Scientific Research and Essays Vol. 6(28), pp. 5865-5882, 23 November, 2011
Available online at http://www.academicjournals.org/SRE
DOI: 10.5897/SRE11.814
ISSN 1992-2248 © 2011 Academic Journals

Full Length Research Paper

Alteration of bus routes in large-scale networks

Murat Ergun[1] and A. Sercan Kesten[2]*

[1]Transportation Department, Civil Engineering Faculty, Istanbul Technical University, Ayazaga, 34469, Istanbul, Turkey.
[2]Department of Built Environment, Yai Laboratory, G3-10F. 4259, Tokyo Institute of Technology, Nagatsuta-cho, Midori-ku, Yokohama, 226-8502, Japan.

Accepted 13 July, 2011

Route assignment and scheduling of buses are critical in network utilization and modification of bus routes should seek more efficient methods for operation. Ineffective operations would increase the average travel time and therefore decrease the level of service which yields increase in social cost. This paper presents an alteration method for increasing the efficiency of bus networks considering the shortening of routes without changing the vehicle headway. Istanbul city has major congestion, environmental, and safety problems. A need exists to develop a practical methodology to modify the bus routes along with efficiency considerations for more reliable and better quality of service. Besides long and inefficient lanes, there are significant kilometers of routes overlapping on existing bus network of Istanbul. The total savings, through reducing parallel capacities along Metrobus (BRT) and Tramway, are determined for both of the operator and user perspective. It is shown that, improvements in terms of service quality for passengers and efficiency for operators can be achieved simultaneously by changing route alternatives. The results shows that by shortening most of the lines analyzed with all the measures proposed, considerable amount of bus kilometers per day can be saved. In addition, by reducing headways in low occupied sections and by accelerating bus lines the average speed of buses are increased which leads to travel time and accordingly economic savings. The alteration of the bus routes has also impacts on other modes, such as privately operated buses, are also investigated. In conclusion, the results are interpreted for the Istanbul metropolitan area in the light of quality of the service measures.

Key words: Bus transport, route alteration, economic analyses, time savings.

INTRODUCTION

As most of the cities in the world, public transportation of Istanbul is strongly dependent on bus transportation. According to the 2006 Istanbul Electric Tramway and Tunnel Operator (IETT) data (IETT, 2006), buses are responsible for almost 70% of the public transport trips. In the last decade, due to the economic changes the debate on efficiency of publicly or even privately operated urban buses has become a critical issue either practically or academically. There are numerous studies on bus network efficiency for European, North American and Australian cities in addition to some guidelines and synthesis reports (Benn,1995;Pratt and Evans, 2004).

Istanbul is the most populated city in Turkey with 13 million inhabitants and geographically the city is fairly large. Given that the size of transit operation, there are a number of problems existing such as monitoring system performance and management. Although smaller organizations are considered as manageable manually, additional unavoidable costs may occur at the level of a large scale system (Van der Perre and Van Oudheusden, 1996).

System efficiency and in this context, effectiveness are the main objectives for bus system alteration projects. Rerouting and changes in the service area may affect both efficiency and effectiveness of the public

*Corresponding author. E-mail: kestena.aa.m@titech.ac.jp. Tel: +81-45-924-5675. Fax: +81-45-924-5675.

transportation. Hence, the adjustment or extension of the existing routes and/or the creation of new bus routes should be dealt adequately. Such alterations should contribute to preserving or enhancing the mobility and accessibility of the non-driving population, create alternative competitive modes to car use, and, especially in congested or sensitive areas, to minimize auto travel and related automobile infrastructure requirements. Conversely, transit route and coverage curtailment may be undertaken as a cost cutting measure (Pratt and Evans, 2004).

To achieve an optimal design of a transit system, researchers have in the last several decades proposed many approaches. Owen (1980) presented an optimal frequency and size of buses by including the costs. The adaptation of the existing networks to increased demand can be costly and various mathematical models such as genetic algorithms (GAs) and simulated annealing (SA) are proposed to solve this issue. Bielli and Carotenuto (1998), Zhao and Zeng (2006) and Zhao and Zeng (2008) described a metaheuristic method for optimizing transit networks, including route network design, vehicle headway, and timetable assignment.

In this paper, the focus is given on the bus network optimization and the alteration of bus routes study. Data collection process and the types of data are initially described. Following this, the statistical facts and analyses are identified with the emphasis on current the situation. The bus transport modeling methodology which allows investigating the critical routes is described in details. Finally, the optimization and alteration of the bus network is delivered, the results are displayed and the conclusion and recommendations are drawn. The cost savings in this paper are calculated as New Turkish Lira (NTL) as of 4th of January, 2007 and 1 NTL corresponds 0.7065 United States Dollars (USD).

DATA COLLECTION AND STATISTICAL FACTS

In order to conduct a bus network optimization and alteration study, building a representative model of the current public transport is a prerequisite. In addition, the mode preferences and the other factors affecting trips such as car ownership, traffic network and congested sections of the network should be taken into consideration. As in most of the studies, it is not possible to collect the data about entire network which yields to the development of simple representative models by utilizing the data available. In this study, the basic information of the model (example, bus stops, line routes, departure times …) is acquired from IETT, SERTEM and ZIV (SERTEM and ZIV, 2007) with mostly different data types and formats. Numerous transformations and adaptations are performed while the development of the public bus transport model. Finally, all the different data was inserted within the specific format requirements of the used macro-simulation program (VISUM®, Version 9.44, PTV).

The dependencies of the different types of transport like railway, seaway and bus made it necessary to build up a model that reproduces the status quo of the current public transport situation. After an extensive calibration of the model with the repetitive changes of network parameters (example, line length, speed, capacities …) and checks with the given basic data, the calibration process completed. With the given project goals, this study only covers the analysis of public transportation system. Nevertheless, the proposed network model gives consistent information about the general impacts of the suggested improvements of the transportation network.

The basic data concerning the geographical situation of the Istanbul road network and the existing bus stops was generated on geographical information system (GIS). The need of even more detailed data for the current bus lines on the given road information was another challenge to receive a working public bus transportation model. For example, small gaps in the digital data between the roads and links had to be manually closed, multiple existing link sections had to be erased carefully and a lot of bus stops had to be aggregated to transfer points which the stops belong to.

The allowed and possible speeds on the links are available for some parts of the road network. Missing speed information is assumed by applying a load factor which is a function of the density on the road and the findings are integrated in the network.

In order to calculate the amount of needed public transport vehicles on all network links, it is essential to know the maximum possible capacity of each vehicle type. The capacities of each vehicle are obtained from IETT (2007). On the other hand, the timetable information of the vehicles operating on the designated routes was digitalized by SERTEM in different data formats. Some missing timetable data are gathered via searching the website of IETT. Transfer points play an important role and it is also included in the model. Another work is combining different data formats in a unique format. The entire data collected and generated are integrated by transforming different formats and used in the network model. With this information together with the schedules, bus stops and speeds, the current demand and overcrowded sections in the public transport model and the IETT bus network is determined.

Descriptive statistics

According to ZIV (2005), the average speeds of the bus lines in Istanbul is different at three regions as; 16.7 km/h in Anadolu, 13.5 km/h in Beyoglu and 15.9 km/h. With an overall average speed of 15.4 km/h, the Istanbul

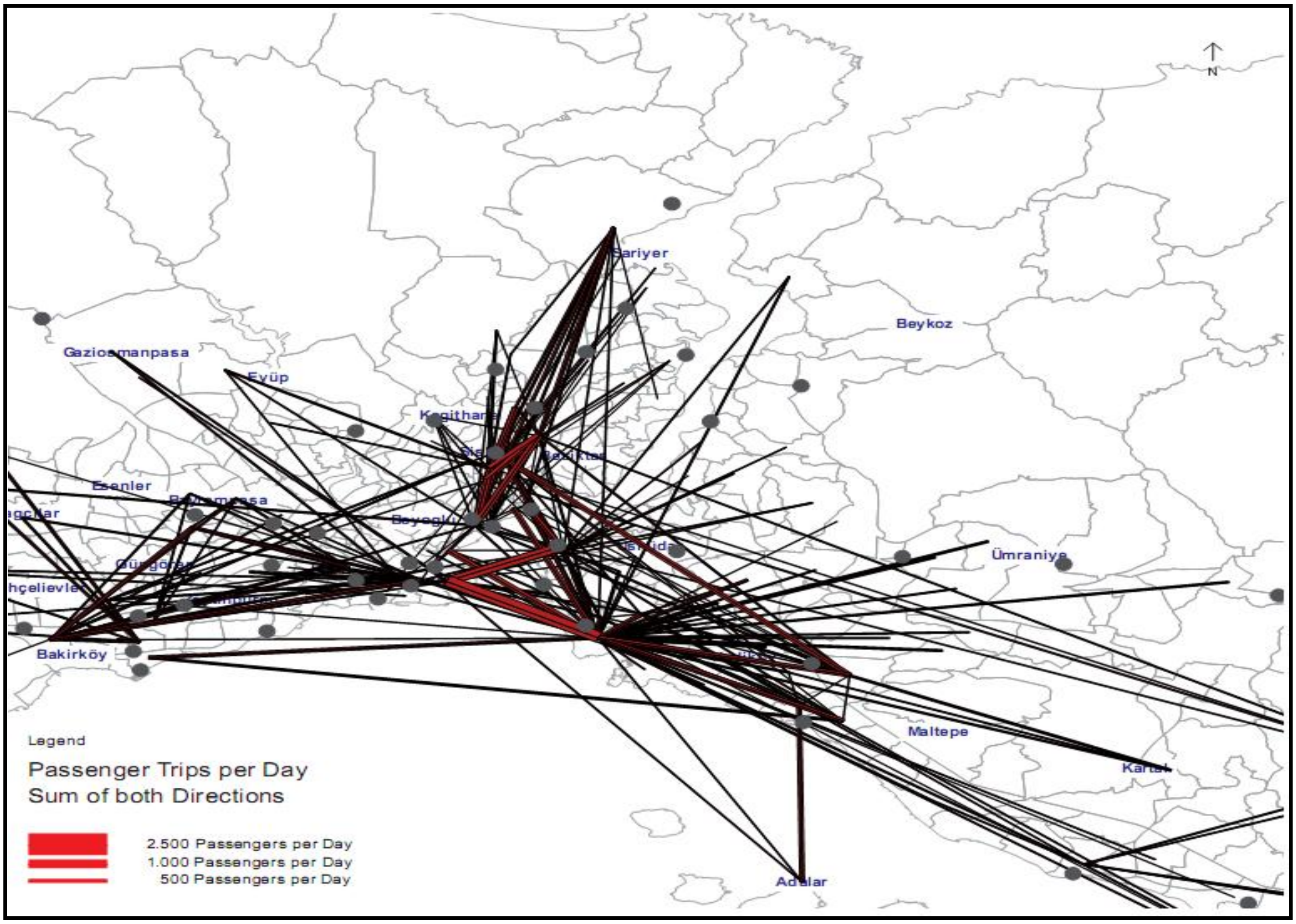

Figure 1. Distribution of the demand and OD matrix trips between zones (>1.000 persons/day).

metropolitan region is at the same level as example, Bucharest (15 km/h) and London (14 km/h) and far better off than Beijing where the average speeds are less than 10 km/h. However, there are also cities with a faster public bus transportation system such as Budapest (25 km/h) and Athens (22 km/h). Indeed, there is a potential in Istanbul to accelerate the bus lines. For this acceleration, several different measures have to be taken. One of the measures would be the introduction of separate bus lanes. In Dublin for example, a remodeling of the major highways leading to the city, the so called Quality Bus Corridors proved to be a big success. Reductions in the travel time of the public transportation system around 30 to 50% and increase in the passenger numbers around 20 to 100% is achieved (depending on the corridor). Moreover, car use decreased over 25% in 2006 in comparison to the year 1996 (Dobruszkes and Fourneau, 2007; Dublin Transportation Office, 2006).

The average age of the 2,800 IETT busses in Istanbul is 12.2 years which is below the average age of major European Capital cities. Compared to other European cities this is very old. In order to improve the comfort for the passengers and to enhance the reliability of the busses, the modernization of the IETT bus fleet should be steadily continued.

One of the most important components for a consistent representative model is a reliable OD demand matrix for public transit. This data is adopted by SERTEM for the 452 traffic zones. In general, the more traffic cells are used, the more precise the result can be achieved. On the other hand, increasing the zone number would yield complex model which requires high capacity computers and obviously to a more computation time. The OD matrix includes whole passenger trips of IETT buses, railways (including LRT and tram) and seaways. Although there is no reliable data available for the minibuses and private buses, these lines and schedules are integrated to the digital public transportation model by assuming fixed amount of demand from those models. Figure 1 shows the process of distributing the demand on the

Table 1. The network model data and the benchmark values.

Attribute	Number
Districts	33
Lines shared with private busses	152
Lines served by IETT busses	437
Zones	452
Stops	981
Bus stops	4,100
Nodes	62,218
Benchmark values	
Km of total length of lines	24,150
Passengers in the morning peak hour	212,500
Bus kilometers per day	490,000
Passenger hours per day	1,400,000
Passengers per day	1,900,000
Passenger kilometers per day	26,000,000

public transport network in the public transport model developed and the OD trips between zones.

It is worthy to note that most of the routes are found to be very dense; even each OD pair have enough potential to possess a direct bus line that serves every hour or every 30 min in the peak hours. Despite the situation is more catastrophically dense around the central part of the city, it is not feasible to operate additional buses due to the congested lanes.

Another important topic to mention is that the original OD matrix had to be modified after the introduction of the different planning proposals in the proposed public transportation model. Modifications on bus network and revamp yields a change on mode preferences. It is expected that more people will use it, when travel times are reduced and the mode is more convenient. Thus, the OD matrix is modified according to the prospected land use and planning policies. The entire network model data attributes used for the public transport model and the benchmark values are shown in Table 1.

MODELLING BUS TRANSPORTATION

The process of modeling the bus transportation system requires some necessary assumptions in order to rebuild the real situation consistently. Transfer time between the vehicles of the same system including the walking and waiting time is assumed 10 min globally. The transfer time between different systems, such as bus and rail or ferry, is also assumed as 10 min. The time to reach the first bus stop from the zones is assigned as 5 or 10 min, depending on the size of the zone. Moreover, model is based on the peak-hour demand, which is estimated 11.3% of OD matrix.

METHODOLOGY

In the research on traffic network modeling, assignment of the link resistance function mainly depends on the relationship between the travel time and the link flow. Most of the previous studies mainly focused on the assignment model establishment and algorithm design, although they used simple functions like one of the most prominent developed by Bureau of Public Roads (BPR) (Sheffi and Powell, 1983). Naturally, it is hard to describe the real traffic flow conditions by using these models, because the link resistance functions used in most of the researches have shortcomings inherent in their approach. For the sake of simplicity, the characteristics of different travel modes have not been considered in the previous link performance functions development studies (SI, ZHONG and GAO, 2008). Therefore, the interferences among different traffic modes have been neglected in this study and only bus vehicle speeds are taken into account in assignment process.

In this paper, as for the network performance there clusters of road type factors are generated according to their relative importance and speed profiles. In addition, the roads are also classified depending on the density of the surrounding road network. Therefore, the average observed speed at the main roads in densely populated areas or in the city centre is much lower than the same road types in the outer areas. In Table 2, the classification of the roads, and general speed and density classes of the network, which are used to identify a road type factor are given. The basic speed of the IETT bus lines is 17 km/h and the average speed is recalculated according to the density and road type factor as:

$$\text{Speed} = \text{Average speed} \times \text{road type factor} \times \text{density factor} \quad (1)$$

This gives the exact speed for each road that can now be used in the model. For example, the speed of a local road at a highly dense neighborhood, where the road type factor and density factor are both 0.7, is: $17 \times 0.7 \times 0.7 = 8.33$ km/h and the speed on a moderately dense highway, where the road type factor becomes 1.5 and density factor gets 1.0, is: $17 \times 1.5/1.0 = 25.5$ km/h.

Table 2. Speed and density classes of roads.

Road type	Speed interval	Factor
Local road	<= 25 km/h	0.70
Arterial	<= 50 km/h	1.00
Highway	> 50 km/h	1.50
Density of road network	**Color**	**Factor**
High	Red	0.70
Moderate	Orange	1.00
Low	Green	1.50

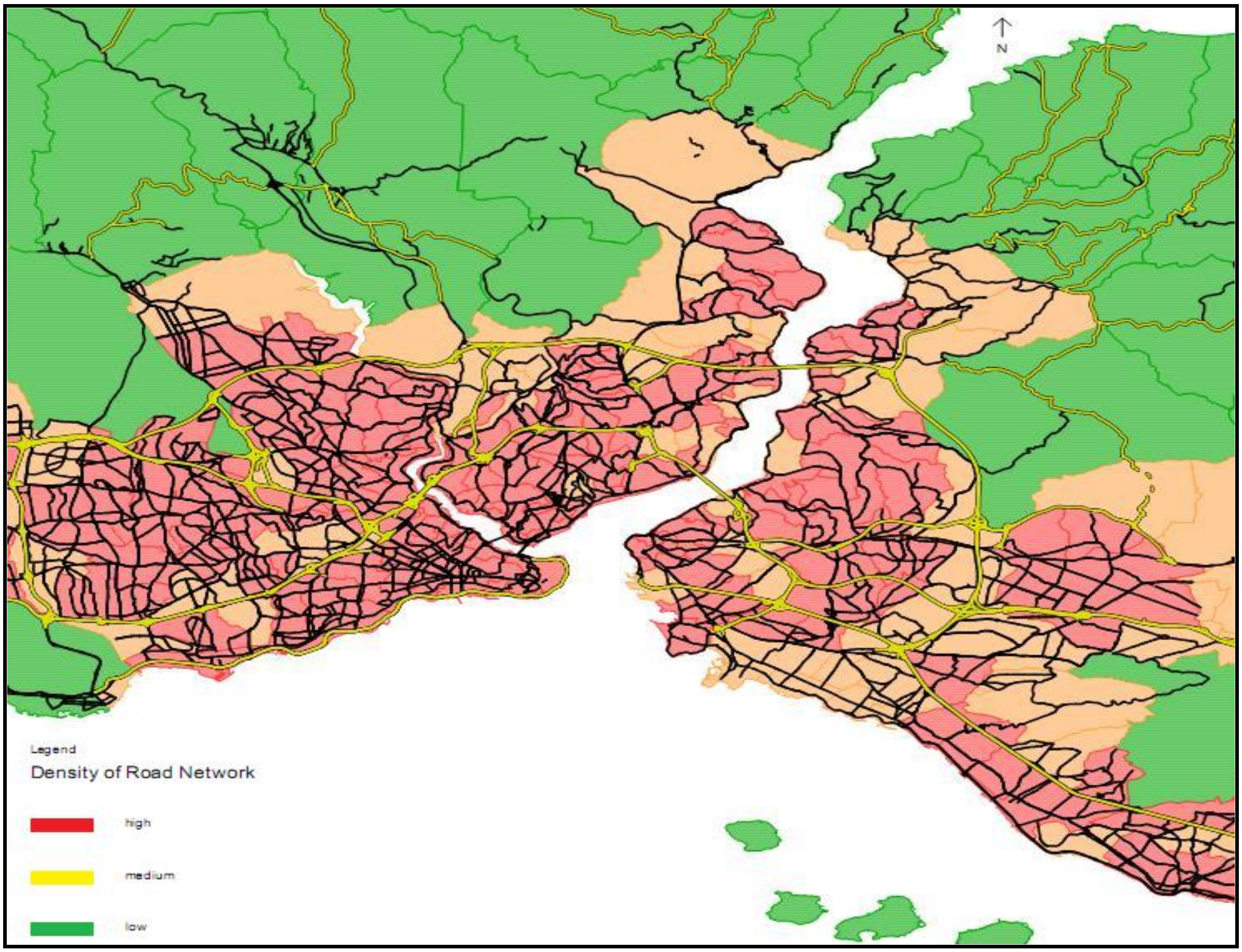

Figure 2. Average link speeds of the network.

Although this speed seems relatively low, the authors believe this result is due to omission of the real dwelling times at the bus stops and also the readers should keep in mind that the calculated speed is the average travel speed of the bus. The link average speeds are illustrated in Figure 2.

In transportation modeling studies, passenger behavior plays an

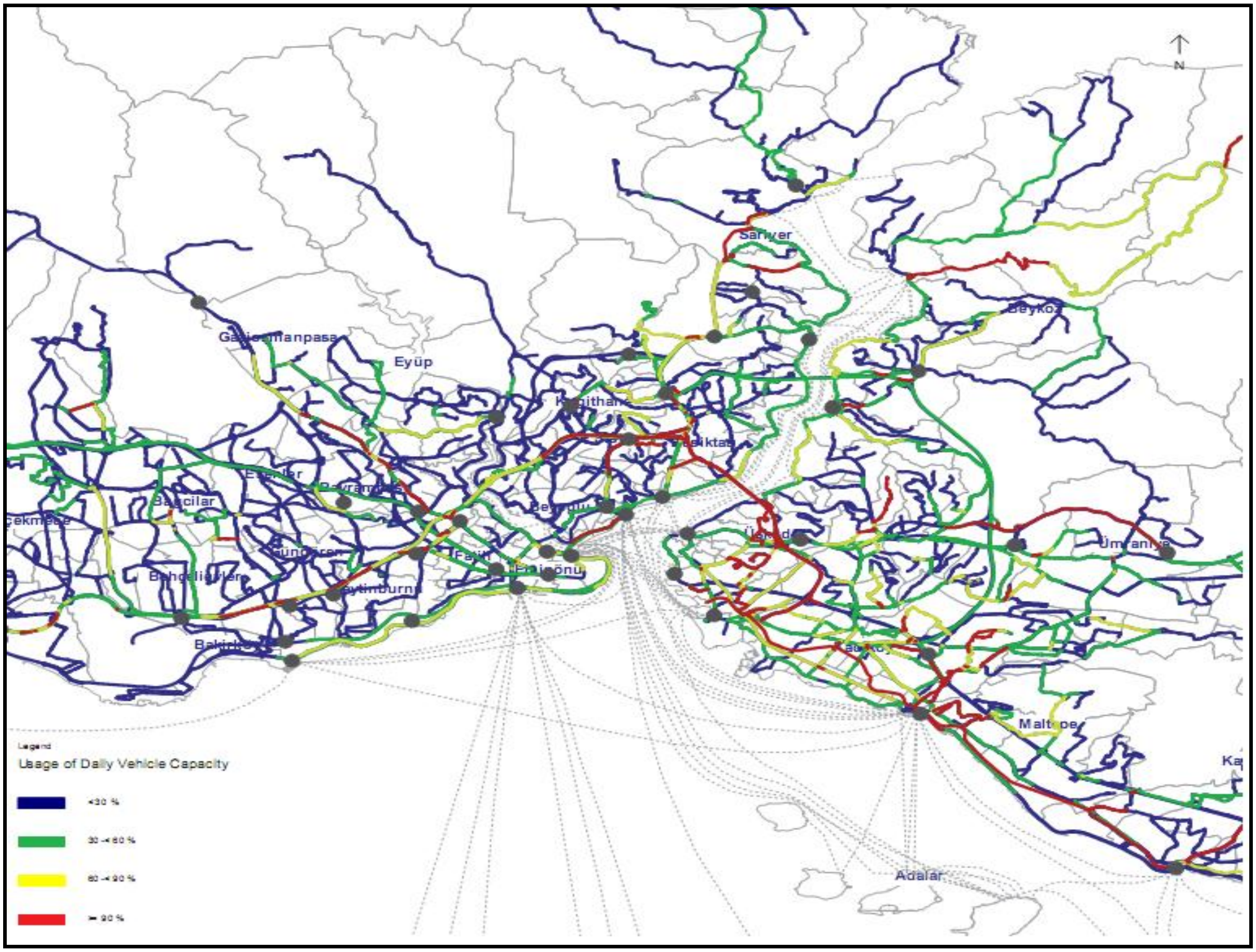

Figure 3. Capacity Usage of the whole bus network.

important role for a coherent estimation of demand and modal split. In this study, not only the pure technical parameters had to be modeled, but also the individual behavior of the passengers. In a variety of former studies regarding the passenger behavior, it is found that transfers form one bus to another is not only time consuming, but also it is not preferred even if it takes a little longer to reach the destination without a transfer. Consequently, the model uses additional parameters to take these kinds of individual based comfort related approaches in regard. But these parameters are not distinguished between different user groups or geographical regions.

Concerning the calibration of the model, successive and iterative changes are performed to check the parameters and results. Eventually, a good representative model in terms of passenger demand and network capacity is generated.

Investigation of critical routes

The network design defines the allocation of vehicles and packages to routes through the network (Taylor and L. de Weck, 2006). Within the complete public transport network, the network structure of the IETT bus lines is very homogeneous and the importance of the lines is not distinguished. As exceptional, the network encompasses most of the areas in the network and it is accessible even the furthest suburbs of the city. Although from the passenger point of view this operation is convenient and comfortable, for IETT it leads to a bulky and almost unmanageable complex network.

Another important fact is that the railway based and high quality public transportation alternative is much more developed in the European side. Thus, on the Asian side, the bus traffic has even more important role, but unfortunately without well defined high quality backbone on the network.

In the public transportation model, since the current capacity usage of each bus line that cannot be identified exactly, the capacity usage of the network sections are given as a percentage value over the whole day. Figure 3 depicts the daily capacity usage of all means of public transport as bus and Bus Rapid Transit (Metrobus in Turkey) on the different roads.

The capacity usage of links given in (Figure 3) can be used very

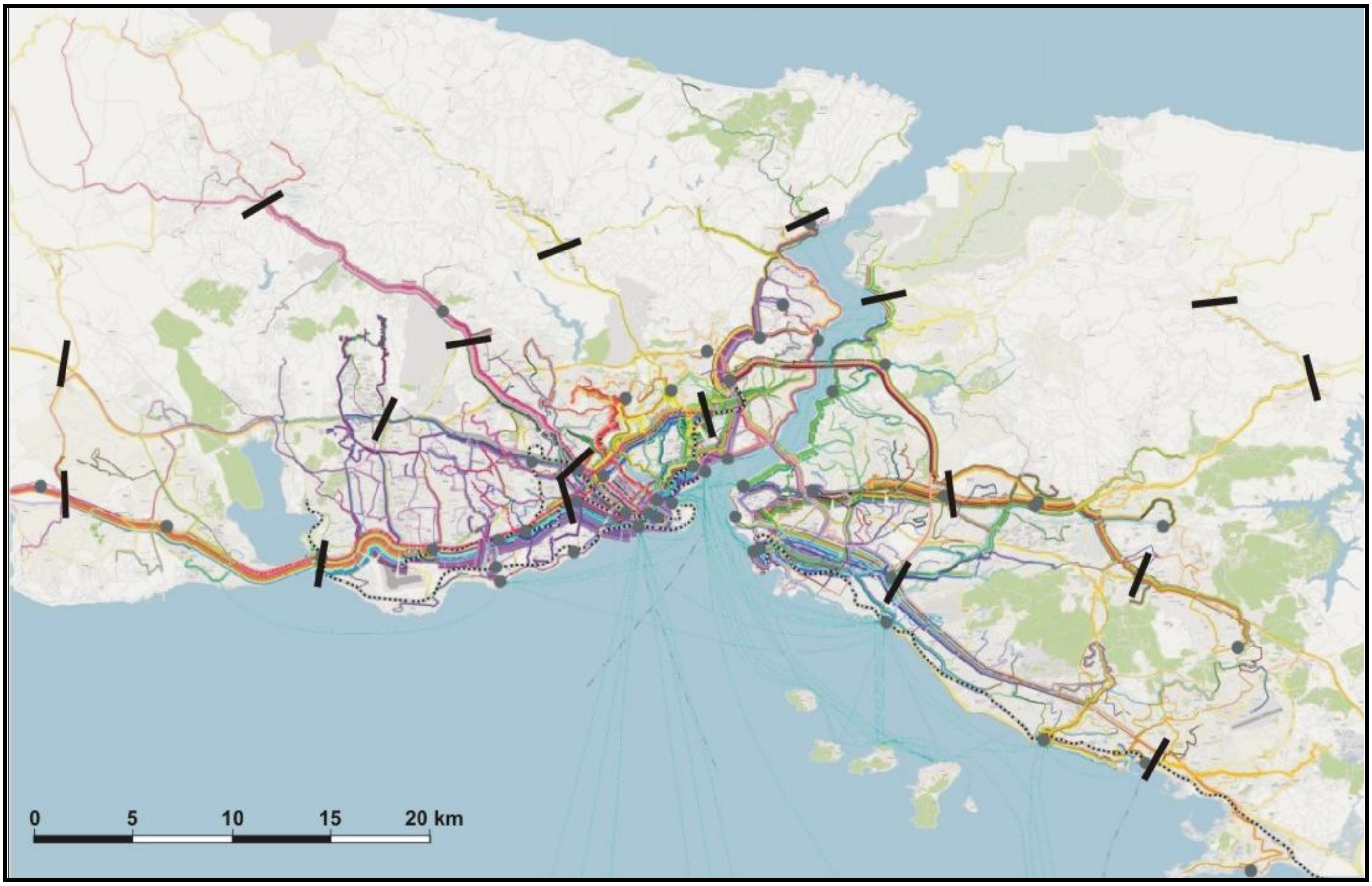

Figure 4. Cut offs for splitting long routes.

efficiently to search for regions, where an alteration required for a more efficient operation or where an increase of the transportation service needs to be offered.

Alteration of bus transport

Planning proposals are initially discussed with IETT authorities in order to determine the policy guidelines. The objective is to operate the bus network more efficiently and increasing the quality of service without any cost increase. During this stage, major prospected transportation projects concerning the new LRT and Metrobus lines are considered as realized. These new lines also have been inaugurated in 2007 or 2008 as it was foreseen.

Parallel bus lines to lines of Light Rail Transit or the Metrobus(Bus Rapid Transit) are one of the biggest concerns of IETT as they have similar routes and serving at close stations in the same region. The bus lines that run within a little distance of the railway lines (commuter rail) and the Metro (4. Levent – Taksim) are not affected, as these transport systems have greater distances between the stops so that the busses can be used for providing a feeder service.

In order to increase the on time performance and decrease the operation cost, another policy proposed to IETT is suggested to be discounting all lines longer than 20 km. Therefore, all lines longer than 20 km is analyzed to be eligible to split into several parts.

For this aim, all lines longer than 20 km have been split into two or more only if it is not practical (example, lines with a length of 25 km where only a very small part of the line would be left) or not possible to have a line longer than 20 km. The cutoff lines which are used for splitting long routes are shown in Figure 4. For some cases it is not possible to cut line routes which bounds for different zones and dwell at the same stops through some stretches. If the lines split in reality this would cause a decrease in service coverage. For these lines, if necessary, line routes have to be modified at first. One obvious result of this splitting is a highly increased number of line routes and trips with changes. Obviously, splitting lines is not an exact method of optimization but mostly an alteration. Especially from the passenger aspect, travel times would be higher than before as the number of changes increases. The increased number of changes also leads to higher trip costs for passengers. In this case, both effects can induce a different behavior in favor of other modes available. Therefore, increasing the speed of buses is one of the most efficient ways of utility maximization. At the same time, it is also the most challenging way that requires an intensive effort.

Yet, reliability and speed of the bus network can be increased and decreased travel times make the system more attractive for passengers while the operator can save up to a more efficient system. To receive an optimum result of the acceleration of bus lines, different measures should be taken such as; bus lanes on important city corridors(main arterials), bus lanes on highways

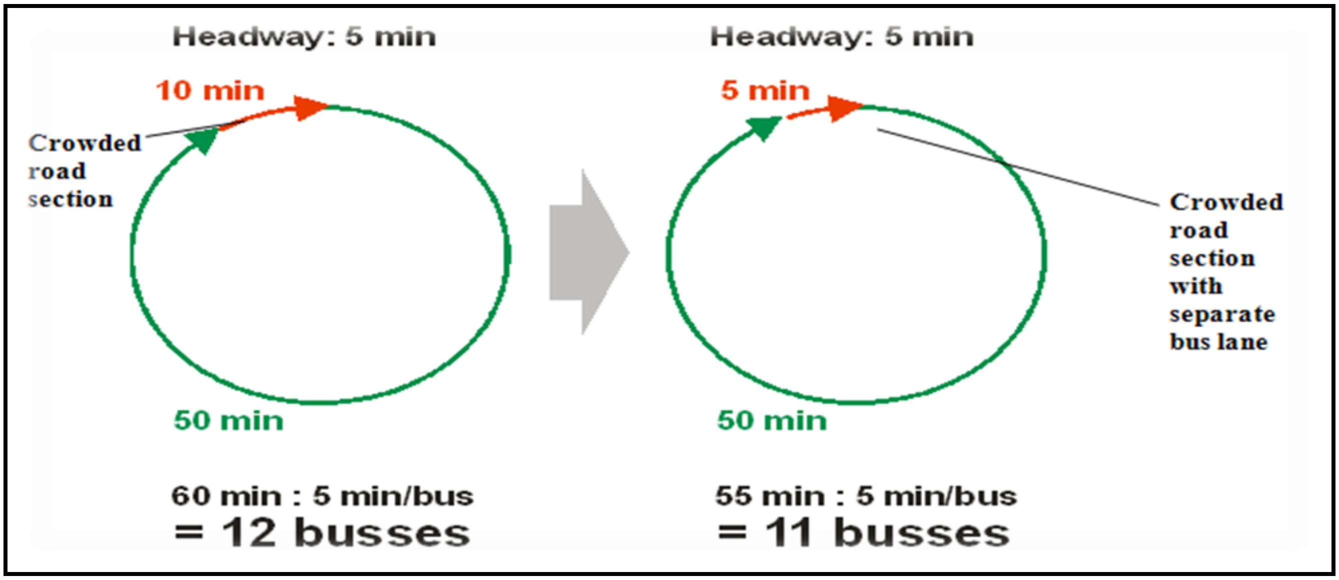

Figure 5. Bus speed increase and savings.

(example, by use of highway safety lanes or extra lanes), sharing of the lanes by tramway and busses, bus priority signaling.

Existing data only include the daily traffic flow and the amount of flow over time for the whole day. Due to the fact that we do not have data about the traffic flow for specific hours it is not possible to distinguish between the morning and the evening peak hour. For the reasons mentioned earlier, the proposals for the maximization of the capacity usage are based on the daily traffic flow. Additionally, capacity utilization may be low only on specific sections of a line, but not on the entire route. In this case, runs can be saved only on the section with low utilization. The model shows the area where the capacity usage changes from a higher to a lower utilization. In reality the utilization changes gradually, in the model it changes at a specific stop.

The average speed increase yields in the increase of the reliability of travel time of public transport, increase of the attractiveness of busses to the bus users, facilitation of the bus circulation and improve accessibility, decrease operating costs via less crew and decreased fuel consumption. Figure 5 explains schematically, how the acceleration of buses helps in saving. Basically, it is obvious that the faster you operate busses, the fewer vehicles and crew are required. Evidently, acceleration of busses will play a key role for the successful modernization of Istanbul's public bus transportation. In general, metropolitan cities having a global importance like Istanbul should find ways to operate the existing network with higher efficiency in order to supply economically sustainable transportation service.

Reduction of parallel capacity

Several bus lines were running parallel to the new tramway line TR3 Topkapi – Edirnekapi – Sultanciftligi or the new Metrobus line, which already started operation between MB1 Mecideyeköy and Avcilar. Two cases of parallel traffic are classified as, lines completely overlapped with Metrobus and lines mostly overlapped with Metrobus. Each of the two figures illustrates the situation before and our proposal for future adaptations of the bus network. The first (Figure 6) deals with the necessary changes due to the construction of the Metrobus line to Mecidiyeköy. The second (Figure 7) shows the situation at the planned tramway line TR3 Topkapi – Edirnekapi – Sultanciftligi which is also in operation today. The routes of the bus lines running parallel to the tramway and Metrobus lines have been either shortened so that longer parts of the line routes running unparallel have been kept or have been fully eliminated. For the two given cases analyzed, the amount of savings per year is calculated on the base of the costs per km. The annual savings are tabulated and given in Table 3.

New line routes

There are some opportunities to redistribute some line routes on both continents of Istanbul. Alteration of the lines aims faster and more reliable service beside the economical efficiency. For those reasons, some line routes running over the Trans European Motorway (TEM) in Asian side can be diverted to E-3 Highway. By reallocating the buses on highways the express lines will be operating more efficiently.

After the development and land use changes of the vicinity at the north of the TEM highway in Istanbul it seems to be useful to lead an alternative line from Ikitelli (or alternatively from the Atatürk airport) to 4. Levent. The second relevant area is on the northern European side where will be one of the most important development zones in the future. The Levent region is also estimated to have a more dense population after the construction of new skyscrapers. To regard this development and to disburden the city centre from traffic load, implementation of a new bus line on the fast highway TEM/O-2 form Ikitelli to Levent over Esenler and Kagithane can be a viable solution. Figure 8 to 10 show the regions of proposed line routes.

The amount of savings per year for Anadolu/Beyoglu line route is calculated and given in Table 4. For the calculation of the maximum possible savings of travel time for the projected passengers that are expected to be induced by introducing the new line at European side of Istanbul (Figure10), we did assume a daily amount of

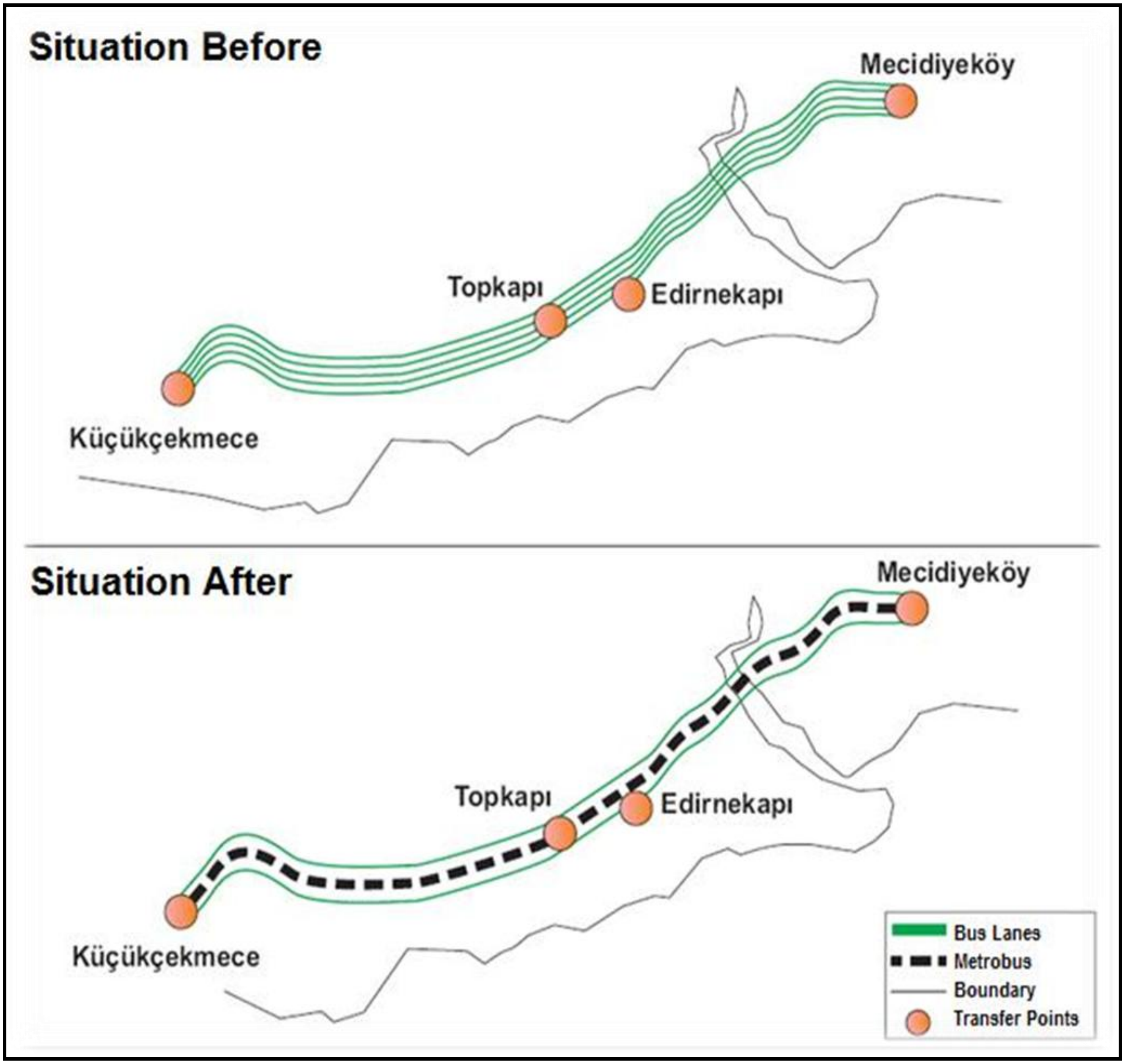

Figure 6. Parallel lines along Metrobus.

50,000 trips. The result of this calculation for one year is shown in Table 5. In the current state there is no significant demand for the new line in the European part of Istanbul which is believed to be in short term and due to the ongoing settlement process. On the other hand, the suggested alternative line routes have rather insignificant effects, when regarding the whole IETT bus network.

Reduction of trips due to low demand

According to the developed model, a reduction of capacities is recommended where capacity usage is low (example, less than 30%) on longer sections. Consequently, there will be some journeys lost in the early mornings and late evenings but it will help operator to finance new services, especially around Central Business District where an increase in services will support the growing economy in that area. However, the service should be provided with minimum policy headway for outer regions. Perhaps in the medium term the demand can be supplied by private transportation companies.

The authors believe that abovementioned changes will not only make the bus network more accessible, but also give faster journey times. An extensive marketing and public involvement campaign should be carried out to better disseminate the information.

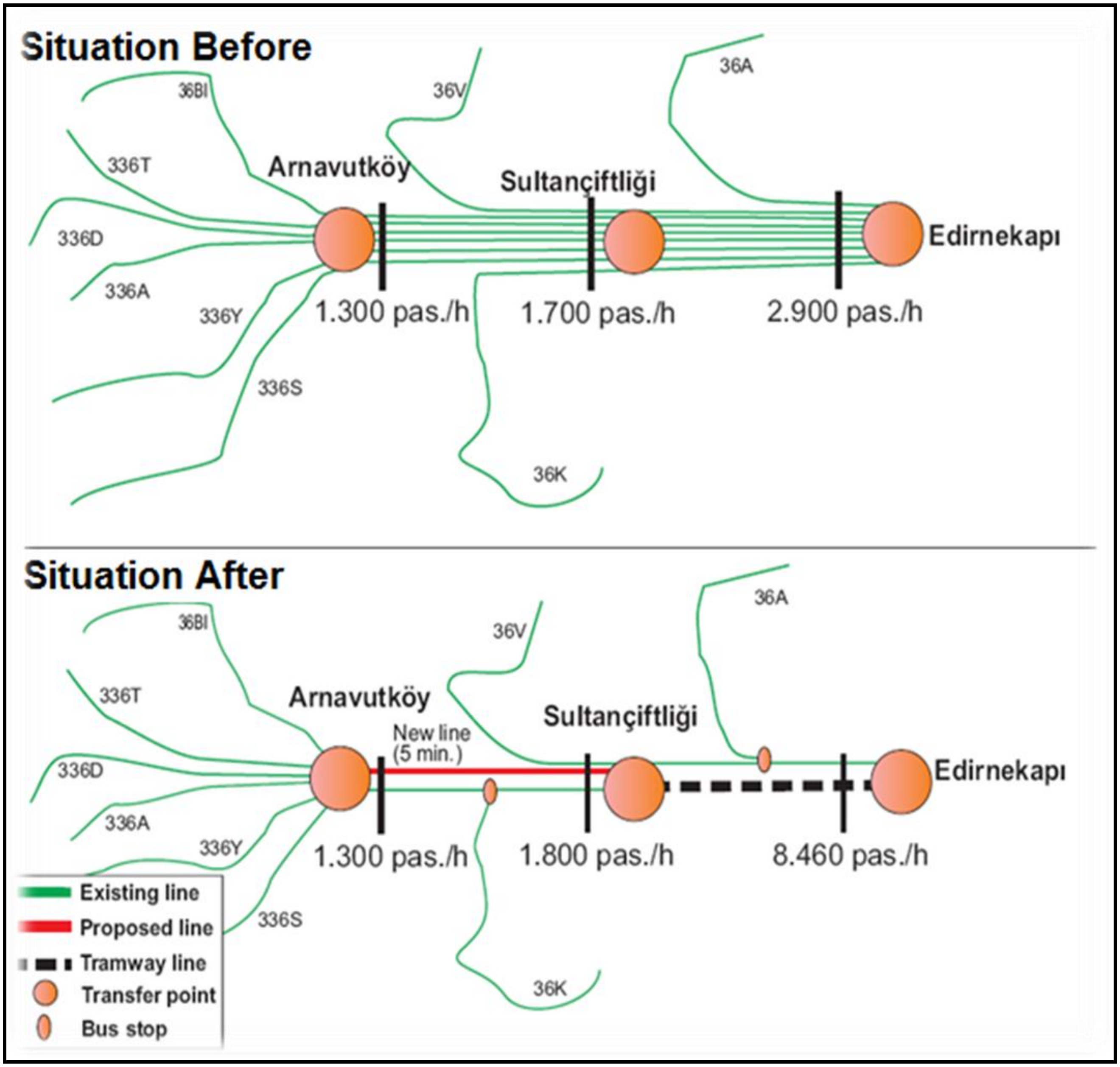

Figure 7. Parallel lines along Tramway.

Table 3. Savings through capacity adaptation.

Case	km/day	NTL/day	Cost (daily)	Cost (annually)	Total daily savings	Total annual savings
Metrobus						
Before	39,000	4.08	159,120	58,078,800	53,040	19,359,600
After	26,000	4.08	106,080	38,719,200		
Tramway						
Before	10,000	3.37	33,700	12,300,500	16,850	6,150,250
After	5,000	3.37	16,850	6,150,250		

Figure 8. Proposed line routes.

Moreover, a more radical reduction can be envisaged, but only when replaced by a more flexible system, for example with smaller vehicles. For our planning proposal, we did choose a conservative reduction, keeping as much IETT bus transportation as necessary to offer a sufficient public transportation service. For a more strict reduction of low saturated runs, IETT has to define the minimum service quality which should be offered in the central part, the middle regions and the outskirts.

The following two examples illustrate this measure of capacity reduction, first one is located in the northern part of Anadolu (the Asian side of Istanbul) the other in the most northern part of Beyoglu (the European side of Istanbul) given at Figure 11. Figures 12 and 13 visualize the low demand on lines in these areas. In the lower part of the illustrations the number of runs on these lines with the originally low capacity usage has been decreased (red line). The two examples just show the proceeding and background information of the planning principle. The effects of savings are consolidated in Table 6. It shows how the kilometres per day change and thereby the amount of saved costs for IETT per year. Additionally, capacity utilization may be low only on specific sections of a line, but not on the entire line. In this case, runs can be saved only on the section with lower utilization.

The model shows the area where the capacity usage changes from a higher to a lower utilization. In reality the utilization changes gradually, in the model it changes at a specific stop. The model can be used to determine the area where we can assume that it is

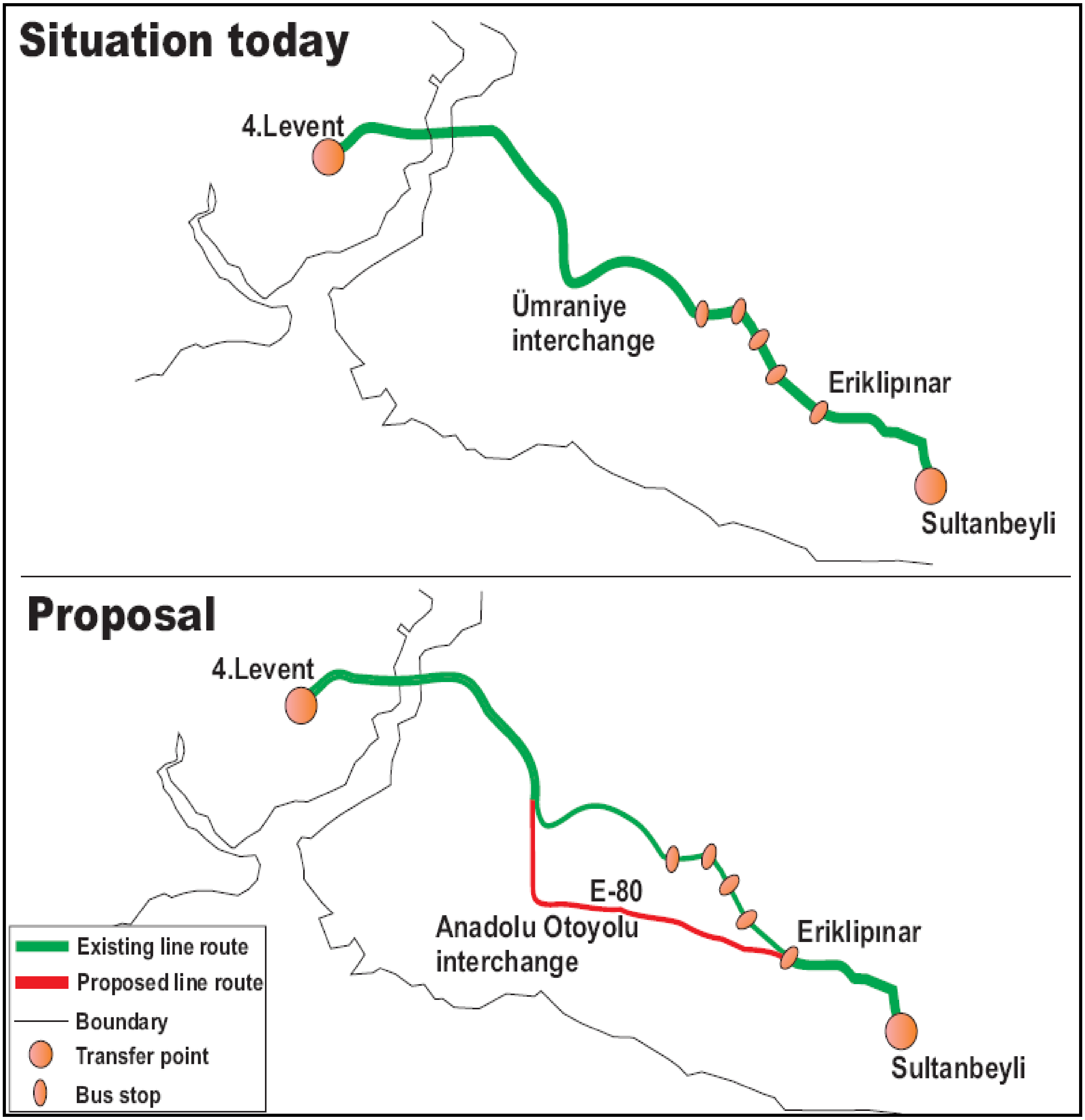

Figure 9. Proposed line routes 4. Levent/Sultanbeyli.

useful to change the headway. To find the exact stop from which the number of runs should be reduced, we recommend making a traffic study for this line and related lines. Apart from the change in utilization on the line, it is obvious that turning must be possible at the chosen place. Upon the reduction of runs, the different demand during peak hours and periods of normal and light traffic has be considered.

Reducing the number of runs must not lead to an unattractive public transport which will not be accepted by the public. A reduction of trips on the other lines in the European part of Istanbul might also be useful but should not be realized without further and more detailed studies.

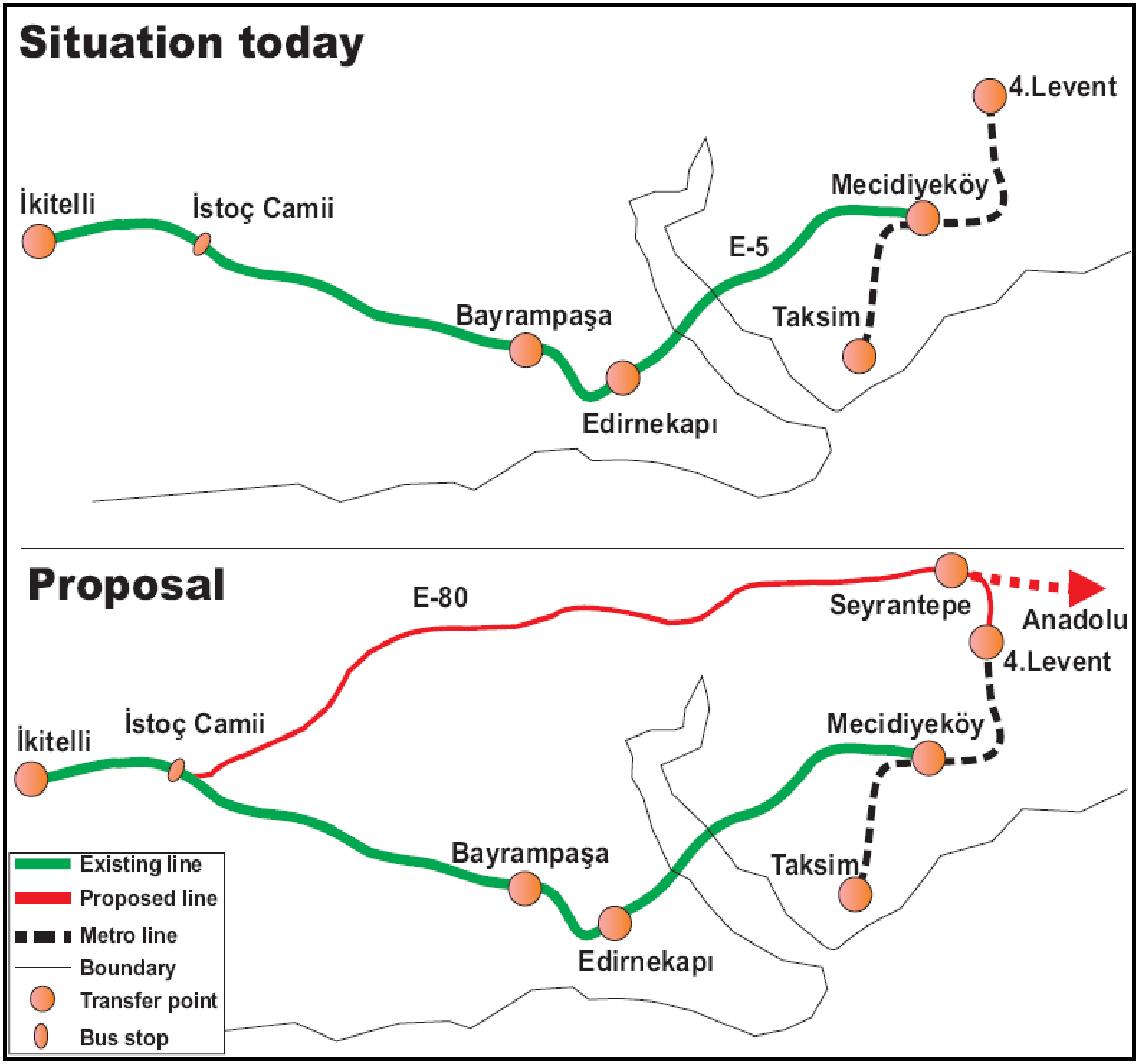

Figure 10. Proposed line routes Ikitelli/4 Levent .

Table 4. Savings through proposed Anadolu/Beyoglu line.

Benefits	minutes/passenger	Trips/day	Hours/day	Hours/year
Before	120	10,000	1,200,000	
After	100	10,000	1,000,000	
Savings/day			200,000	
Savings/year				73,000,000

For all reductions of trips, the following recommendations should be taken into consideration.

i) A detailed analysis of the characteristics and the efficiency of every line have to be determined before any reduction of runs is

Table 5. Savings through proposed Ikitelli/4 Levent line.

Benefits	Minutes/passenger	Trips/day	Hours/day	Hours/year
Before	70	50,000	58,300	
After	63	50,000	52,000	
Savings/day			6,300	
Savings/year				2,299,500

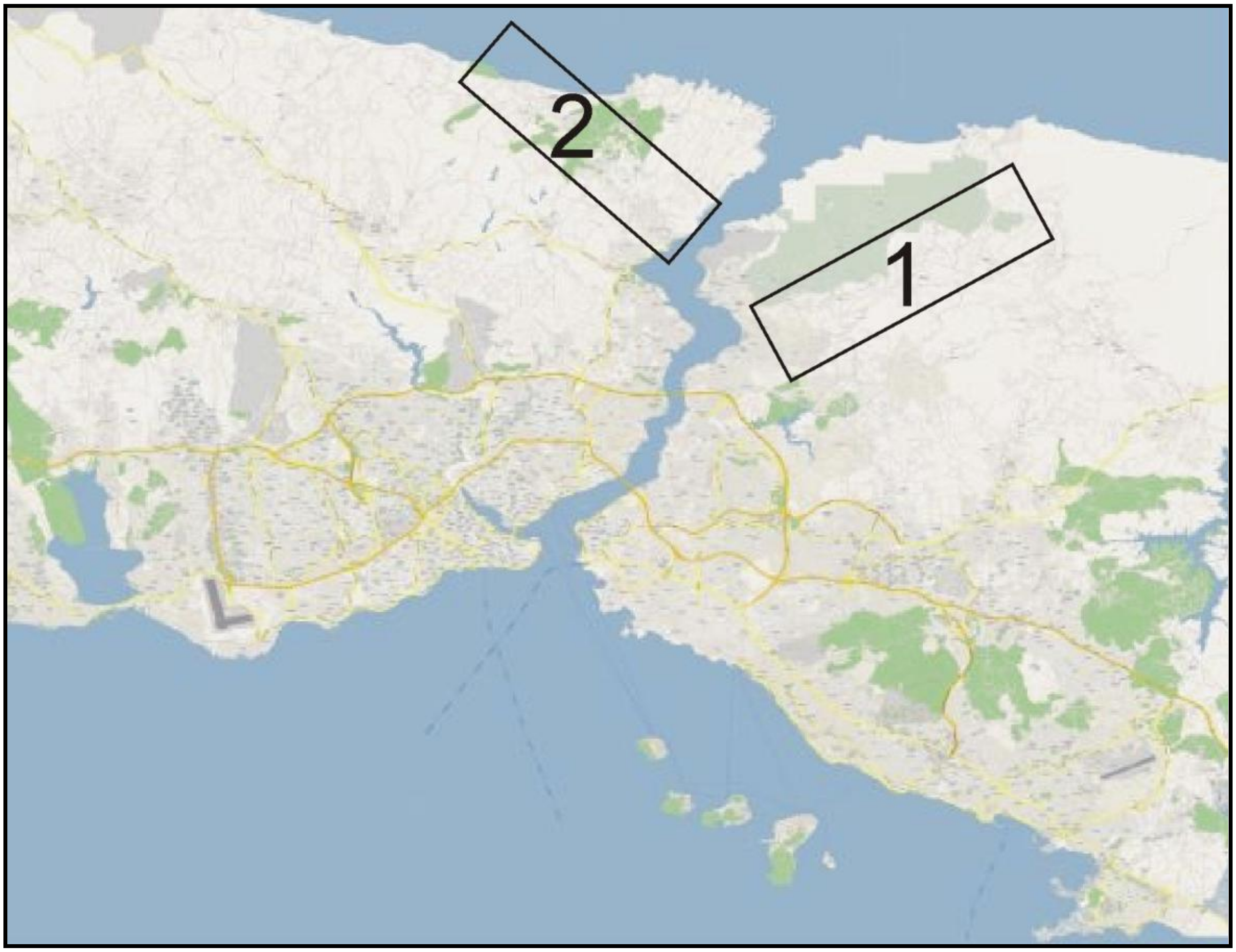

Figure 11. Low capacity usage areas.

realized.

ii) A special attention should be paid to neighbouring lines. A decreased number of runs might induce passengers to choose other ways, lines or means of transport for their travel, if possible. Passengers switching to other lines may lead to an overload. iii) Mode choice behaviour must be carefully investigated to the fact that in Istanbul people often take the first mean of transport embarking where they wait. If the IETT bus is late a passenger might instead take a private bus or a Minibus. Passengers' behaviour can vary in case if they have an Akbil valid for a month or an Akbil from their first part of the trip with an IETT bus due to the long and indefinite waiting times at stops.

RESULTS

The model indicates that the lengths of a huge amount of bus lines will be changed due to the planning restrictions given by IETT. The cutting was done for all variations as IETT only, shared lines and private bus lines only. The amount of bus lines and their percentage before and after

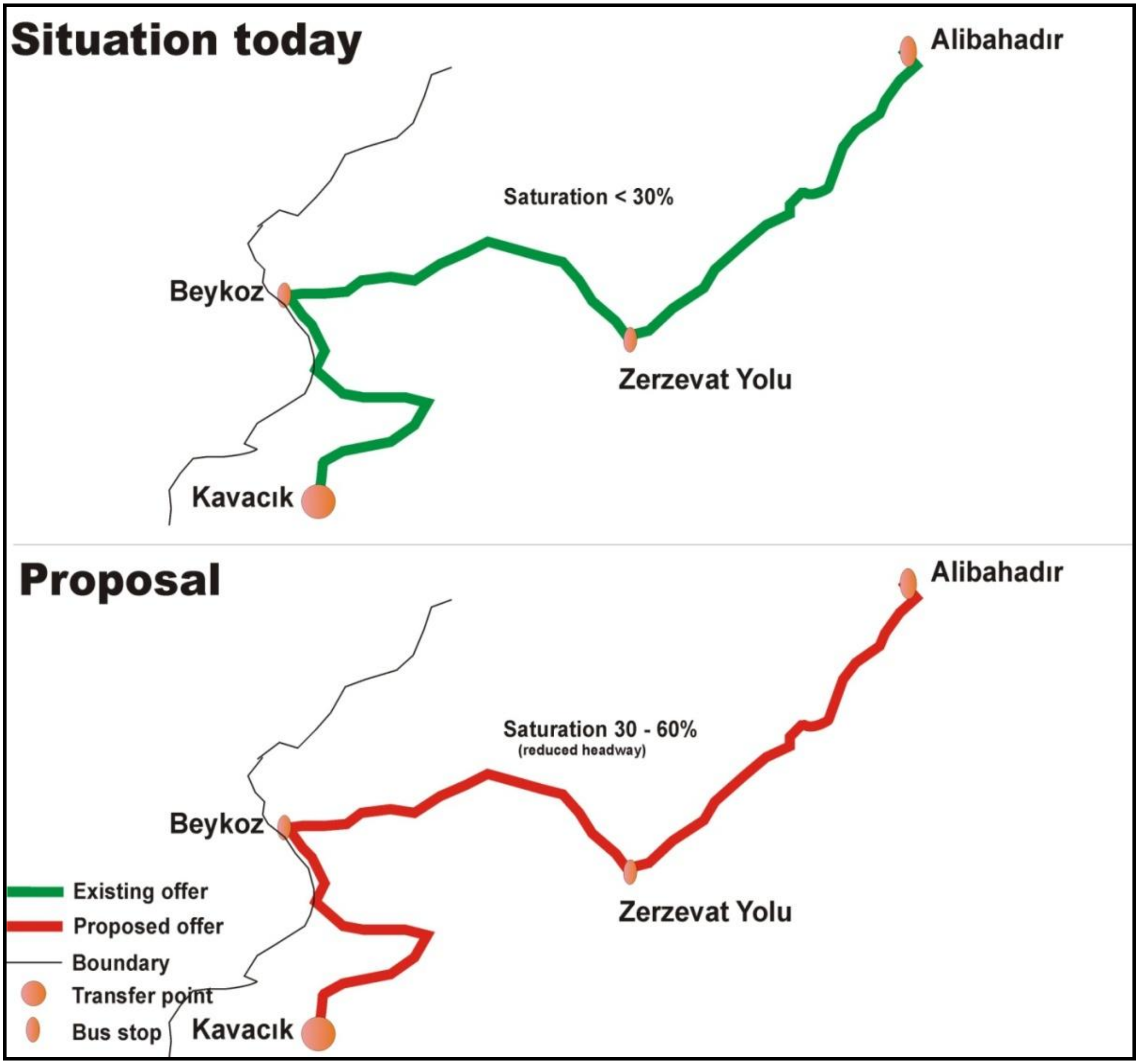

Figure 12. Low capacity usage areas Kavacik – Alibahadir.

the alteration are given as well as the variation in percent in Table 7.

The result of the cutting of lines is evident. The number of longer bus lines is reduced drastically and the number of shorter lines increased. After this cutting, a new arrangement of lines between IETT and private busses could make sense to increase the efficiency and profit for both participants. Nevertheless, it is necessary to split the passengers' point of view and the IETTs' point of view, because sometimes the gains of stakeholders are not equal.

The statistics in Table 8 shows the effects for the passengers, when all the described measures realized in the bus network of Istanbul.

Considering the economic value of one passenger hour, therefore the economic saving would be 273,000 trip hours per day and 99,645,000 trip hours per year which corresponds to 373,668,750 NTL monetary saving for base year of 2007. This huge amount of total economic savings can legitimate the investment in acceleration of the busses or investing economic and environmentally sustainable modes of transport.

For the IETT, there will be a considerable amount of savings of bus kilometers and bus hours, resulting from

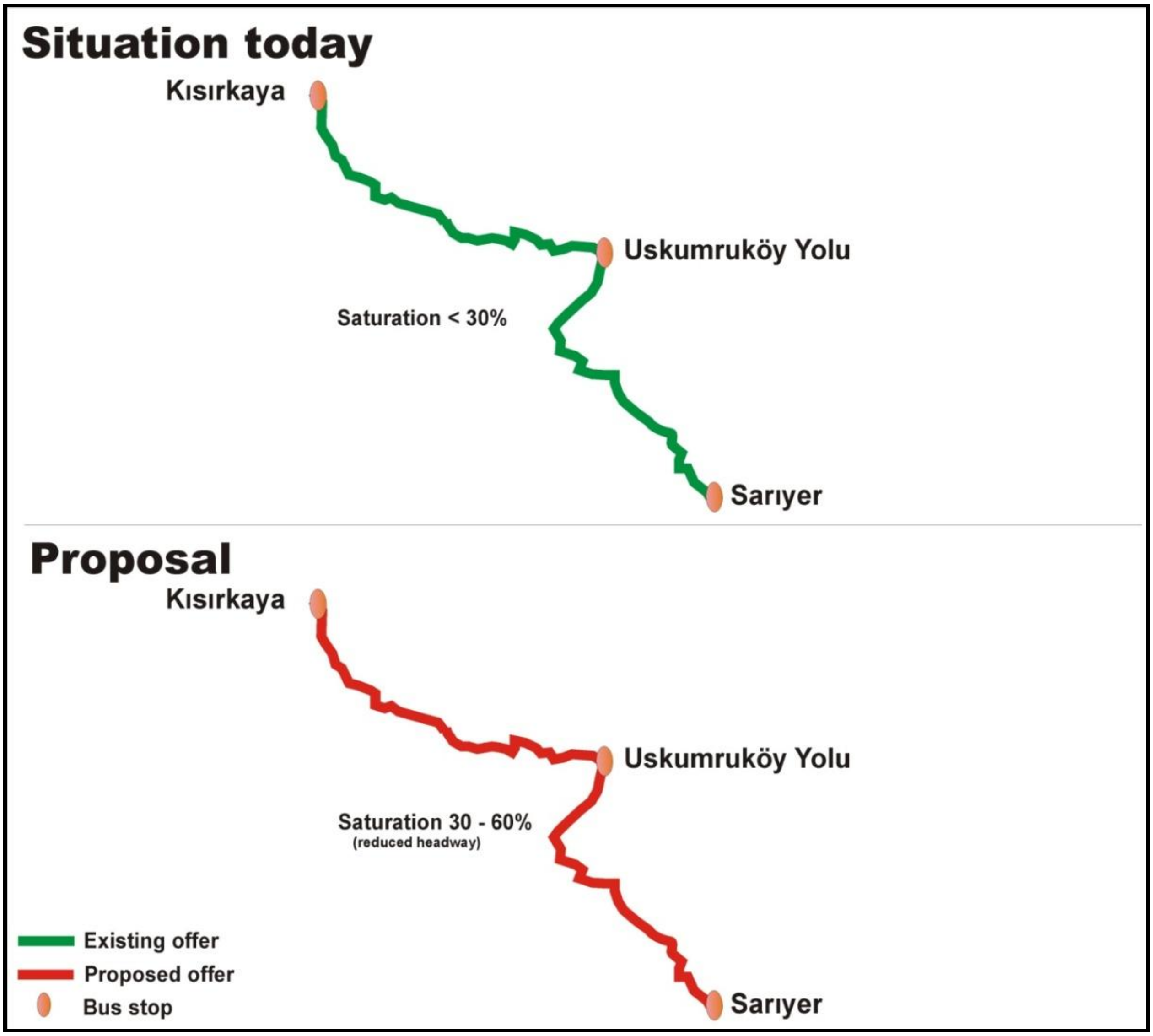

Figure 13. Low capacity usage areas Uskumruköy Yolu – Kisirkaya.

Table 6. Savings through reduction of trips.

Kavacik/Alibahadir	km/day	NTL/km	Total/day(NTL)	Total/year(NTL)
Before	958	3.12	2,990	
After	479	3.12	1,495	
Savings/day			1,495	
Savings/year				545,700

Kisirkaya/Sariyer	km/day	NTL/km	Total/day(NTL)	Total/year(NTL)
Before	644	4.08	2,630	
After	483	4.08	1,970	
Savings/day			660	
Savings/year				240,900

Table 7. Bus routes before and after alteration.

Length of IETT lines (km)	Length before alteration		Length after alteration		Variation (%)
	(km)	%	(km)	%	
>= 25	66	15	23	5	-10
>= 20	49	11	36	9	3
>= 15	100	23	90	21	1
>= 10	126	29	147	35	-6
>= 7.5	55	13	56	13	-1
>= 5	28	6	39	9	-3
< 5	13	3	28	7	-4
Total	437		419		

Length of private lines (km)	Length before alteration		Length after alteration		Variation (%)
	(km)	%	(km)	%	
>= 25	63	26	14	3	23
>= 20	30	12	24	6	7
>= 15	56	23	60	14	9
>= 10	59	24	76	18	6
>= 7.5	24	10	25	6	4
>= 5	8	3	16	4	-1
< 5	3	1	14	3	-2
Total	243		229		

Table 8. Trip statistics of passenger.

Attribute	Before	After	Variation (%)
Average trip time (min)	79	68	-14
Average trip time (including in access time and waiting time) (min)	54	44	-19
Average trip length (km)	24	24	0
Ratio of trips without transfers (%)	51	49	-4
Ratio of trip with one transfer (%)	25	35	0
Ratio of trip with two or more transfers (%)	14	16	15
Average speed of trip (km/h)	18.2	21.0	15
Average speed of vehicle (km/h)	34.3	44.0	28
Daily total trip time (h)	2,318,000	2,045,000	-12
Daily total trip time (including in access time and waiting time) (h)	1,599,000	1,316,000	-18
Passenger hours per day	1,232,000	979,000	-21
Total trip length	22,700,000	23,202,000	2
Directness (transfer/trip)	0,651	0,703	8

the proposed changes. In Table 9, savings of IETT are given according to the results of the developed public transport model.

Conclusions

In this study a model for increasing the bus network efficiency has been developed, which takes maximum route length as the goal and considers benefits of both passengers and transit operators. The results of the model show that shorter lines increase the average travel speed and thus reduce the travel time and increase the profit of bus operators.

The developed digital model can be utilized in future research including scheduling and fleet management which is outlined by Horn (2002). However, the model should be maintained and kept up to date. Moreover, as

Table 9. Savings of IETT after alteration.

Attribute	Before	After	Variation (%)
Passengers per day	1,879,000	1,909,000	2
Passengers in morning peak	216,085	219,535	2
Number of bus stops	3,641	3,617	-1
Lines served by IETT buses	437	419	-4
Number of IETT buses in daily service	2,500	2,170	-13
Total length of lines (both direction) (km)	14,400	12,500	-13
Bus kilometers per day	488,000	436,000	-11
Bus hours per day	34,000	21,700	-36
Average speed of buses (km/h overall)	14.4	20.1	40
Cost per day for all bus kilometers (NTL)	1,664,080	1,486,760	-11
Savings per day for All bus kilometers (NTL)		177,320	

Shih and Mahmassani (1994) studied, the model can be adapted to determine the appropriate vehicle size for each bus route by incorporating demand responsive capabilities to meet the demand. Improvements such as faster travels between the transfer points and on the backbone connections will enhance the quality of service and at the same time the efficiency of public transportation system (Fang and Xiaogang, 2008).

In general, it will not be misapprehension to state that The IETT bus network has good standards on a worldwide scale. Nevertheless, there is still potential for optimization, mainly by increasing the average travel speeds and by route alteration with respect to the changes of the transportation network. For further studies, the performance of the bus routes could be determined with methods suchlike data envelopment analyses (DTA) or Stochastic frontier analyses (SFA) if performance data would be available. Furthermore, different optimization methods such as Genetic Algorithm or Ant Colony Algorithm can be used to find the optimum fleet size and optimum routes for the given demand levels.

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