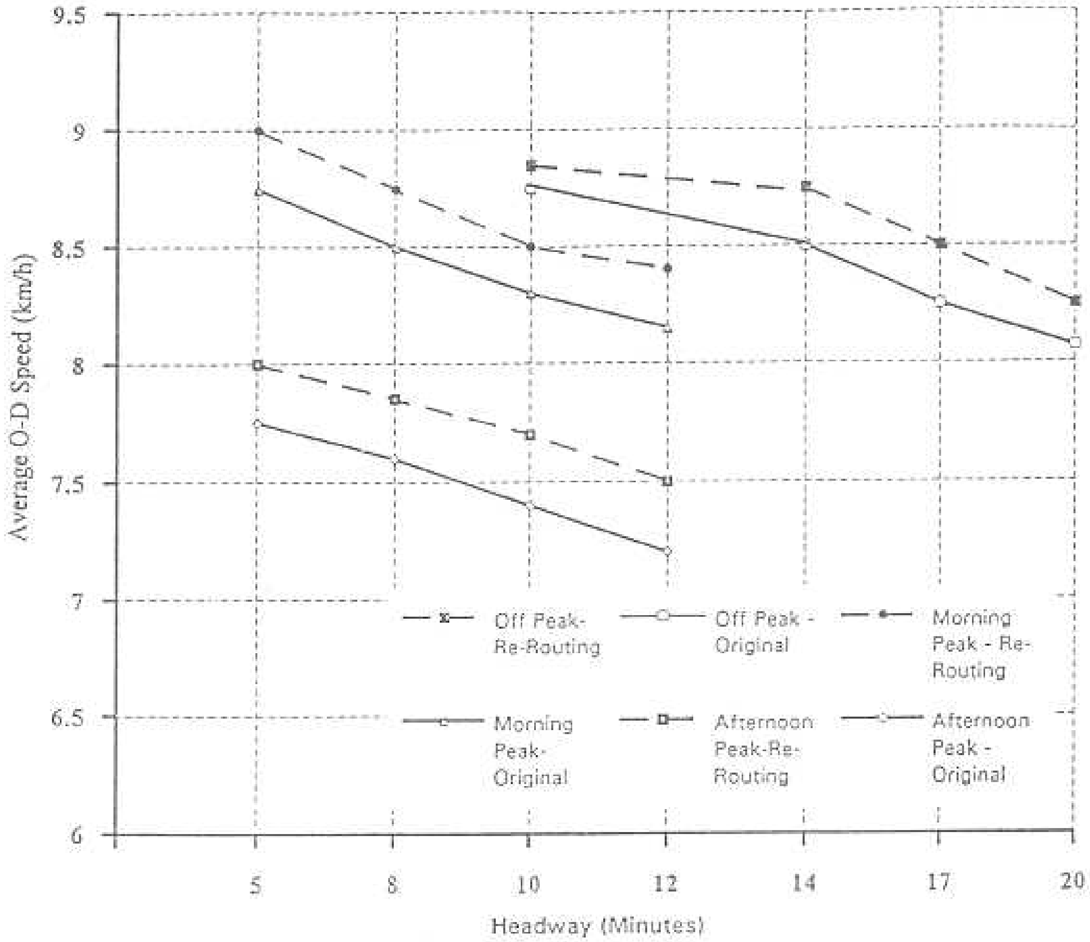

Figure 8. Headway and Mean Travel Speed (Batha-Ulayya).

re-routing indicated the insensitivity of demand (riders) with respect to reductions in headways (bus frequencies). Reducing the headway by 50 %, for example, increased the ridership by less than 100 passengers for the peak period. The change in ridership was even less during the off-peak periods. The main reason for the insensitivity of demand to this significant change in the level of service characteristics stems from the fact that the demand for bus transit services in Riyadh, in general, and in Al-Batha/Al-Ulayyah district in particular, consists of those of the "captive" nature. Regardless of the service characteristics of the transit system, captive riders remain the users of the system due to the lack of any alternative choice of travel mode.

Conclusions and Recommendations

The TOP model is a simple-to-use analytical tool, intended for a quick evaluation of alternative transit service options, employing a number of default parameters in its demand, supply and cost components. These variables are all based on the characteristics of transit systems in the United States. Clearly, these characteristics vary significantly from an industrialized society to a developing nation. The default parameters need to be calibrated and replaced by those reflecting the socio-economic and transit systems characteristics of the area under study.

Modifications to the TOP model for application to transit routes in Riyadh, Saudi Arabia, included those concerning walking characteristics (length and speed), distributional split of daily trips by trip purpose, fare elasticities of travel demand, and cost input factors. With these parameter modifications, the TOP model system may effectively be used to evaluate mass transit service operations in other countries of the Arabian Gulf.

Based on the findings of this study, the following conclusions and recommendations are made:

1. The Batha-Ulaayah route is extremely unproductive. The route serves the area with the highest income and lowest residential density. No change in the service variables could improve the productivity of this route. The regular transit

service should be offered by smaller/less costly vehicles (minibuses), and with lower service frequencies, especially during off-peak hours.

2. Small increases in fare for the other two study routes resulted in increases in route revenues. The total operation and maintenance costs of the routes can be covered fully by this additional income. However, when considering the low-income nature of the SAPTCO bus ridership (captive expatriates), the enormous financial resources of the country and the deteriorating urban environment due to heavy auto use, increasing bus transit fares may not be a good policy to implement.
3. In most areas of developing nations, bus transit riders include mostly the "captive" submarket. Attempts should be made to attract ridership from the "choice" submarket. Use of marketing techniques, improvements in the level of service of transit systems, and application of pricing mechanisms to parking, gasoline, and tolls to discourage auto users, all have proven records in increasing demand for bus transit systems.
4. The effectiveness of microcomputer-based planning and evaluation models in developing countries may be limited due to limitation of certain data such as elasticities of ridership with respect to transit fare and travel time. These are non-existent in Saudi Arabia, and generally limited in developing countries.

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