PAMUKKALE ÜNİVERSİTESİ MÜHENDİSLİK FAKÜLTESİ
PAMUKKALE UNIVERSITY ENGINEERING COLLEGE
MÜHENDİSLİK BİLİMLERİ DERGİSİ
JOURNAL OF ENGINEERING SCIENCES
YIL : 1996
CİLT : 2
SAYI : 3
SAYFA : 167-176

USER EQUILIBRIUM AND SYSTEM OPTIMUM TRAFFIC ASSIGNMENTS; ISTANBUL ROAD NETWORK EXAMPLE

Banihan GÜNAY
Pamukkale Üniversitesi, Mühendislik Fakültesi, İnşaat Mühendisliği Bölümü, Denizli

ABSTRACT

The concept of road networks and traffic flow equilibrium conditions are briefly reviewed and discussed. In order to see whether some benefits for the society (e.g. whole network) by employing a System Optimum assignment approach can be achieved or not, an assessment study was carried out on the Istanbul road network using the actual data gathered. As a result of the system optimising simulation, queuing times on the Bosphorus Bridge dropped by 12% and speed of an average car increased by 16%, compared to the results produced by the User Equilibrium assignment. Besides, the total system journey time was also reduced by about 4%.

Keywords: User equilibrium, System optimum, Traffic assignment

KULLANICI DENGESİ VE SİSTEM OPTİMİZASYONUNA GÖRE TRAFİK ATAMALARI; İSTANBUL YOLLARI ÖRNEĞİ

ÖZET

Yolağı kavramı ve trafik akım denge koşulları kısaca ele alınıp incelenmiştir. Kitleye (örneğin tüm yolağına) Sistem Optimumu yaklaşımının kullanılması ile bazı yararların kazandırılıp kazandırılmayacağı, İstanbul yolağı üzerindeki gerçek veriler kullanılarak irdelenmiştir. Sistemi optimize eden simulasyon, Kullanıcı Dengesi atamasının sonuçlarına nazaran, Boğazici Köprüsü üzerindeki kuyruklanma sürelerinde %12'lik bir düşüş, ortalama araç hızlarında %16'lık bir artış ve ayrıca toplam sistem yolculuk sürelerinde ise yaklaşık %4'lük bir azalma vermiştir.

Anahtar Kelimeler: Kullanıcı dengesi, Sistem optimumu, Trafik ataması

1. INTRODUCTION

The theory of network equilibrium is based on two major approaches which are the characterisation of individual driver behaviour and the characterisation of optimum utilisation of a transportation network. Wardrop's basic assignment principles state that (Sheffi, 1985 and Bell, 1995): (a) the journey time for each O-D pair on all used routes are equal, and also less than or equal to the travel time that would be experienced by a single vehicle on any other unused path; and (b) the average journey time in a network is minimum regarding the benefit of the society (i.e. whole traffic).

While the first statement is the User Equilibrium case, the second principle forms the System Optimum assignment strategies. As long as congestion on networks is not ignored these two assignment strategies produce different results. The major aim of this study is to compare the results of these two cases in vehicle travel times by using the data which represents the İstanbul road network traffic conditions.

167

2. TRANSPORTATION NETWORKS

A *network* is a set of links and a set of nodes, where nodes connect links and links connect nodes. In the context of transport, nodes represent intersections and links represent roads and streets. Each network link has an *impedance* magnitude which directly affects the flow on that particular link. The relationship between the impedance and the flow on a link is generally a non-increasing one. The higher the impedance, the lower the flow. On a transportation network low levels of service refer to high impedance. Therefore, in terms of traffic flow theory, the aim of a traffic engineer is to achieve higher level of service values on each link by reducing the resistance of the network.

The term *resistance* can be expressed as geometry of roads, degree of queue formation, bendiness or degree of delay. A *path (route)* is a sequence of directed links starting from any node and ending on another one. The impedance of a path is the sum of impedances along the links building up that particular path. This means that each link along a given path might have different levels of service. Travelling from an origin to a destination might be possible via two different paths, and each of these paths might have different combinations of levels of service. Frequent changes in levels of service along a route is also another factor affecting "route choice decisions" made by drivers. While both the average of space mean speed values and the travel times along a route, which consists of a number of links, remain constant, the level of service of each link could easily vary from time to time. The impedance of links may be expressed by different indicators such as travel time, travel cost, safety, comfort, stability of flow, etc. Studies show that travel time or cost are primary and good representatives of impedance of links. Accordingly, in this study, calculations and assessments are based on cruise times between nodes as indicators of link impedances. Reasons for this decision:

- During the limited data collection period, geometrical link lengths and free flow speeds, which lead to determine travel times, were the only available data, since travel costs (in terms of money), safety or comfort were not available.
- As Sheffi (1985) states, empirical studies seem to indicate that cruise time representation is primary deterrent for flow; and almost all other possible measures of travel impedance are highly correlated with travel time and, thus, it exhibits the same trend.

On transportation networks, travel times are almost independent of flows only at low flow levels, while there is considerable interaction between flow and travel time at higher flows. The measurement and determination of link performance functions are based on empirical work. The diagram given in

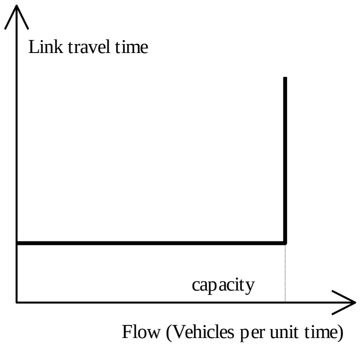

Figure 1 The simple form of link performance function

Figure 1 is the simplest representation which shows the link performance function of rail-type networks rather than road-type networks.

The level of service (or impedance) offered by many transportation systems is a function of usage of these systems. Because of congestion, travel time on urban streets is an increasing function of flow. Consequently, a performance function rather than a constant travel time measure should be associated with the urban network. The *performance function* relates the travel time on each link to the flow traversing this link (Sheffi, 1985). Figure 2 shows a typical link performance function for an approach arm to a signalised intersection. Exact parameters of this function are determined by lengths and widths of streets, parking restrictions, turning bays, etc. When q is almost equal to zero, then T will be the free flow travel time (Tf).

3. EQUILIBRIUM ON NETWORKS

Strong interaction between link flows and travel times is the origin of *equilibrium analysis*. It is clear that link travel times depend on link flows. The question of interest here is how motorists, who wish to travel between a given origin-destination (O-D) pair which has more than one route, are distributed among these possible paths.

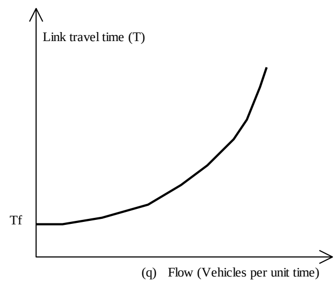

Figure 2 A typical link performance function

Transportation network equilibrium analyses have been studied by various researchers (Steenbrink, 1974; Newell, 1980; Sheffi, 1985; Damberg, 1996 and Ran, 1996). The main logic is briefly discussed in the following paragraphs based on these literature:

While at the beginning of an assessment procedure there might be only one shortest route in terms of travel times, as the flow rate increases on that particular route, it cannot be considered as the shortest one at the time, at which the flow reaches the capacity and congestion starts to occur. Drivers will choose the second shortest path and so on. Assignment of traffic on these alternative routes is a *demand-performance equilibrium* problem. Demand cannot be defined for each link separately because it is the result of drivers' behaviour. The question is to specify how motorists will choose among the alternative routes. This demand-performance equilibrium analysis requires that no link, path or O-D pair can be analysed in isolation. Drivers' choice of routes and consequently flow-travel time calculations can be considered through:

i. representation of the network;
ii. link performance functions; and
iii. determination of O-D matrix.

The question, now, becomes a *traffic assignment* problem. The equilibrium flows and the corresponding travel times throughout the network are the determination of interaction between routes chosen and the performance functions of all links.

Every driver tries to minimise his/her travel time between an origin and destination pair by choosing the shortest route in terms of time. Decisions among these routes will affect all factors determining flow and travel times as time passes. This fluctuation dies down and the stable position is achieved when drivers are unable to shorten their travel times by changing routes. This case is called *a user equilibrium* (UE). The definition of user equilibrium requires such presumptions as all motorists are fully informed of traffic situations which directly affect their route choice decisions to find the shortest route and they always make correct decisions continually. What is more, UE approach also assumes that each single driver is individually identical. Since there is difference between actual travel times and perceived travel times by drivers, the perceived travel times can then be looked upon as a random variable distributed across the population of drivers. In other words, each motorist may perceive a different travel time over the same link. Equilibrium is reached when no traveller believes that his/her travel time can be improved by unilaterally changing routes. This is called *a stochastic user equilibrium.*
If it is assumed that all perceived travel times are entirely correct and as same as actual travel times, stochastic user equilibrium will become deterministic user equilibrium. In other words, the flow patterns resulting from both models are assumed to be identical. The analysis discussed above requires steady-state flow patterns which mean that the flow values during the assignment should not change from time to time. Nevertheless, this condition cannot be met in urban areas during the day. That is why traffic engineers and transport planners consider either morning or evening peak hours to perform assignment analyses.

Unlike the equilibrium problems of economics between supply and demand, in this context, equilibrium is discussed with regard to the relationship between flow (vehicles per unit time) and level of service (or impedance, or travel times). In short, while user equilibrium assumes that all drivers do know all link travel times with certainty, stochastic user equilibrium models are based on the assumption that each individual motorist perceives a different travel time and behaves accordingly. User equilibrium is the state where the travel times for each O-D pair are same and individual travel times of each path is less than or equal to the one which belongs to any unused path. For a given O-D pair that has no alternative connection links with different distances, the equilibrium conditions can be shown as in Figure 3.

The two parabolic curves in the above diagram demonstrate the relationship between flow and link travel time. In other words the change of travel time is a function of the change of link flows. q_e is the flow level at the equilibrium conditions. It also has to be stated that the real O-D performance function shows a continual feature having a continual curve progress as it is seen in Figure 4.

Wardrop's first statement (given in the introduction), the UE case, is only achieved when drivers are rational, capable of estimating their own minimum travel costs in terms of choosing the best route, and perfectly informed of traffic and network conditions. The second principle is the basic definition of System Optimum (SO) assignment, which states that drivers should be convinced to choose their routes in such a way that the total journey costs of the society are minimised. The objective function for system optimum approach is to minimise the total travel time spent in the network.

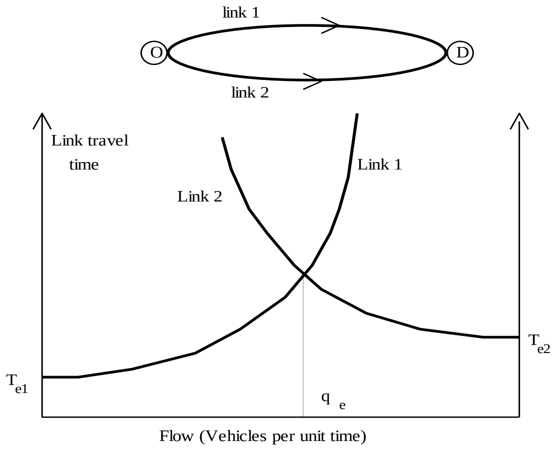

Figure 3 Equilibrium in a simple road network

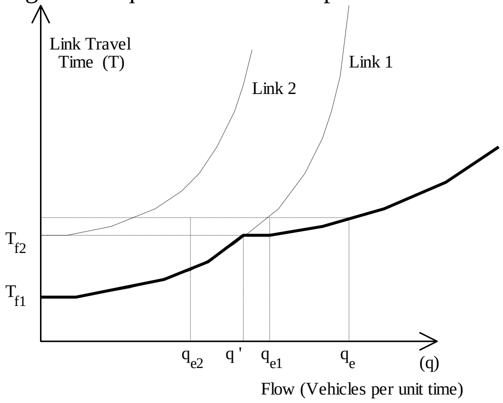

Figure 4 Origin-destination performance function

In Section 2, it was stated that link travel times strongly depend on link flows. Therefore if the effects of congestion on a network are ignored, the SO approach will give the same result as UE. In other words, both UE and SO programs will produce identical results.

The relevance of these mathematical explanations to the study is to provide some basic knowledge about networks and traffic flows on the roadways. It is believed that this theoretical approach will be helpful in understanding the analyses and the practical findings given in the following sections (e.g. Section 5 specifies UE and SO approaches regarding the CONTRAM analysis of the study).

4. ISTANBUL ROAD NETWORK AND DATA

4.1. The Study Area and Its Characteristics

Almost seven million motorised trips are made in İstanbul everyday (Gedizlioğlu, 1995) leading to extensive traffic problems. Geographical location of Istanbul requires to accommodate a roadway connection with a high volume of traffic travelling between Europe and Asia. The motorway, called Kınalı-Sakarya, passes across the Istanbul City.
The network chosen for the study is the city segment of this motorway connection which lies on about a 300 km²-territory, (see Figure 5) surrounded by:

- in the West, Bağcılar and Mahmutbey;
- in the North, Kağıthane and the Fatih Sultan Mehmet (FSM) Bridge;
- in the East, Ümraniye and Göztepe; and
- in the South, Kadıköy, Üsküdar, the Bosphorus Bridge, Unkapanı and Bahçelievler.

The selected territory has an appropriate network of roads and intersections capable of offering alternative routes for drivers. The network itself has some convenient features, such as heavy flows, considerable queue formation in rush hours and long links (i.e. rather homogenous isolated motorways with few entries and exists), which enables us to obtain a simple representative network. The network has three main bridges, two are over the Bosphorus and one is over the Golden Horn, and four tunnels. The bridges over the Bosphorus, both of which were built as suspension type bridges and are capable of serving as main arterials, called the Bosphorus and Fatih Sultan Mehmet (FSM) Bridges, in the South and North, respectively. All the 25 intersections in the network identified are grade separated. Most of the links can be considered as urban motorways.

4.2. Data Collection

Two places were visited on December 1994 to collect the necessary data. The Transport Engineering Division of the Civil Engineering Department of İstanbul Technical University provided the network, the demand and the control data. The 17th Regional Branch of the General Highways Authority of Turkish Republic (T.C. Karayolları 17. Bölge Müdürlüğü) provided material such as maps and bridge toll counts.

The network data included link lengths, layout of the network, layouts of junctions, number of lanes, speed limits, free flow speeds, capacity, minimum speeds, and saturation flows. In addition, an O-D matrix containing 22 origins and destinations that are based on 22 zones of the city was supplied by the university. Carrying out a combination process, this trip matrix was reduced to 17 origins and destinations, which has better fit to the data. Table 1 gives the names of these zones. Based on these zones, Table 2 is the trip matrix showing the number of vehicles travelling between origins and destinations, as well as presenting the distances between them. The control data were fixed (public transport) bus routes together with the number of buses per one-direction on some special links like bridges were also obtained from the University.

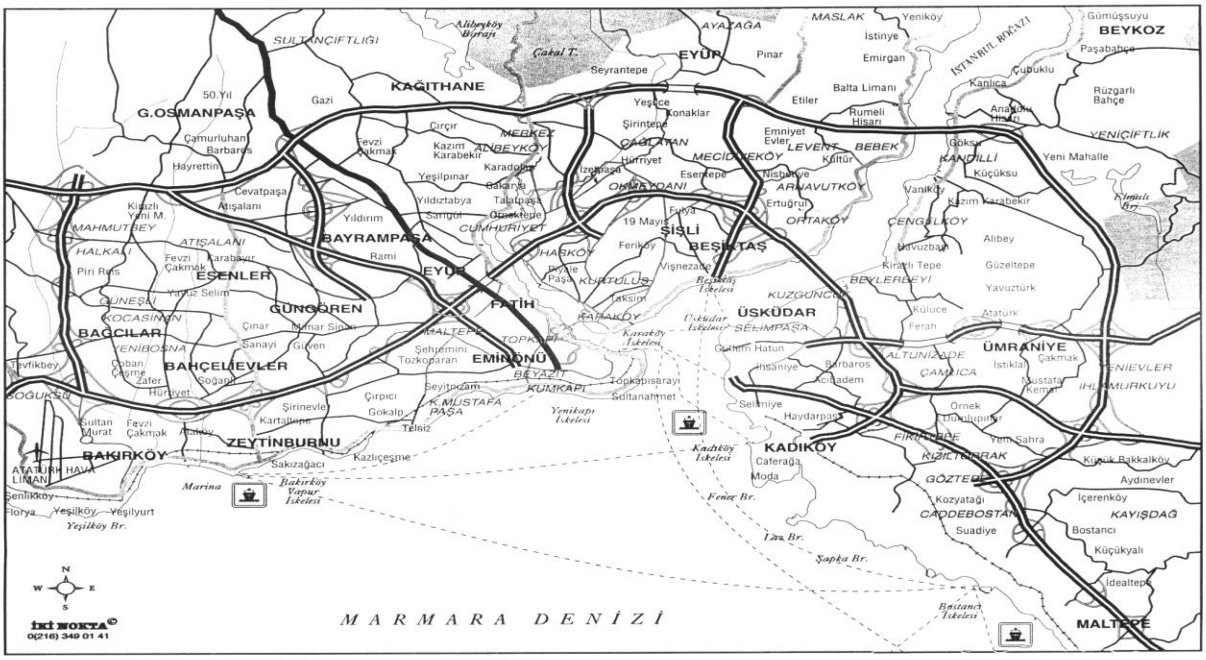

Figure 5 The layout of the network

Table 1 Names of The Zones

1	Outer Zone (West) + Gaziosmanpaşa	9	Kadıköy
2	Eyüp + Bayrampaşa	10	Üsküdar
3	Levent + Sarıyer	11	Beşiktaş
4	Beykoz + Kandilli + Çengelköy	12	Şişli + Beyoğlu + Mecidiyeköy
5	Ümraniye	13	Eminönü
6	Outer Zone (East) + Anatolia Motorway	14	Topkapı + Fatih
7	Kartal	15	Bakırköy (East) + Zeytinburnu
8	Göztepe	16	Bahçelievler + Bağcılar
		17	Bakırköy (West) + Yeşilköy Airport

Table 2 Traffic Between Zones Given in Passenger Car Units per Morning Peak *

	01	02	03	04	05	06	07	08
01	0	1558 (7.7)	7719 (21.1)	2965 (26.9)	178 (34.3)	300 (35.5)	1995 (30.4)	508 (33.9)
02	1558 (7.7)	0	3036 (19.1)	1163 (24.8)	154 (32.2)	180 (34.2)	2070 (28.1)	287 (31.5)
03	7719 (21.1)	3036 (19.1)	0	3156 (7.8)	328 (15.6)	955 (19.3)	2370 (32.8)	839 (21.4)
04	2965 (26.9)	1163 (24.8)	3156 (7.8)	0	766 (9.4)	760 (13.3)	1283 (19.8)	932 (16.1)
05	178 (34.3)	154 (32.2)	328 (15.6)	766 (9.4)	0	1432 (6.1)	2610 (18.3)	1517 (8.0)
06	231 (35.5)	180 (34.2)	955 (19.3)	760 (13.3)	1432 (6.1)	0	4005 (14.8)	9283 (4.4)
07	2175 (30.4)	1815 (28.1)	1995 (32.8)	1290 (19.8)	1800 (18.3)	3315 (14.8)	0	4035 (9.1)
08	508 (33.9)	287 (31.5)	839 (21.4)	932 (16.1)	1517 (8.0)	9283 (4.4)	4200 (9.1)	0
09	491 (32.5)	418 (29.8)	910 (22.3)	925 (18.3)	1090 (10.1)	5579 (7.2)	3570 (11.3)	16249 (3.8)
10	416 (29.7)	316 (27.1)	819 (21.4)	774 (17.4)	1045 (10.0)	4971 (6.9)	4065 (11.9)	13719 (2.7)
11	492 (18.3)	374 (14.0)	1065 (8.2)	1371 (13.1)	2268 (13.4)	5855 (12.9)	3405 (19.2)	6839 (9.9)
12	4049 (16.7)	2923 (12.2)	5248 (9.1)	7492 (10.4)	988 (15.5)	1454 (15.3)	3525 (20.1)	2139 (11.4)
13	4179 (9.0)	3481 (5.2)	4719 (15.5)	3754 (19.5)	683 (21.7)	1075 (21.9)	2325 (29.1)	2361 (18.2)

14	5795 (10.1)	5405 (6.3)	9575 (18.4)	324 (21.1)	716 (22.2)	893 (22.7)	3030 (30.8)	1472 (19.9)
15	7306 (11.4)	1789 (8.3)	8433 (35.7)	2277 (24.1)	157 (23.4)	251 (23.6)	2790 (31.9)	448 (20.7)
16	5949 (12.1)	1918 (6.1)	8932 (33.4)	2158 (24.8)	204 (23.9)	340 (24.2)	2625 (33.4)	576 (21.6)
17	4104 (9.7)	1865 (9.4)	7619 (22.0)	2301 (28.4)	184 (26.9)	349 (27.3)	2580 (34.7)	578 (22.9)

Table 2 Traffic Between Zones Given in Passenger Car Units per Morning Peak (cont.)

	09	10	11	12	13	14	15	16	17
01	491 (32.5)	416 (29.7)	492 (18.3)	4051 (16.7)	4179 (9.0)	5854 (10.1)	7306 (11.4)	5949 (12.1)	4104 (9.7)
02	418 (29.8)	316 (27.1)	374 (14.0)	2923 (12.2)	3481 (5.2)	5611 (6.3)	1789 (8.3)	1918 (6.1)	1865 (9.4)
03	876 (22.3)	819 (21.4)	1065 (8.2)	5245 (9.1)	4719 (15.5)	9595 (18.4)	8433 (35.7)	8932 (33.4)	7619 (22.0)
04	925 (18.3)	740 (17.4)	1371 (13.1)	9257 (10.4)	3754 (19.5)	3299 (21.1)	2277 (24.1)	2158 (24.8)	1950 (28.4)
05	1090 (10.1)	1157 (10.0)	2268 (13.4)	988 (15.5)	683 (21.7)	716 (22.2)	157 (23.4)	204 (23.9)	184 (26.9)
06	5579 (7.2)	4971 (6.9)	5855 (12.9)	1453 (15.3)	1075 (21.9)	895 (22.7)	251 (23.6)	340 (24.2)	349 (27.3)
07	3630 (11.3)	3720 (11.9)	3150 (19.2)	2880 (20.1)	2625 (29.1)	3600 (30.8)	2805 (31.9)	2625 (33.4)	2520 (34.7)
08	16249 (3.8)	13719 (2.7)	6839 (9.9)	2159 (11.4)	2361 (18.2)	1461 (19.9)	448 (20.7)	576 (21.6)	581 (22.9)
09	0	12545 (2.1)	6471 (7.8)	2570 (9.3)	2190 (16.1)	2021 (17.8)	450 (18.6)	573 (19.5)	702 (21.8)
10	12545 (2.1)	0	5151 (6.6)	2194 (8.1)	1610 (14.9)	1477 (16.6)	373 (17.4)	460 (18.3)	458 (20.6)
11	6471 (7.8)	5151 (6.6)	0	3880 (3.2)	2517 (10.8)	1814 (12.1)	406 (14.4)	525 (15.0)	516 (17.9)
12	2562 (9.3)	2205 (8.1)	3868 (3.2)	0	12739 (7.6)	9792 (9.1)	3326 (10.8)	3785 (11.5)	3876 (14.2)
13	2190 (16.1)	1610 (14.9)	2517 (10.8)	12577 (7.6)	0	8105 (2.9)	2700 (4.0)	2971 (4.9)	3580 (7.2)
14	1970 (17.8)	1484 (16.6)	1816 (12.1)	9792 (9.1)	8200 (2.9)	0	5205 (2.1)	8614 (1.7)	7341 (2.8)
15	450 (18.6)	373 (17.4)	406 (14.4)	3329 (10.8)	2700 (4.0)	5190 (2.1)	0	10378 (1.4)	9350 (2.1)
16	573 (19.5)	460 (18.3)	525 (15.0)	4155 (11.5)	2971 (4.9)	8271 (1.7)	10378 (1.4)	0	16463 (1.5)
17	704 (21.8)	458 (20.6)	516 (17.9)	3793 (14.2)	3580 (7.2)	7387 (2.8)	9350 (2.1)	16463 (1.5)	0

* Values in the parentheses are the distances, in kilometres, between the zones

4.3. Network Definition

After the study area was chosen and the necessary data were collected, another main task was the determination of the best network in the domain. As described in Section 2, intersections (nodes) and motorway parts (links) are the main elements of the network together with other measurements, such as link lengths, number of lanes and junctions types. The nodes on a network are major decision points for route selection during the journey from an origin to a destination. There are some alternative routes for drivers using the network. As far as crossing the Bosphorus is concerned, two roadway bridges (the Bosphorus and FSM) offer the main alternative routes. The route via the FSM Bridge and its outer motorway connections are considerably longer in distance than the routes using the Bosphorus Bridge whilst those outer routes provide less congested traffic. Therefore to meet this study’s requirements, it is assumed that on the approach arms of some junctions in the Asian part of the network, installation of Variable Message Signs can be carried out to tell the drivers to divert their routes to the FSM Bridge in the morning peak. To compare the two cases (described in Section 5.5), in terms of travel times, some major alternative routes were determined. In order to be able to show the effects of the two different scenarios, it was not necessary to compare all links and routes in the whole network.

5. CONTRAM ANALYSIS

5.1. The Theory of the Software

CONTRAM (CONtinuous TRaffic Assignment Model), developed by Transport Research Laboratory (TRL), is software used in traffic assignment and modelling studies. It is based on the representation of time varying traffic flow conditions, queue and delay calculations for networks. Therefore demands can be expressed in time slices over the investigation period. All travel times are composed of cruise times and delay times.

Time variation is carried out by splitting the study period into a number of consecutive time slices. Vehicles are treated in groups (packets) with the purpose of reducing cumbersome computing processes. Demand is in the form of an O-D matrix in which each figure of an O-D pair is the totality of packets.

At the commencement of running the program, the whole network is assumed to be empty and after the first iteration of assignment, packets start to enter the network from origins and must leave the network from destinations after some time. Packets are assigned to routes that minimise their travel costs. These travel costs can be considered in the form of either time or fuel price. (see also Leonard, 1989, for other details of the software)

5.2. Iteration Process

An iterative algorithm is employed by CONTRAM to produce the desired equilibrium distribution of traffic in a network. Mechanically speaking, within the first iteration, all the flows are set to zero and the first packet is assigned to its quickest route. Then the flow estimates at the corresponding links of the chosen path are updated considering this packet's entering/exiting times to/from the network. After that, new delays are calculated for the assignment of the next packet. This process is repeated until all packets are assigned to their estimated quickest routes through the network. Due to the time dependent user equilibrium feature of the program, further iterations are necessary, because in the first iteration the quickest route for the packets was determined by flows which had not taken into account the packets entering the network later on.

In the subsequent iterations the flow values are the ones obtained at the end of the preceding iteration. This second type of iteration continues until the assignment settles down and the procedure converges satisfactorily.

5.3. Data for the Software

The following three different types of data are required by CONTRAM Version 5:

i) Network Data File consists of card types (1-49 and 60-) defining such information as network topology, link and node characteristics, signal settings, cost functions and vehicle features.

ii) Traffic Demand Data File contains flow rates, expressed in veh/h, for different vehicle classes like cars, buses and lorries, distributed over time slices for each O-D pair.

iii) Control Data can be subcategorised as:

a) instructions for running the program and the form of its outputs; and

b) fixed Route definitions in card types 81 and 85 (if desired, Fixed Route Data can be combined with the Network Data as well).

5.4. Specification of CONTRAM

This study deals with congestion and queues in the morning peak in İstanbul road network. Therefore the software, being capable of representing time varying behaviour of traffic during the peak period, is the most appropriate modelling tool for such study. The network, in CONTRAM, is represented in nodes and links together with other magnitudes, which are described in Section 5.3. Time slices are determined as 30 minutes from 6.30 to 8.00 am., 15 minutes from 8.00 to 9.00 am. and again 30 minutes from 9.00 to 10.00 am. Analyses are carried out by considering car and bus traffic only. The network of the project consisted of 146 uncontrolled and 95 give way links, 17 origins and 17 destinations, and 146 junctions of all types. In addition, layouts of the network and each junctions, link lengths, number of lanes; and speed limits, free flow speeds, free flow rates, capacity speeds, capacity, minimum speeds, minimum capacity and saturation flows for each link were also entered. 17 zones and traffic movements between each origin and destination, and special counts on some entrances and exits, and on both bridges were the traffic demand data for the software. Fixed public transport (bus) routes together with the number of buses per one-direction on some special links like bridges were finally the control data.

5.5. Two Cases for the Assessment

For a given O-D pair, the most convenient route might vary from one driver to another due to the difference in perception, anticipation or some other criteria. However, basically travel time criterion is the most dominant one for decision making. In addition, the objective function for SO approach is the total travel time spent in the network. In this study two scenarios, Case I and Case II, were chosen to present basic results of such a travel time based approach. In more detail:

In Case I, it was assumed that drivers are capable of correctly estimating their own shortest routes, without taking account of society's general benefit. Wardrop's first principle states that traffic on a network distributes itself by making the travel costs on all routes taken by drivers from any O-D pair are equal, while all unused routes have equal or greater travel costs. Therefore, Case I assumes that actual traffic on the network is quite close to the User Equilibrium approach, as would be the case if most of the drivers are every day users and familiar with the network and traffic conditions. In this UE sense, the first CONTRAM run uses minimum travel time assignments in an iterative manner until convergence, to obtain a set of routes taken by drivers. Main results reflecting the whole system and some important routes are presented in the relevant column of Table 2.

In Case II, CONTRAM was run a second time, this time with some traffic diverted to alternative uncongested routes. Some drivers experience higher travel costs while the system as a whole has lower total travel times. The assumption of this case is based on an assumed 15% compliance to the suggestion of a possible Route Guidance (RG) system which is a diversion to the FSM Bridge. To implement the requirements of Case II, traffic demand data was arranged in such a way that 15% of traffic generated by Origins 09 and 10 and travelling to Destinations 11, 12 and 13 were diverted to the second bridge by using CONTRAM's fixed route facility, because these six O-D pairs are the major movements (due to the special attitudes of drivers in the city, this amount was determined as 15%; by choosing different percentages, a compliance analysis can be carried out for the same network in future studies). This RG should be understood as a hypothetical one assuming that some Variable Message Signs are installed on the approach arms of intersections, located on the Asian side. Necessary route recommendation could also be implemented by Radio Message Channels or any other collective dissemination (Günay, 1996). In short, Case 2 is the representation of the same network from the SO aspect.

6. RESULTS

Significant reduction in travel times was obtained on the major routes for Case II. Regarding the whole network, system journey times have also fallen down by 3.56% due to the System Optimising diversion. Summary results of the whole network are given in Table 3.

Table 3 Concise Results Regarding the Whole Network

	Case I (UE)	Case II (SO)	Difference (%)
System Journey Time	116076 (veh-h)	111942 (veh-h)	- 3.56
Total Distance Travelled	3906199 (veh-km)	4087131 (veh-km)	+4.4
Overall Network Speed	33.7 (km/h)	36.5 (km/h)	+7.67

Table 4 Decline in Travel Times on Some of the Major O-D Pairs

	% Reduction
Göztepe-Beşiktaş	7.1
Ümraniye-Beşiktaş	6.3
Göztepe-Mahmutbey	3.2
Kadıköy-Bakırköy	1.4
Üsküdar-Okmeydanı	9.3

Some selected paths shown in Table 4 were deliberately chosen to demonstrate the changes in travel times for major O-D-pair movements.

Since the predominant interest of the study was the traffic crossing the Bosphorus, some results obtained from the two runs of CONTRAM are compared here with a particular consideration of the two bridges. In Table 5 this comparison is made for the morning peak (traffic flow direction is from the East to the West) and for the selected links (the two bridges).

Table 5 Some Changes in Case II on the Two Bridges

	The Bosphorus Bridge	The FSM Bridge
Cruise Time	% 3.4 decrease	% 30.0 increase
Flow	% 1.0 decrease	% 2.0 increase
Queuing Time	12.2 % decrease	% 27.0 increase
Average Car Speed	16.2% increase	% 35.0 decrease

The table basically shows drops in travel times, flows and queues, and increase in speed values on the Bosphorus Bridge crossing for Cases II. For the second crossing (the FSM Bridge), it can be deduced from the table that increases in travel times, flow and queues are observed in Case II compared to Case I. All of these might suggest the effect of some traffic diversion towards the FSM Bridge in Case II resulting from a SO assignment.

7. CONCLUSION

7.1. Discussion

As the tables in Section 6 revealed, drops in travel times could indicate congestion release on some of the links on these routes. It was expected that diverting some traffic from the Bosphorus Bridge to other alternatives would cause less total journey times to the whole network as far as system optimising effects of this diversion are concerned. The outcomes of the study produced by the CONTRAM simulation model have justified our belief, in the importance of a traffic management solution to the existing network conditions. Nevertheless, it should be noted that this belief does not conflict with the benefits of engineering solutions, in particular an undersea tunnel connecting the two sides. The results of the study regarding the network defined in Section 4.3 enables us to estimate some effects of a possible RG application. Ascertaining the differences among the two cases, in terms of journey times, was the main objective of the study, because the basic traffic problems seek solutions to the congestion occurring on the Bosphorus Bridge’s approach motorways. In Case II, traffic demand data for CONTRAM was arranged in such a way that a certain proportion of all demand, which travel from the Origins 09 and 10 on the eastern side of the Bosphorus to the Destinations 11, 12 and 13 on the western side of the Bosphorus, are assumed to obey the suggestions given by a hypothetical RG system. The remaining did not accept these messages which recommend a diversion to the second bridge. Therefore Case II, is the investigation of the effects of a proportional diversion from the congested bridge to the other one by using some Variable Message Signs installed in the necessary positions or by any other type of RG techniques. These recommendations might be considered as unwanted messages, because initially they seem to offer longer routes to the individual drivers. In order to see how much longer travel times will be experienced by the drivers who accept these RG messages, a comparison of the two paths can be made as shown in Table 6.

Table 6 Comparison of Journey Times between the Conventional Path (the Bosphorus Bridge) and the Recommended Path (the FSM Bridge)

O-D	% increase in the recommended path	
Pairs*	in time	in distance
9-11	19.6	186
9-12	16.4	123
9-13	8.3	84
10-11	15.8	244
10-12	11.1	206
10-13	3.4	126

* See Table 1 for the numbers

As can be seen in the tables, the FSM Bridge alternative does not offer much longer journeys, although considerably longer routes are travelled in distance. Therefore it can be stated that, based on the results demonstrated in Tables 2 and 3, the society (or the whole network) gained a significant benefit from this diversion. Total system journey times reduced, while a proportion of vehicles experienced slightly longer alternatives. As a result of this reduction in the total travel times, reduced fuel consumption and emission is expected. That is to say, less environmental damage and more national savings are likely to result. Moreover, less waiting times caused by the queues, and therefore less loss in time values are also expected. Thus, it is useful to emphasise that most of the journeys which are from the East to the West in the morning in Ýstanbul are business trips. This study’s analyses were based on the morning peak, too. Therefore the total travel time saving of 3.56% in Case II is likely to have more importance when converted to the monetary values.

7.2. Recommendations and Further Research

It is concluded from the results that re-routing a certain proportion of traffic by means of a RG application would be beneficial if utilised. It is also recommended that for short term applications, Variable Message Signs and/or specially assigned radio channel should be used to provide information to drivers in order to ease the congestion. Prior to deciding to establish RG systems in the study area, the following points should also be investigated by the authorities:

i. the cost and technical performance of the system;

ii. consumer response; and

iii. safety aspects.

For further work the following points could be investigated in the future:

- Similar study with more up-dated and expanded data including internal links within the zones;
- similar study for evening peak because the network is not symmetrical (it should be noted that the main congestion happens on exactly the opposite direction in the evening);
- specifying the traffic demand data, to investigate what would be the effect of "Car and Public Traffic Only" policy for the Bosphorus Bridge;
- an economic analysis of the effects of bridge toll on the flows of two bridges where one is highly congested and the other one is not; and
- the effect of a new link to the network (a proposed undersea tunnel connecting the two sides of the Bosphorus) on the flow and travel time magnitudes of the same network.

8. ACKNOWLEDGEMENT

I would like to thank Professor Michael G. H. Bell for his supervision with an inspirational guidance of the work which formed a basis for this paper, and Professor Ergun Gedizlioðlu for his immense help at the data collection stage.

9. REFERENCES

Bell, M. G. H., Shield, C. M. and Anderson, J. M. 1995. Assignment in the integration of Urban Traffic Control and Dynamic Route Guidance, Urban Traffic Networks: Dynamic Flow Modelling and Control, Ed. N. H. Gartner and G. Improta, Berlin: Springer-Verlag.

Damberg, O., Lundgren, J. T. and Patriksson M. 1996. An Algorithm for the Stochastic User Equilibrium Problem. Transportation Research-B, 30 (2), 115-131.

Gedizlioğlu, E. 1995. “İstanbul Kentiçi Ulaşımında Aktarmalı Yolculukların Önemi **3. Ulaştırma Kongresi**, 5-7 Haziran ‘95, İstanbul.

Günay, B. ve Bell, M. G. H. 1996. “Trafik Tıkanıklıklarına Çözüm Olarak Elektronik Yol Yönlendirme Sistemlerinin Kullanımı; İstanbul Boğaz Geçiçi Örneği” **1. Ulusal Ulaşm Sempozyumu ve Sergisi,** 6-7 Mayıs ‘96, İstanbul.

Leonard, D. R., Gower, P. and Taylor, N. B. 1989. CONTRAM: Structure of the model. TRRL Research Report, R178, Crowthorne.

Newell, G. F. 1980. Traffic Flow on Transportation Networks. The MIT Press, USA.

Ran, B. and Boyce, D. 1996. Modeling Dynamic Transportation Networks: An Intelligent Transport-ation System Oriented Approach. Springer-Verlag, Berlin.

Sheffi, Y. 1985. Urban Transportation Networks Prentice-Hall, Inc., New Jersey.

Steenbrink, P. A. 1974. Optimisation of Transport Networks. John Willey & Sons Ltd., Bristol, England.