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CHARACTERIZING TRAFFIC CONDITIONS IN URBAN NETWORKS WITH MINIMAL CONTROL: A CASE STUDY OF POST-WAR BEIRUT

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Abstract

This paper attempts to investigate the quality of traffic service under mostly uncontrolled conditions. A framework for analysis is provided by the urban road network in the city of Beirut in the period after 17 years of war. A useful tool to characterize traffic at the network level is the two-fluid model; the two fluids consist of moving and stopped vehicles as a result of traffic conditions, and their interaction is observed to produce several parameters contributing to the scope of this research. This model also makes it possible to perform a sensitivity analysis whose objective is to evaluate the impact of introducing several control measures in a context characterized by lack of control. The study indicates that implementation of traffic control measures in situations characterized by lack of control will yield lower delays primarily at higher levels of traffic concentration.

INTRODUCTION

Since geometric features of urban roadway networks are fixed to a great extent, studies aiming at improving urban traffic flow are mostly concerned with enhancing features dealing with operational aspects, namely, traffic control. The extent of traffic control has been addressed using many probabilistic theories trying to optimize the performance of networks given several variables. This paper presents an attempt to investigate the quality of traffic service under mostly uncontrolled conditions. The case where high travel demand is accompanied by a nearly complete lack of traffic control in an urban setting may lead the network to operate in conditions nothing short of extreme. Opportunities to observe networks operating under such extreme conditions are normally unavailable. This paper satisfies the need to conduct a research into situations characterized by the above settings and will focus on the city of Beirut in an attempt to identify characteristics of traffic flow in urban networks with minimal control. The two-fluid model was used in analyzing the performance of the urban traffic network of Beirut.

The context of Beirut

During the period from 1970 to 1994, several changes occurred to traffic in Beirut at the operational level, including a greater than two-fold increase in auto ownership by residents of Municipal Beirut at a time when the road network has remained practically the same if not more restricted. Reliance on the private auto increased drastically from 44% to 72% partly due to lack of adequate mass transport and absence of enforcement of vehicle condition and use restrictions such as mechanical inspection and parking bans.

The situation at the end of the war in 1990 was also marked by a high increase in mobility needs of Lebanese people and particularly Beirut residents, manifested by the noticeable increase in traffic congestion. At the same time, the following operational features characterized traffic conditions in the city of Beirut:

- Inadequate street capacities due to bad pavement conditions, illegal curb parking, and pedestrians trafficking the roadways instead of using sidewalks occupied by vehicles.

- Capacity problems of intersections due to inadequate geometric design, and bad traffic handling by inexperienced policemen.

- Undisciplined driving behavior including one-way traffic violations, aggressive driving especially by taxi-service drivers, and disrespect of priorities.

The study areas

This research analyzes urban traffic network performance in a study area inside Beirut, as well as in Municipal Beirut as a whole, relying primarily on the two-fluid model of network performance.

The road network in Municipal Beirut is composed of approximately 286 kms of roadways of which 76% are one-way, 13% two-way undivided, and 11% two-way divided, spreading over an area of about 20 sq. kms. It also consists of about 130 signalized intersection (not all are operational) of which 35% are of four approaches and 40% of three approaches (TEAM International, 1994). Part of this research has focused on a smaller area where data collection was more manageable while general features, such as driving practices and the extent of traffic control, reflect those common to the city-wide network of Beirut.

The smaller study area is located in the Hamra / Ras Beirut sector of Beirut. It includes an important commercial arterial, namely Hamra street and several educational, cultural, business, and shopping activity centers in addition to numerous residential buildings. The study area has an area of 768,000 sq. m and consists of 15,420 m of streets.

THE TWO-FLUID MODEL

Overview

Over the past 25 years a kinetic theory of vehicular traffic which provides a macroscopic description of traffic characteristics on multi-lane highways has been developed. The two-fluid model of town traffic has been suggested as an extension of the multi-lane kinetic theory to describe, in a similar overall fashion, the traffic in a non-highway urban network. This came mainly as a consequence of the difficulty associated with trying to assess the quality of traffic service in such urban networks based only on characterization and traffic at the microscopic level. Such an undertaking requires great efforts to consider the traffic movements on all links and junctions and build a certain degree of knowledge which can lead, through the aggregation and averaging of gathered data, to relations among traffic variables used in determining the quality of prevailing service at the network level (Ardekani *et al.*, 1992).

The two-fluid concept is meant to simulate the behavior of vehicles in a town as two traffic fluids: one composed of moving cars and the other of cars that are stopped as a result of congestion, traffic signals, stop signs and other traffic control devices and obstructions resulting from construction, accidents, or other factors. The parked cars are ignored since they are not a component of the traffic but instead a part of the geometric configuration of the street.

This methodology has been applied successfully in many cities around the world such as Mexico, San Antonio, Tehran and London. The parameters obtained for these cities suggest a useful way of assessing the quality of service in urban networks. They involve mainly the observation of trip-time/stop-time for every city (Ardekani *et al.*, 1985).

Data collection procedure

The collection of data required to calibrate the two-fluid model involves recording the trip time and stop time of one or more test vehicles making trips of known distances in the network area of interest (Ardekani *et al.*, 1985). In the case of Beirut a trip was defined as a two-kilometer segment of travel. The observations involve a number of test vehicles carrying a driver and an observer with a digital watch. The driver is responsible for informing the observer of the odometer readings at the beginning and end of each trip. In order to randomize the routes taken within the test area, the chase-car technique is employed within the boundaries of the test area. The task of the observer includes recording the odometer readings and the absolute time corresponding to the start and the end of each trip as well as noting the absolute times associated with every stop and the subsequent resumption of motion of the test vehicle. A stop is defined as the absolute cessation of motion of the test vehicle. This information is recorded on separate sheets for every 2-km trip.

Model formulation and parameter estimation

The two-fluid model relation developed between the trip time per unit distance and the running time per unit distance is:

$$T_r = T_m^{1/(n+1)}T^{n/(n+1)} \tag{1}$$

where,
T_r = average running time per unit distance,
T = trip time per unit distance,
T_m = minimum trip time per unit distance,
n = parameter whose significance is discussed later.

Also, the stop time T_s is related to total trip time and running time by the following:

$$T = T_s + T_r \tag{2}$$

which yields the two-fluid model as:

$$T_s = T - T_m^{1/(n+1)}T^{n/(n+1)} \tag{3}$$

In the two-fluid model it is also assumed that the fraction of time stopped for an individual vehicle circulating in a network, (T_s/T), is equal to the average fraction of vehicles stopped in the system, f_s, over the same period ($f_s = T_s/T$). This assumption holds as long as the concentration does not fluctuate rapidly during the time of a trip. It has been shown through the use of aerial photographs in the two Texas cities of Austin and Dallas (Ardekani *et al.*, 1987) that f_s did not vary greatly for a given level of concentration. This is due to the fact that the average fraction of vehicles stopped during a time period is mainly a function of the average concentration in the network during that time.

The relation between T_r and T could be rewritten in the following form:

$$\log T_r = A + B \log T \tag{4}$$

A and B are the parameters to be determined from the collected data and are used in developing the following relations:

$$\log T_m = A/(1 - B) \tag{5}$$

and

$$\mathbf{n} = B/(1 - B) \tag{6}$$

The values of T_m and n are used to characterize traffic networks. While T_m has a physical interpretation of being the minimum trip time per unit distance, **n** is only a theoretical parameter. It has been shown by Ardekani *et al.* (1992) that a network with smaller values of T_m and **n** offers lower trip time and stop time per unit distance, knowing that for a given level of traffic demand, a street network that yields smaller trip time and stop time has a better quality of traffic service.

Relation to network geometric and operational features

Separate research efforts by Ardekani *et al.* (1985 and 1992) have indicated that T_m and **n** may be related to various geometric and operational features of urban road networks. These network features include: average block length (X_1), fraction of one-way streets (X_2), average number of lanes per street (X_3), intersection density (X_4), signal density (X_5), average speed limit (X_6), average cycle length (X_7), fraction of curb miles with parking allowed (X_8), fraction of signals actuated (X_9), and fraction of approaches with signal progression (X_{10}). The study by Ardekani *et al.* (1992) provides a listing of these features for several cities, from which models relating T_m and **n** to network geometric and operational features were obtained using regression analysis:

$$T_m = 3.393 + 0.0035X_5 - 0.047X_6 - 0.433X_{10} \qquad R^2=0.72 \qquad (7)$$

$$n = 1.73 + 1.124X_2 - 0.180X_3 - 0.0042X_5 - 0.271X_9 \qquad R^2=0.75 \qquad (8)$$

The parameter **n** was found to be mainly influenced by X_2, the fraction of one-way streets, a geometric feature of the network; the higher this value for a certain network, the higher is **n** and hence the worse is traffic service quality of that network. On the other hand, other features like average number of lanes (X_3), signal density and their mode of operation (X_5 and X_9) have less influence, and are negatively related to **n**: the higher their values the lower is the value of **n**. T_m was found to be significantly influenced by operational network features, mainly the fraction of approaches with signal progression, X_{10}, and to a lesser extent the average speed limit (X_6) and the signal density (X_5). The higher X_{10} and X_6 the lower is T_m, while the opposite is true for X_5.

APPLICATION OF TWO-FLUID MODEL IN BEIRUT

Data collection in Beirut

Data for the calibration of the two-fluid model in Municipal Beirut and the Hamra study area were obtained from a number of in-vehicle chase-car studies, carried out between 1995 and 1997.

Parameter estimation results

The two-fluid model parameter estimation results are presented in **Table 1**, without any modification. As shown, the models estimated for Municipal Beirut in the year 1995 differ greatly from those estimated later. The data points for Municipal Beirut and for Hamra are plotted in **Figure 1** as trip time T versus stop time T_s, while values used directly for the estimation of the 2-fluid model (log T_r vs. log T) are plotted in **Figure 2**.

Table 1 – Results of two-fluid model parameters (combined surveys)

Network	Two-Fluid Model		
	T_m	n	R^2
Municipal Beirut (1995)	1.00	3.90	0.71
Municipal Beirut (1996/97)	2.25	2.01	0.71
Hamra (1997)	4.38	1.16	0.75

Analysis and conclusions

Figure 3 shows curves of the 2-fluid models of equation 3 for Municipal Beirut (1995 and 1996/97 surveys), and for the Hamra area as determined from the estimated values of T_m and **n**. Also plotted on the same chart is the fraction of stopped vehicles, $f_s = 0.4$, considered as representative of normal traffic conditions for the day-time periods when the surveys were carried out. It is shown that for the same fraction of vehicles stopped, T for Hamra is higher than that for Municipal Beirut (both surveys), which indicates a lower quality of service for the Hamra network during normal operations. This comes as the result of Hamra network having the highest intercept, or worst conditions with free flows. However at high concentrations ($f_s>0.43$), the network of Municipal Beirut as surveyed in 1995, having a steeper slope, exhibited higher trip times than Hamra.

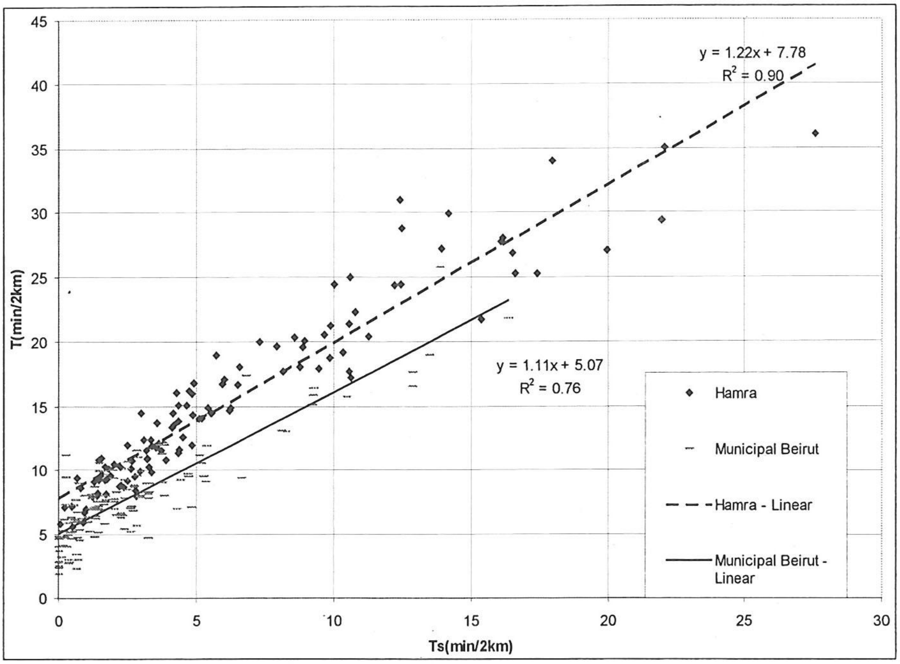

Figure 1 – Trip time vs. stop time

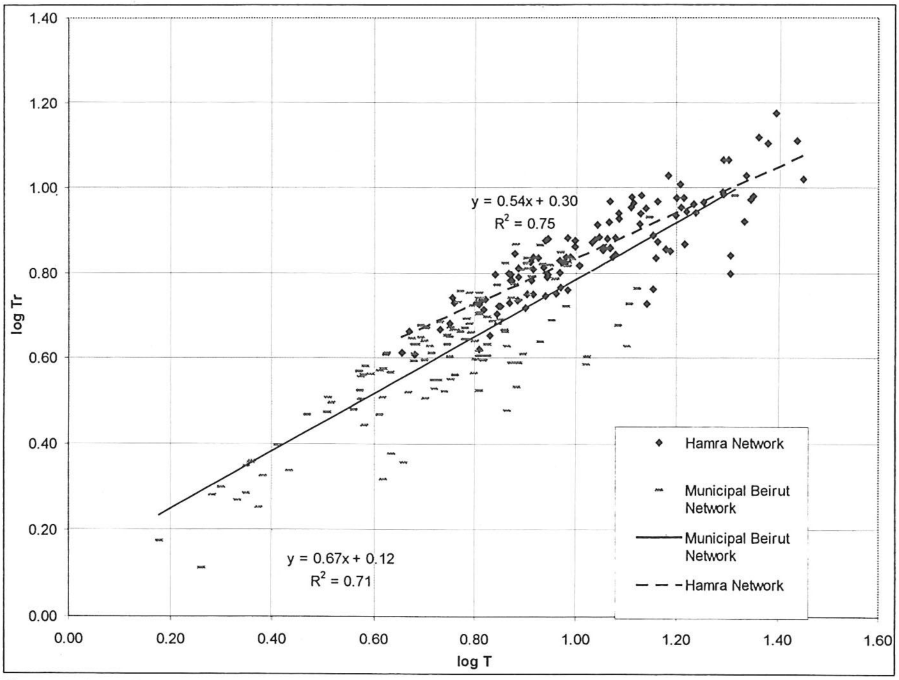

Figure 2 –Two-fluid models

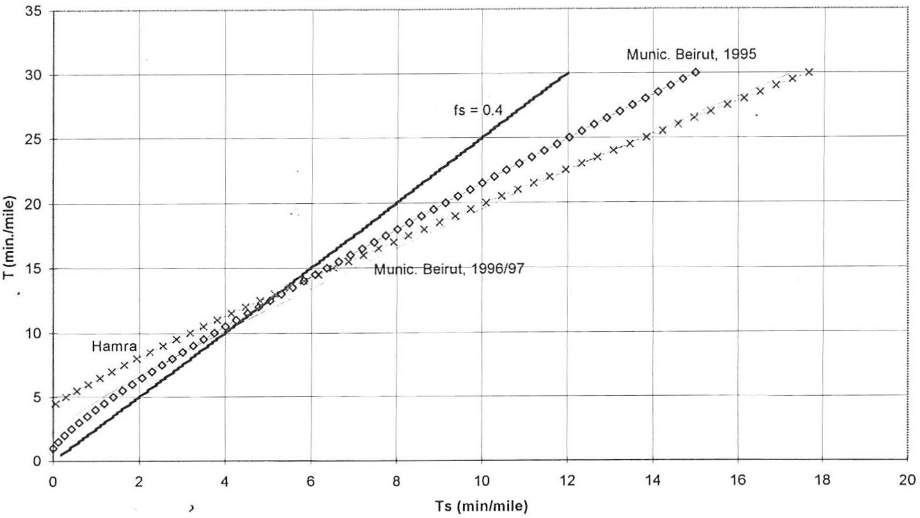

Figure 3 – Comparison between two-fluid models at $f_s = 0.4$

Also, with f_s greater than 0.55, the Municipal Beirut network in its current state (1997), would have greater travel times than Hamra. One possible interpretation could be that the geometric features of Hamra are playing a greater role in influencing its traffic service quality, and hence its travel times are less sensitive to different traffic concentrations. Comparing Municipal Beirut surveys with each other, it is observed that at low concentrations ($f_s < 0.3$), the 1995 survey yielded lower travel times. This is a direct result of the control implemented between 1995 and 1997. At high f_s, the complete lack of control in 1995 is evident in the deviation of its curve from that of 1997 and Hamra (also surveyed in 1997), the later two being relatively close in that region.

In order to better understand the two-fluid model and its properties, it is important to examine the trip time/stop time data points (**Figure 1**). The location of many data points for the Hamra network in the higher T/T_s region indicates a poorer quality of service, at least during the survey periods. This is expected from a highly congested area with major commercial centers located in it, with narrower streets and more pedestrian-vehicle interactions. In general, the chart indicates that for a certain 2-km trip having the same T_s in Hamra and Municipal Beirut, the Hamra trip entails a larger T (total trip time) since the running part of the trip is conducted at significantly lower speeds. The existence of low operating speeds in Hamra was confirmed by travel time/delay studies conducted separately by Alam (1997). However, the scattering of points towards the upper part of the chart reveals less consistency of traffic performance in case of extreme congestion. The bulk of observations in Hamra with low T_s is not far from those obtained for Municipal Beirut. Comparing the two-fluid parameters of Municipal Beirut between 1995 and 1996/97 reveals significant changes in both T_m and **n**, which are not unexpected. The increase in T_m is attributable to two factors: (i) improvement in traffic control at some intersections in the city, in specific those for which traffic signals were installed and became operational, and (ii) the escalating driving friction due to intensified curb parking (and double parking) in the city especially during off-peak hours as the number of vehicles operating (and parking) on city streets continues to spiral. On the other hand, the reduction in the value of **n** indicates that the city network is becoming more robust in dealing with heavy traffic volumes due to: (i) completion of many road/infrastructure projects which had interrupted several city streets; (ii) improved traffic control and new traffic management schemes which were implemented during the last year or two; and, (iii) improvements to some intersections and roads, and addition of a few road links to the city network.

COMPARISON OF TWO-FLUID-MODEL AND ITS PARAMETERS WITH OTHER CITIES

In order to be able to conduct a comprehensive comparison of the results of the calibration of the two-fluid model for Beirut with results elsewhere, estimated relationships between T and T_s for several cities around the world are plotted in **Figure 4**, using corresponding values of T_m and **n** (**Table 2**) in equation 3. To compare network performance in the various cities, T and T_s values corresponding to an f_s of 0.5 are computed. Data for these cities was obtained from Ardekani *et al.* (1985).

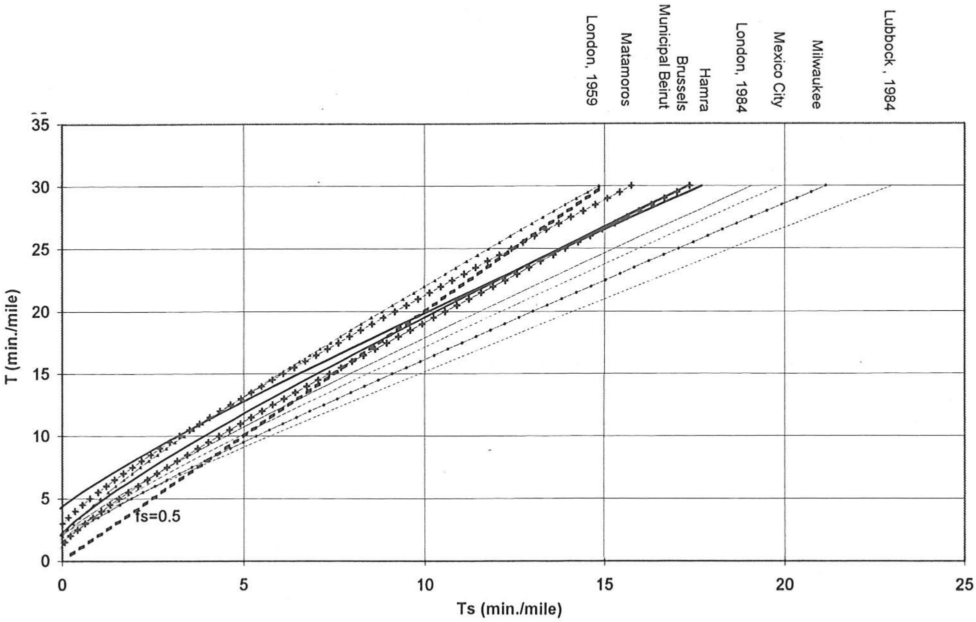

Figure 4 – Comparison of two-fluid models for several cities

Table 2 - Network geometric and control features

Network	Tm	n	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
Arlington 1 (90)	1.98	1.06	496	0	2.77	108	17	30.6	94	0.375	1	0.537	0.157
Arlington 2 (91)	1.95	0.61	479	0	2.92	124	25	30.3	91	0.315	1	0.557	0.202
Fort Worth (90)	2.52	0.88	300	0.71	3	355	268	30	75	0.36	0.11	0.5	0.755
Dallas 1 (83)	2.12	1.36	350	0.4	2.6	160	80	30	80	0.218	0.324	0.328	0.500
Dallas 2 (90)	2.79	0.77	338	0.65	3.2	282	224	30	80	0.131	0	0.488	0.794
Dallas 2 (91)	2.77	0.8	340	0.67	3.1	270	215	30	84	0.13	0	0.29	0.796
Austin (84)	1.95	1.58	430	0.52	3	209	82	30.3	64	0.834	0	0.32	0.392
Austin (90)	2.14	1.46	409	0.43	2.9	175	82	30.2	68	0.834	0	0.32	0.469
Lubbock (84)	2.03	0.97	380	0.3	3.1	187	45	31.1	81	0.602	0.01	0.27	0.241
Lubbock (90)	1.78	1.27	446	0.15	3.05	153	30	31.1	97.1	0.602	0.02	0.37	0.196
Houston (83)	2.7	0.8	324	0.76	4.3	309	213	30	80	0.366	0	0.77	0.689
Houston (90)	2.24	1.11	324	0.76	4.3	309	213	30	80	0.366	0	0.77	0.689
San Antonio (84)	1.99	1.33	365	0.45	2.7	244	144	30	100	0.28	0.008	0.327	0.590
San Antonio (90)	2.52	1.14	365	0.41	2.6	240	150	29.8	89.3	0.28	0.008	0.395	0.625
San Antonio (91)	2.4	1.05	365	0.4	2.82	252	148	30	61.8	0.269	0.008	0.451	0.587
Albuquerque (83)	1.93	1.62	381	0.47	2.7	222	111	25.5	61	0.441	0.171	0.52	0.500
Albuquerque (90)	2.32	0.94	381	0.46	2.7	221	113	25.5	62.2	0.428	0.169	0.53	0.511
Matamoros (83)	2.98	2.1	380	0.67	1.2	269	22	12.9	70	0.85	0	0	0.082
Mexico City (83)	1.72	1.63	359	0.72	3.9	225	47	31.2	120	0.11	0	0.613	0.209
Municipal Beirut	**2.25**	**2.01**	**358**	**0.76**	**1.5**	**309**	**16**	**25**	**85**	**0.865**	**0.923**	**0**	**0.052**
Hamra	**4.38**	**1.16**	**351**	**0.985**	**1.363**	**368**	**27**	**25**	**84**	**0.832**	**0.875**	**0**	**0.073**

As expected, the travel times of Hamra and Municipal Beirut for peak flows are higher than most of the other cities indicating a lower quality of traffic. **Table 3** shows values of T and T_s at f_s=0.5.

Table 3 – Comparative T and Ts values

	T, minutes per mile	T_s, minutes per mile
Hamra	19.6	9.8
Municipal Beirut	18.1	9.1
Matamoros	25.6	12.8
London, 1984	12.8	6.4
Lubbock, 1984	7.6	3.8

Only selected cities are included in this chart since all the rest of the curves fall between London (1959) and Lubbock (1984). Municipal Beirut may be the network with the lowest extent of control, but it still does not fall far from cities elsewhere. In fact, London in 1959 was the worst network tested, and currently Matamoros in Mexico has the highest travel times for most of the values of fs. Comparing parameters for Beirut against the parameters of other cities, it is found that Tm for Hamra is highest while n for Beirut is among the highest.

The two-fluid parameters for the Hamra network are worthy of discussion. The T_m value of 4.38 min/mile is quite high but may be related to a number of critical factors including a very high proportion of one way streets, a very high intersection density, and a very high occurrence of curb side parking coupled with a minimal number of street lanes. With a high T_m, indicating poor performance at low traffic volumes, the value of **n** is low, a reflection of the fact that as traffic volumes increase, the increase in delay (from an already high level) is limited. This results in the Hamra network having an inferior performance compared to Municipal Beirut (as well as other networks) for values of f_s lower than 0.4 or 0.5, but similar performance for higher f_s values.

COMPARISON OF NETWORK FEATURES

As mentioned earlier, research has indicated that T_m and **n** may be related to specific network features and their values may be explained by examining those features. The effect of these individual network characteristics on the 2-fluid parameters is investigated next.

Determination of network features

For Municipal Beirut, the values describing features were determined by sampling from representative city areas, and then expanding the results over the whole network. The geometric features were obtained from 1/2,000 maps, while operational features were obtained on site.

In order to determine the main geometric features of the study area network, city maps of a scale 1/2000 were used along with field surveys. The study area has an area of 768,000 sq. m and consists of 15,420 m of streets among which only 235 m are two way, and the rest are one way streets, with a density of 0.02 m of roads per sq. m of land area, or 0.22 sq. m of roads per sq. m of land area. Road widths vary from 4m to 14m with an average of 11.4m including the travel lane(s), the parking lane(s) and the sidewalk(s). Most of the 44 street links constituting this small network are acting as streets with one travel lane. Only 8 links comprise two lanes in part or all of them. Nevertheless, for all the streets, the lanes are not well defined and illegal parking reduced some two lane streets to one lane during several hours of the day. Moreover, The low fraction of two way streets in the Hamra study area (and in Beirut at a larger scale), results in a poor traffic circulation pattern, which could translate into a lower traffic service quality.

The total number of intersections in the Hamra study area is 109, with an average distance of 220m between two consecutive intersections. Recently all these intersections have been equipped with stop signs and regulatory signs indicating the priority of each traffic stream. However there are only 8 intersections which are practically controlled either by a policeman or by a traffic signal. The rest of intersections are stop controlled, but there exists little respect for priority.

Analysis

Values of all the features X_1 through X_{10} (in addition to X_{11}, the fraction of signalized intersections, whose relevance is discussed later on) are listed against parameters from other cities in **Table 2** (Ardekani *et al.* , 1992). Comparing the values of Municipal Beirut and Hamra against the other cities, the following interesting observations can be made:

- The fraction of one-way streets is the highest for the Hamra network and among the highest for Municipal Beirut, a fact which is expected to adversely affect the values of **n**.
- The average number of lanes is among the lowest for Beirut and Hamra. This is due to the fact that the number of lanes reflects the actual lane usage restricted by illegal parking, rather than the designed lane configuration, in addition to the initial narrow streets configuration.
- The Hamra network has the highest intersection density among all networks, whereas intersection density for the Municipal Beirut network falls in the high range.
- It is found that signal density is lowest for Beirut. This result includes policemen-controlled intersections, since traffic signals are very few and some newly installed signals are completely disregarded by vehicles. Therefore, policemen are present mainly on major intersections, and are operating as actuated signals with variable cycles.
- The average speed limit, determined for other cities as the posted speed, is completely irrelevant in the case of Beirut, owing to the fact that no speed limit is posted and none is observed. One may observe, however, a running speed limit which would be in the vicinity of

25 mph. Considering the similarity of this parameter for most of the cities, it is expected to have little influence on any comparative assessment of city networks.

- The fraction of curb miles with parking allowed is the highest in Beirut. This is partly explained by the fact that no real enforcement over parking prohibition is present, therefore curb parking is treated as allowed if it is actually taking place.
- Police controlled intersections are considered as actuated signals, which explains the high value for the fraction of actuated signals in Beirut, while it is zero in most of the other cities.
- No signal progression is in practice at all in Beirut.

An additional factor of interest in comparing features of different cities is the fraction of intersections which are signalized. This is determined by dividing the signal density X_5 by the intersection density X_4. This factor is 5.2% for Municipal Beirut and 7.4% for Hamra. These values are compared to values for other cities and are found to be the lowest. It is worth mentioning that while unsignalized intersections in other cities have some kind of control, they are completely uncontrolled in Beirut. As such, it can be concluded that close to 95% of all intersections in Beirut are completely uncontrolled.

In summary, the features of Municipal Beirut and Hamra networks which exhibit significant differences relative to other cities are: fraction of one-way streets (X_2), average number of lanes (X_3), intersection density (X_4) (and consequently X_{11}), fraction of curb miles with allowed parking (X_8), and fraction of approaches with signal progression (X_{10}).

RELATING TWO-FLUID MODEL PARAMETERS TO NETWORK FEATURES

The T_m and **n** models (Equations 7 & 8) developed by Ardekani *et al.* (1992) using data for various cities, are applied using features (X_1 through X_{10}) of Municipal Beirut. The resulting values are: $T_m = 2.27$ (value estimated from collected data = 2.25); **n** = 2.00 (2.01). Since the models yielded very close results for Municipal Beirut, they may be used for any prediction of the effect of changes in geometric and operational features regarding this network. On the other hand, the T_m and **n** values obtained for the study area of Hamra using equations 7 and 8 were far off from those determined directly from calibrating the 2-fluid model. As a result, other equations for T_m and **n** were developed by incorporating geometric and operational network features which would provide a better reflection of the Hamra network case. The adopted models were as follows:

$$T_m = 1.660 + 1.100X_2 + 0.129X_8 + 0.620X_9 - 1.048X_{10} + 0.830X_{11} \quad (9)$$

$$\mathbf{n} = 2.272 - 0.176X_3 - 0.714X_9 - 0.964X_{11}\ ; \quad (10)$$

Plugging in the values of Hamra from **Table 2** result in: $T_m = 3.45$ (value obtained from collected data = 4.38), **n** = 1.34 (1.16).

IMPACT OF INCREMENTAL TRAFFIC CONTROL MEASURES IN BEIRUT: A SENSITIVITY ANALYSIS

A sensitivity analysis is carried out in order to assess the effects of introducing control measures in Beirut in the period after the war. These measures could be summarized by: Installing signals, introducing progression or eliminating curb parking, or all of above. Every action is first investigated alone then all actions are combined. The results are presented in **Table 4**, with all values expressed in units of minutes per mile.

The shift in travel times and stop times is quantified for f_s=0.4. In order to perform the sensitivity analysis on the networks of Municipal Beirut and Hamra, the models which yielded the closest results of T_m and **n** to each network are used. Thus, equations (7) & (8) are used for Municipal Beirut, and equations (9) & (10) are used for Hamra. The models are used to compute T_m and **n** for the 'before' case, instead of using the values obtained from the surveys, in order to obtain comparative results.

Table 4 - Summary of sensitivity analysis results

Action	T_m		N		T		T_s	
	Before	After	Before	After	Before	After	Before	After
Double number of signals-MB	2.27	2.33	2.00	1.93	10.51	10.41	4.20	4.16
Double number of signals – Hamra	3.45	3.51	1.34	1.27	11.40	11.10	4.56	4.47
Ban half of curb parking-MB	2.27	2.27	2.00	1.90	10.51	10.02	4.20	4.01
Ban half of curb parking-Hamra	3.45	3.41	1.34	1.26	11.40	10.83	4.56	4.33
Ban all curb parking-Hamra	3.45	3.35	1.34	1.13	11.40	9.92	4.56	3.97
50% of signalized intersections are part of a progression-MB	2.27	2.06	2.00	2.00	10.51	9.51	4.20	3.80
All signalized intersections are part of a progression-Hamra	3.45	2.41	1.34	1.34	11.40	7.94	4.56	3.18
Apply all improvements-MB	2.27	2.11	2.00	1.84	10.51	9.00	4.20	3.60
Apply all improvements-Hamra	3.45	2.36	1.34	1.06	11.40	6.75	4.56	2.70

MB: Municipal Beirut

Increasing the Number of Signals: This is a reasonable assumption for both Municipal Beirut and Hamra considering the low fractions of signalized intersections in the two networks. A possible scenario is a doubling of the number of actual signalized (or police controlled) intersections. The effect of such an action on both networks follows:

- Municipal Beirut - Improvements in the value of travel time and stop time per unit distance were recorded. As expected, the value of T_m, being directly related to X_5, the density of signals in the network, increased by 0.06 min/mile due to the fact that the delays experienced on signals especially in the off peak periods are more than those on unsignalized intersections, while the value of **n** (also directly related to X_5) decreased by 0.07. The overall improvement on travel time and stop time is a decrease of 0.95%.
- Hamra - Again, T_m increased by 0.06 min/mile and **n** decreased by 0.07, which means that doubling the number of signals has the same effect on both networks, but occurring at different levels of service, it resulted in a decrease of 1.97% and 1.84% in stop times and trip times consecutively.

Banning of Curb Parking: This action could be taken as a measure to account for the lack of space facing the increase in traffic volumes. Actually, 50% is assumed in both networks, which denotes banning parking on one side of all the roads on the average. In the case of Hamra, this should be thought of as the minimum requirement in terms of increasing streets capacity. For this reason, the case of banning all curb parking in Hamra is also considered.

- Municipal Beirut - In the model of T_m, the curb parking variable is not present, and is not related to any of the present variables. For this reason T_m is not affected by any change in the curb parking policy. The value of **n**, even if not related directly to curb parking, is affected through the average number of lanes (X_3) resulting from a change in X_8. This relation is estimated by calculating the area saved from banning curb parking (2.5m width x half of curb parking miles in the network less the actually banned curb parking miles), then dividing this area by a typical lane width (assumed to be 3.5m). The outcome would be the additional lane width to be added to X_3. The corresponding decrease in **n** is 0.1, and the resulting decrease in T and T_s is 4.7% and 4.5% consecutively.

- Hamra - As mentioned earlier, two scenarios could be tested for Hamra network under this action: banning half of the curb parking and banning all curb parking. As T_m is directly related to the fraction of allowed curb parking, it follows that for a decrease of X_8 from 0.832 to 0.5 (first scenario), T_m decreases by 0.04min/mile. **n** is related to curb parking through the average number of lanes (same reasoning as for Municipal Beirut), and thus for the first scenario, **n** decreases by 0.08. The effect on trip time and stop time would be a decrease of 5.0% for both. For the second scenario, a decrease of 0.1min/mile in T_m and 0.21 in **n** are observed. The resulting trip time decreased by 1.48min/mile (13.0%) and the stop time decreased by 0.59min/mile (12.9%).

<u>Introduction of Progression for Consecutive Signalized Intersections:</u> It is assumed first that half of signalized intersections in Municipal Beirut will be part of a progression. In the Hamra network it can be safely assumed that all the actually signalized intersections are part of a progression, since they are all located on two main streets (Hamra and Emile Eddeh).

- Municipal Beirut - In this case only Tm is related to X_{10}, the fraction of approaches which are part of a signal progression scheme. Having 50% of the signalized intersections part of such a scheme ($X_{10} = 0.5$), decreases T_m by 0.21min/mile, which leads to an overall decrease in travel time and stop time of 1min/mile and 0.4min/mile respectively (9.5% for each).
- Hamra - As mentioned above, all signalized intersections in Hamra could be part of a progression scheme. Again, only T_m will be affected by the change with a decrease of 1.04min/mile. A decrease in travel time of 3.46min/mile (30.4%) is also noticed. The high change in Tm is also revealed in the initial state where $T_s = 0$ with an improvement of about 1min/mile.

<u>Applying all the Above Improvements:</u> An optimistic scenario is to assume that all the above improvements are applied. It is assumed also that for the Hamra network, all the curb parking are banned.

- Municipal Beirut - The resulting overall improvement was found to be proportionally increasing with the increase in the level of concentration, represented here by f_s. Numerically, T_m decreased by 0.16min/mile while **n** decreased by 0.16 as well. The resulting decrease in travel time at f_s=0.4 is 1.5min/mile, and the decrease in T_s is 0.6min/mile, or 14.3% for each.
- Hamra - In the case of Hamra, applying all the improvements affected more the overall behavior. In fact it is reasonable from a small network to be more sensitive to changes in one or more of its features. The result of the changes is a decrease in T_m of 1.09min/mile and a decrease in **n** of 0.28. T decreased by 4.65min/mile and T_s decreased by 1.86min/mile (40.8%).

It is worth noting that all actions showed improvements at all levels of concentration, with a better improvement for higher concentrations (higher f_s). This highlights the poor condition in which the observed networks (Municipal Beirut and Hamra) are in. The introduction of control schemes or enhancement of existing ones, may in some cases have a negative influence on off-peak traffic conditions, but for high volumes persisting for long periods of the day as is the case in Beirut, improvements are inevitable to account for the high travel times per unit distance.

CONCLUSION

The issue of appropriate levels of traffic control inside urban areas remains a critical point in transportation and traffic engineering practice. The use of several types of control in cities around the world has contributed to keeping traffic moving in a manner which distributes delays over all users. The type of control adopted is mainly a function of the intensity of traffic flows (e.g.

signalized intersections are used at high volumes, while for lower volumes intersections are stop controlled). Only in cases where traffic volumes are very low, and no type of control could be warranted, is "no control" applied.

The effect of lack of control on a whole network was investigated through the application of the 2-fluid model in the case of Beirut. The model parameters were estimated through data collection for two cases: the Hamra study area and the Municipal Beirut area. The 2-fluid model parameters, which are interpreted as network performance measures, were compared against those obtained in other cities around the world. Several geometric and operational features were used in explaining the values of these parameters. In the Municipal Beirut area data was collected in two shifts (1995 and 1997) and the 2-fluid parameters were estimated in each case. The difference between the two surveys is that some control measures were applied in the city of Beirut during that period. The values of parameters for the two cases confirmed that lack of control was associated with a better performance of the network at low traffic concentration levels, as evidenced by lower travel times per unit distance. However, at higher concentration levels, the case where some traffic control had been applied yielded better performance.

An important factor in the comparison of cities was shown to be the nature of their networks. Since the parameters of the 2-fluid model may be related to geometric and operational characteristics of each network, their values do not only reflect the extent of control but also geometric features of urban road networks. As an example, the network of Municipal Beirut yielded better performance than that of Hamra, even when both of them have virtually the same control features. This could only be explained by the fact that the two networks differ mainly in two geometric features, namely, the fraction of one-way streets and the intersection density. The analysis at the network level led to the development of two models (one for Municipal Beirut and the other for Hamra), relating the parameters of the 2-fluid model to those features that were found statistically significant in each case. These two models were used to test several scenarios of introducing different control measures.

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REFERENCES

Alam, G. (1997) Characterizing Uncontrolled Traffic Conditions in Post-war Beirut. Unpublished Master's Thesis, American University of Beirut, Lebanon.

Ardekani, S. and Herman, R. (1985) A Comparison of the Quality of Traffic Service in Downtown Networks of Various Cities Around the World. **Traffic Engineering and Control 26(2)**, 574-581.

Ardekani, S. and Herman, R. (1987) Urban Network-Wide Variables and Their Relations. **Transportation Science 21(1)**,.1-16.

Ardekani, S., Williams, J. and Bhat, S. (1992) Influence of Urban Network Features on Quality of Service. **Transportation Research Record 1358**, 6-12.

TEAM International - IAURIF – SOFRETU (1994) Greater Beirut Transportation Plan. Technical Reports. Council for Redevelopment and Construction, Republic of Lebanon.