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Reduction of energy costs and traffic flow rate in urban logistics process

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Abstract

Energy cost is a phenomenon relating to logistics and transportation activities of logistics operators, as well as governments, local authorities and citizens. Actually, all the logistics parties may be affected by energy costs. At the same time, logistics and transportation flow rate is declining continuously. Increases in traffic volume and decreased logistics flow rate cause to decrease in logistics productivity and efficiency in a city. On the other hand, changes in these factors cause to increase energy cost. Minimum energy consumption plays an important role for efficient and productive urban logistics operations. Increasing traffic volume and congestion may absorb the energy of cities, in addition to that, it causes to increase energy requirements of urban areas. According to scientific research, a significant correlation can be seen between traffic volume, congestion, energy cost and using the urban economic resources. This study focus on relations between these factors and it tried to show that, ways for reduction of energy cost on optimum traffic volume and traffic flow rate. In addition to that, the findings of this study depend on fieldwork related to Istanbul city.
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Keywords: energy costs; traffic flow rate; congestion; marginal costs

1. Introduction

The traffic flow rate is one of the factors affecting the energy costs of transportation activities. There is a significant correlation between the traffic flow rate and energy costs of transportation, traffic volumes in urban areas can influence

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the energy costs of transportation directly or indirectly. From this perspective, traffic flow rate can be evaluated as a variable for energy costs. On the other hand, since the traffic flow may easily change, it is difficult to measure its impact. This paper focuses on the effects of the changes in traffic flow in marginal energy costs of transportation and logistics activities as well as impacts of traffic volume on total energy costs. In this paper it is argued that, if the traffic flow rate decreases to a certain level, unit energy costs of transportation can become unbearable. Accordingly, decreases in traffic flow may cause a negative effect on the energy cost and it may lead to an increase in marginal energy cost. Traffic flow rate and volume on a specific route may vary depending on a number of factors and variables. These variables can be listed as follows: the number of vehicles on the route, the number of intersections, the peak hours of the route, the number of residential and social areas around the highway, types and characteristics of vehicles in traffic, driver behaviors. These factors may be affected by the traffic volume together or individually. The traffic flow rate can be decisive in the formation of total costs of logistics and transportation. Additionally, its impacts on energy costs may be measured at the micro level. According to various traditional assumptions, when traffic slows down, energy consumption of each vehicle increases. Although this proposition is true, it does not allow an analysis at the macro level. A different set of data is necessary for an analysis in a broader perspective. As a result, some variables such as total energy consumption obtained from official sources, the number of vehicles on the route, the gradual flow of traffic, times of day when the route is used as well as the distances may be beneficial for this analysis. This research is based on the field studies which related to the Istanbul city. On the other hand, observation and analysis are within the scope of this research.

2. Literature

There are many studies about transportation and traffic management focusing on energy consumption. These studies, trying to establish a link between performance and efficiency of logistics operations and energy consumption, focus on energy consumption at the micro level. The increase in the energy consumption in each vehicle leads to negative effects on the efficiency and productivity of logistics and transportation operations. The majority of these studies argue that, if energy consumption is reduced, performance and efficiency of transportation operations might be increased. At the same time, the decrease in energy consumption would lead to economic benefits. However, the common assumption of these studies is reducing the energy consumption for more efficient logistics operations.

The majority of these studies focus on unit energy consumption, emissions, and other external costs of transportation. According to Mraihi, Abdallah ve Abid [1] the unplanned urbanization and rapid increase in population have caused economic and environmental problems. As a result, energy consumption is increasing rapidly in urban areas. Therefore, unit consumption per vehicle, population, urbanization and traffic density are interrelated concepts. Wang et al. [2] drew attention to the relationship between energy consumption and increases in production volume. They argued that significant and positive correlation can be observed between energy and production activities. Increases in production volume lead to increase in transportation needs. Because of the increasing transportation needs, energy consumption and cost may be increased. According to Manzone and Balsari [3], energy consumption may vary depending on vehicle types and specifications. Hao et al. [4] tried to establish a link between energy consumption and transportation modes such as road, maritime, railway. According to them, each transportation mode has different energy consumption and emissions levels. If choosing transportation modes that have lower emission and energy consumption, energy costs of transportation may be reduced. According to Huzayyin and Salem [5], increases in energy demands and consumption are linked to rapid urbanization. Marique and Reiter [6] associated vehicles types and energy costs. Unit energy consumption per vehicle type as a variable is taken into consideration in their study. Görçün [7] has compared the energy consumption and emission of fossil fuel vehicles and electric vehicles. He argued that, if electric vehicles used for passenger transportation such as subways and trams can be used for freight transportation, energy costs may be reduced in urban areas. Hosseinlou et al. [8] tried to determine an optimal speed limit in traffic networks. Their study argues that determining the speed limit of road transport systems has a significant role in the speed management of vehicles. In most cases, setting a speed limit is considered as a trade-off between reducing travel time on the one hand and reducing road accidents on the other, while the two factors of vehicle fuel consumption and emission rate of air pollutants have been neglected. Yanli et al. [9] drew attention to energy demand of road transportation. They argued that since energy demand is restricted by many factors, which have complex relationships with each other, it is difficult to apply causality model or structure proportion to forecast the energy demand. Even though it is, the forecast result is not accurate due to the uncertainty of some factors in future. Mallon et al. [10] tried to show relationships between energy consumption and emission cost of transportation. Similarly, Barisa et al. [11] drew attention to the relationship between emission and energy consumption. The majority of these studies focus on energy consumption at the micro level. These analyses depend on unit energy consumption per vehicle. Whereas, analyzes at the macro level are necessary for more feasible solutions. Therefore, all the parameters related to energy costs should be considered in a scientific study.

3. Methodology

The analysis basically consists of three phases. The first step is collecting data, the second is the evaluation of these data, the third step is analyzing the data and obtained results. The routes are selected in the first step of the analysis. While choosing the case area, selected routes must be the most heavily used highways in transportation activities. They should be used for freight transportation between the city and outside the city, including transit on these highways. Once the routes are selected, the number and specifications of vehicles on these routes have to be determined.

The second step of the analysis is determining the marginal energy cost for each limit of traffic flow rates. Marginal energy cost can vary depending on different speeds and when it falls below a certain speed limit, changes in marginal energy cost may increase more and the curve of marginal energy cost can show the sharp upward trend in a certain speed limit. This point may be accepted as the minimum speed limit for each road section. If the traffic flow rate is below these limits, it would be impossible to cover the energy costs of transportation. By using Eq. (1), to reach the unit energy cost per unit time, total energy costs sourced from the transportation activity should be divided into the total using time of routes. As a result of this, we can reach to the unit energy cost per minute. Secondly, route distance should be divided into the gradual traffic flow rates and the results should be multiplied by the time in minutes. When these values are multiplied the result should be divided by the number of the vehicle. The equation can be seen as below:

$$e_{uc} = \frac{\left[\left(\frac{r_d}{v_{sp}}\right).t\right].\left(\frac{u_{ec}}{a_t}\right)}{v_n} \tag{1}$$

While e_{uc} represents marginal energy cost per vehicle for each traffic flow rate level, r_d is the distance of the selected road section, v_{sp} is the gradual traffic flow rate, t is the using time of route in minute, u_{ec} is the total energy cost in the selected route, a_t is the annual route using time in a minute, v_n is the number of a certain type of vehicle moving in the selected route. Secondly; The value of unit energy cost per minute can be calculated as below:

$$e_{pm} = \frac{u_{ec}}{a_t} \tag{2}$$

While e_{pm} represents unit energy cost per minute, u_{ec} is the total energy cost in the selected route, a_t is the annual route using time in a minute. The main purpose of this analysis is determining the minimum traffic flow rate that caused the highest marginal cost of energy for each road section. This point may be an indicator for decision makers in traffic management. The third step is evaluating the obtained results. In this process, all the values of marginal costs of energy for each road section should be taken into account together and the minimum speed limits should be determined for each route.

4. Data and Variables for Analysis

Data and variables depend on official statistics and projections which are published by the relevant authorities. These data, include different factors such as route distances, types, specifications and number of vehicles, total energy costs and consumption, total using times of routes. The main highway heavily used for freight transportation is selected as the case in this research. These routes are divided into many sections. Each part of the highway between two junctions is defined as a road section. A route can include more than one road section. Vehicles moving on these routes can be classified into groups such as automobiles, buses, freight vehicles and heavy freight vehicles. For the aims of this paper, freight vehicles, and heavy freight vehicles are taken into consideration: not only loaded vehicles, but also empty freight vehicles. The number of freight vehicles can be obtained from the detailed statistical data that published by General Directorate of

Highways of Turkey. Time of use for a road section can be defined as annual time and should be converted to minute value. When the time of use is known, energy cost per minute can also be calculated.

Since this analysis is related to logistics and transportation activities, determining the total energy consumption and energy costs in terms of diesel used by heavy freight vehicles is necessary. These data may be obtained from statistical data published by official institutions and authorities.

5. Study Area

Istanbul city is selected as the research area. Istanbul is one of the important cities of the world in terms of its cultural, social, historical and economic aspects. It is located between the Black Sea and the Marmara Sea and is divided into two parts as the European and the Anatolian sides by the Bosporus linked by the Bosporus Bridge and Fatih Sultan Mehmet Bridge (FSM). The construction of the third bridge called Yavuz Sultan Selim Bridge (YSS) is almost complete. Istanbul is also an important city in terms of logistics, transportation and international trade. Istanbul is a transit city for the majority of the international trade, carried out among the Middle East, Central Asia and European countries. An important part of materials which are subject to international trade is passed through Istanbul. The city has two main highways in the eastern and western axis. All of the international and domestic freight transportation are carried out on these routes called D-100 and O-32 highways. Istanbul has a transportation system based on an east-west grid, with the bulk of its heavy traffic shouldered by the E-5 and TEM highways Fig. 1. Compared to its geographic characteristics, the volume of logistics operations carried out in this city is very high and have a significant density. Organized industrial zones have an area of 2088 ha totally. Because of the insufficient connections among them, there is very busy traffic and speeds of logistics activities are low. In addition to that, there are 113 small industrial sites in this city and they have busy logistics operations. Especially spare parts logistics have a high level presence in these sites. These sites are not planned in terms of logistics and transportation requirements [12]. While the eight organized industrial zones and small industrial sites meet their requirements as raw materials and semi-finished goods from suppliers located outside the city, they send the high volume of products from Istanbul to other cities. Moreover, fresh food and cargo terminals as well as waste collection centers are other factors affecting the urban logistics processes in Istanbul city. From this perspective, the size of the actual logistics operations in the city of Istanbul can be better understood. Transport options and modes are not developed sufficiently. It is one of the problems of the logistics system. Therefore, the use rate of road transportation is very high compared to other transportation modes. Every day 50,823 road freight vehicles pass through Fatih Sultan Mehmet Bridge and 15,123 of them are reaching to Selimpasa–Silivri route. As a result, 73,041 road vehicles are entering the center of Istanbul city [12].

Fig. 1. Main transportation networks in Istanbul City.

Istanbul is a city which has significant limitations in terms of logistics. It has been divided into two by the natural waterways and this situation is the main constraint of the city in terms of logistics and transportation. In the framework of these constraints, access between the two sides is made possible by the two bridges. These bridges may lead to the contraction for intensive traffic flows on both sides of the city. The execution of all transportation activities on the only two main highways can be defined as another constraint. Istanbul has entered a rapid process of urbanization in the past decade. As a result of this, the population of this city has shown significant increase. Rapid urbanization and increase of population density have become more important non-natural constraints. Although not as intense as in the past, rural to urban migration continues which leads to the increase in the requirements for energy, transportation and infrastructure in the urban area.

According to the official statistics, the urban population has exceeded 20 million, is moving toward 30 million. Istanbul city does not have the geographical competence for hosting of this population. Therefore, social areas such as shopping centers and newly built homes are created on the vertical axis. While the development of urban areas in the vertical axis may respond to housing requirements of people, it can cause an increase in the number of people per meter square. As a result of this, traffic volume may increase per unit square meter. Especially, high-rise buildings and shopping centers have negative effects on the urban traffic and logistics activities. Another problem is the concentration of the business centers in the urban area. As a result, traffic flow may increase to an unbearable level, especially during morning and evening hours. Shopping centers and their locations can be defined as another reason for traffic problems. They are concentrated in the center of the city and their number is increasing gradually. These shopping centers may cause more intense of urban traffic since each mall can be defined as logistics nodes of urban logistics systems which may lead to increase in the passenger transportation volume between malls and other areas. On the other hand, hundreds of trucks arrive at the entrance to these malls in order to meet their supply requirements. At the same time, stores located in these malls carry out their logistics activities individually which may be inefficient. As a result of this, more trucks may enter into the city center and can stay in daily urban traffic for a long time. Finally, the use of resource and energy cost increase and productivity shows a decrease in logistics operations. More importantly, significant reductions in urban logistics flows may occur.

6. Results and Discussions

Within the framework of this research, the main highways are divided into different sections and each section can be defined as a road section located between two vehicle counting points (Fig. 2). While the international highway that is called O-32 is divided into eight sections, D-100 highway consists of five sections. The number of vehicles moving on each road section is automatically counted by the general directorate of highways and is annually published as the official statistical data (Table 1). These statistical data are used in this study. In this research, only heavy freight vehicles used on these road sections are taken into consideration and their characteristics and quantitative values are included in the analysis.

Table 1. The Number of Vehicles and Road Sections.

Highway	No	Road sections	Distance	Number of lanes	The number of heavy vehicle	Heavy vehicle per km
0-32	1	Mahmutbey West-Mahmutbey East	2.7	7	33,047	12,240
	2	Mahmutbey East-Metris	3.5	7	61,483	17,567
	3	Metris-Hasdal	8.5	7	88,967	10,345
	4	Hasdal-Levent	5.4	6	14,871	2,754
	5	Levent-FSM Bridge	1.5	8	50,371	33,581
	6	FSM Bridge-Kavacık	4.8	9	73,365	15,284
	7	Kavacik-Sile Turnoff	7.4	6	56,497	7,635
	8	Sile Turoff-Camlica	3.9	7	42,448	10,884
D-100						
	A	Silivri - Selimpaşa	12.1	5	2,562	42.3
	B	Selimpaşa - Kumburgaz	7.5	4	2,442	81.4
	C	Kumburgaz - Tepeüstü	7.2	4	2,773	96.3
	D	Tepeüstü - B.Çekmece	5.1	4	2,138	104.8
	E	B.Çekmece - Çatalca Turnoff.	6.2	4	2,310	93.1

Fig. 2. Road sections in Istanbul City.

According to the official statistics, the monetary value of the fuel consumption is calculated as € 33,272,357 annually. Only heavy freight vehicles are taken into consideration in this evaluation. When this value is converted to the unit cost of energy per minutes, unit energy cost can be calculated as approximately € 63.3 (Eq. 2).

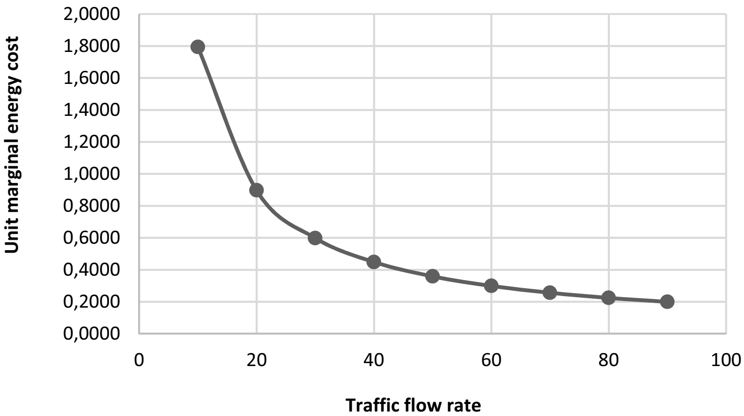

Fig. 3. Marginal Energy Cost Curve in Section A.

When Eq. 1 is applied to reach the unit cost per vehicle, any section of the road may be selected for analysis as an example. The road section between Silivri and Selimpaşa defined as section A is selected for this analysis. According to the official statistics, daily 2,562 heavy freight vehicles pass through this section. The distance of this road is 12.1 kilometers. In Turkey, high speeds for heavy freight vehicles is banned by traffic regulations. The legal speed limitation is 90 kilometers per hour for heavy freight vehicles. According to Eq. (1), the unit energy cost per vehicle on this road section and at maximum speed can be calculated as 0.20 €/per vehicle. When the traffic flow is reduced ten kilometers for each calculation, the marginal energy cost chart is composed as follows. While other parameters are fixed, it can be defined as a variable. When the traffic flow rate is reduced, the marginal energy cost curve has an upward trend. When traffic flow is reduced to a certain point, the marginal energy cost curve shows a more rapid upward trend. When the traffic flow is reduced to 30 km/h, marginal energy cost can show a more rapid upward trend according to the chart above Fig. 3.

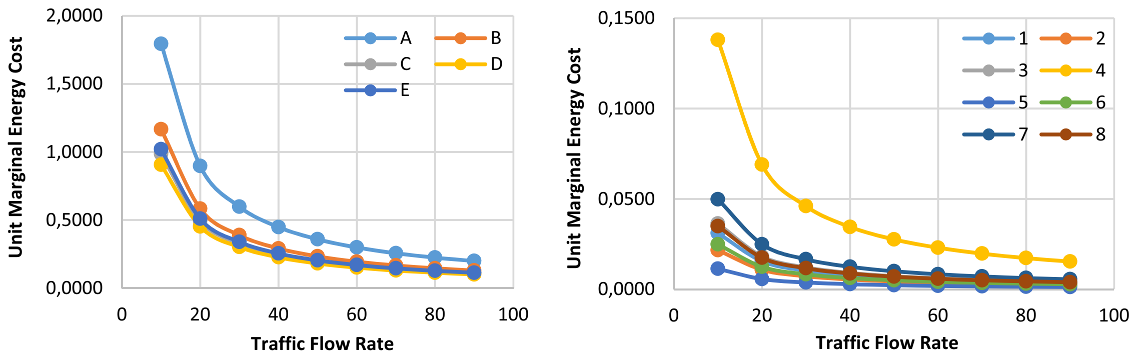

Fig. 4. Marginal Energy Cost Curve for All Section in D-100 and 0-32 Highways.

For all the road sections, this trend is similar. On the other hand, changes in marginal energy costs are more sensitive to speed and distances of road sections and have not shown a sensitivity to the number of the vehicles. The unit cost of energy may vary depending on the number of vehicles. Whereas, the trends of the marginal energy cost curve are constant for each road section and all the parameters Fig. 4.

When the analysis is applied to another highway known as the O-32, unit energy cost per vehicle is lower than the D-100 highway since the number of vehicles passing from this route is very high compared to the D-100 roadway Table 2.

Table 2. Unit Marginal Energy Cost Per Vehicle.

	O-32 Highway Sectors								D-100 Highway Sectors					
Speed	I	II	III	IV	V	VI	VII	VIII	A	B	C	D	E	F
90	0.003	0.002	0.004	0.015	0.001	0.003	0.006	0.004	0.20	0.13	0.11	0.10	0.11	0.20
80	0.004	0.003	0.005	0.017	0.001	0.003	0.006	0.004	0.22	0.15	0.12	0.11	0.13	0.22
70	0.004	0.003	0.005	0.020	0.002	0.004	0.007	0.005	0.26	0.17	0.14	0.13	0.15	0.26
60	0.005	0.004	0.006	0.023	0.002	0.004	0.008	0.006	0.30	0.19	0.16	0.15	0.17	0.30
50	0.006	0.004	0.007	0.028	0.002	0.005	0.010	0.007	0.36	0.23	0.20	0.18	0.20	0.36
40	0.008	0.005	0.009	0.034	0.003	0.006	0.012	0.009	0.45	0.29	0.25	0.23	0.25	0.45
30	0.010	0.007	0.012	0.046	0.004	0.008	0.017	0.012	0.60	0.39	0.33	0.30	0.34	0.60
20	0.016	0.011	0.018	0.069	0.006	0.012	0.025	0.017	0.90	0.58	0.49	0.45	0.51	0.90
10	0.031	0.022	0.036	0.138	0.011	0.025	0.050	0.035	1.79	1.17	0.99	0.91	1.02	1.79

7. Conclusions

Energy costs related to road transportation may vary depending on some parameters and factors. These parameters and factors can be listed as distances of road sections, a number of lanes, the number of heavy freight vehicles and, traffic flow rate. Within the framework of analyses, it has been observed that the sensitivity level of the energy cost is higher for some factors and can show a reaction in the lower level for different factors. Unit marginal energy cost per vehicle can increase depending on low traffic flow rate. If the traffic flow rate is reduced, marginal energy cost may increase. Moreover, if it is down increases in marginal energy cost may be high compared to other speed levels. As a result, this speed point that caused a jump in costs can be described as the limit speed for each road section. If the traffic flow rate is reduced to this point, energy cost of transportation may be bearable for all parties of logistics and transportation. In general, traffic administrative authorities in a country can describe the maximum speed level for any route, but regulation is not available for the minimum speed level. Within the framework of this research, decision makers of traffic administration such as local authorities and governments can determine the minimum speed level like the maximum speed level for each road section. As a result, this study argues that, some precautions can be taken by authorities to provide a regular traffic flow and to reduce energy costs. In additon to that, optimized traffic flow in a city may lead to decrease enviromental problems and difficulties.

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