TECHNICAL AND ECONOMICAL COMPARISON OF USING ITS TECHNOLOGY FOR ENFORCEMENT OF PLATE NUMBER RATIONING IN TEHRAN (EVEN-ODD ZONE)

Mahmoud Saffarzadeh[1], Professor, Tarbiat Modares University, Tehran, Iran

Hooman Alenoori[2], M.Sc. Graduate, Tarahan Parseh Transportation Research Institute,Tehran,Iran

Babak Mirbaha[3], PhD Candidate,Tarahan Parseh Transportation Research Institute, Tehran,Iran

Tarahan Parseh Research Institute,No.23, 55 alley, Jahan Ara st.,Tehran Iran,1436815361

Email for correspondence: H.Alenoori@Gmail.com

ABSTRACT

Studying experiences of other countries in the implementation of plate number rationing scheme shows that the congestion pricing strategy mostly has short time effects; also, most of these countries only have used police presence as a mean for enforcement. Thus, successful experience of using ITS technologies for enforcement of other congestion pricing strategies convinced policy maker that using ITS technologies for implementation of the plate number rationing may have better results than police presence. Tehran as the largest and most crowded metropolitan city in Iran has confronted with crowded streets and highways. As a demand management strategy, the congestion pricing is applying on congested areas in two cordons. The first cordon constraints the entrance of vehicles into the downtown and the second one which is around it implements the plate number rationing. Because of successful experiences of enforcement of the first cordon via intelligent transportation systems, the Traffic Organization of Tehran Municipality decided to extend this technological surveillance to the second cordon. In this paper, authors try to study the enforcement of the plate number rationing scheme by technical and economical points of view with cost-benefit analysis. Technical evaluation of using ITS technology for enforcement of the second cordon result the reduction in violation rate; also, fuel consumption, traffic pollution and traffic congestion would be decreased. In the other hand, economical evaluation of this scheme result that its benefit-cost ratio is about 35. So, this scheme is so economical and its benefits outweigh than its costs.

Keywords: Plate number rationing, Enforcement, ITS technologies, Violation, Congestion, Cost-benefit analysis

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[1] Saffar_m@modares.ac.ir
[2] H.Alenoori@Gmail.com
[3] Bmirbaha@Gmail.com

1. INTRODUCTION

Increasing car ownership in the last decades has led into enhancing congestion in urban streets. These changes have negative effects on people's life style and environment due to long delays experienced in traffic queues. Nowadays, traffic congestion is a common problem in most of urban roads network that caused increasing accident probability and pollution (air, sound, etc.) and wasting time, non-reproducible fuels and national capitals.

Traffic congestion is a result of unequal growth of supply and demand in road networks. Thus, there are three solutions for solving this problem. Firstly, by increasing capacities of roads that needs making some infrastructures (roads, bridges and tunnels) and also large investment and long time. Studying experiences of other countries illustrates that this solution is not effective because traffic demands would rise by increasing roads capacities. Secondly, optimizing available roads network by resetting traffic signals, ramp metering and using HOV lanes that would increases traffic flow and on the other hand decreases the delay time and compulsory costs. Finally, traffic management is the most effective solution for this problem [1].This solution is based on making some constraints for drivers who want to enter to the congested zone.

Traffic management plans such as congestion pricing, parking management and access management would decrease desirability of using cars and leads private vehicle's users to public transportation system [2].

Early 1920's, congestion pricing and giving some charges from network users discussed by some economists such as Arthur Pigou. They believed by getting some charges from network users and suggesting them to use public transportation would have positive effects on the congested roads because more people per vehicle would be transferred [3]. Creation of a congestion pricing cordon in the downtown is a common way for managing traffic demands, controlling air pollutions, decreasing travel time and delay time globally. Studying the experiences of other cities in the implementation of plate number rationing show that this restriction has short-term effects and do not improve traffic conditions in long-term.

Tehran is the biggest city of Iran which has over 9 million residents people and more than 4 million registered vehicles but only, 2.5 million vehicles are circulating in this city [4]. Tehran is now controlling its traffic on congested areas with a multilayer cordon pricing. First layer constraints the entrance of vehicles into the downtown and the second layer which is around it constraints the entrance of vehicles upon the last digit of their plate number. The second layer has expanded due to air pollution and traffic congestion since 2005. The Traffic Organization of Tehran Municipality had successful experiences in enforcement of traffic congestion zone (first cordon) with ITS technologies. Therefore, they decided to extend their experiences in implementation of ITS technologies to the second cordon. In this paper, authors try to study enforcement of plate number rationing in Tehran with ITS technologies from the technical and economical points of view with cost-benefit analysis and evaluated to check if this project is more worthwhile and effective than the police presence or not.

2. LITERATURE REVIEW

Traffic congestion is the main problem of crowded cities of industrial and developing countries. Each city implements different policies for solving this problem. Some cities implement congestion pricing such as London, Bergen, Oslo, Trondheim, Milan, Bologna and Rome. In some countries levy usage, fuel and vehicle ownerships tax such as Netherland and Singapore. Some cities extend public transportation networks such as Bogota and the others implement plate number rationing scheme such as Mexico City, Sao Paulo and Beijing. Although, the quantities of these policies are not numerous, the purpose of the implementation of these policies is widespread. Therefore, one city may use more than one scheme for managing its traffic demands simultaneously.

Implementation of any traffic demand management scheme may have many purposes. First, traffic flow increases in roads which congested by private vehicles, some constraints for entrance of private vehicles applied or preferences to public transportation are given, that it would lead to a decrease in the number of private cars and increase in the desirability of public transportation. Therefore, this purpose would be accessible, but the degree of success depends on the method of implementation. Secondly, by developing some investment for urban schemes expands road networks and improving serviceability of current network. Congestion pricing in the downtown provides the amount of money for investment in the urban mega projects. Thirdly, by expanding public transportation networks that transfer more people per vehicle than private vehicle improves traffic flow and decreases private vehicle usage. Finally, it reduces air and sound pollutions related to vehicles. As cited above, decreasing usage of private vehicles and extending public transportation network decreases traffic congestion improves traffic flow and reduces travel distance, therefore, all of these results in reduction of vehicle's pollutions.

In this part, authors decide to review the experience of other cities that are like Tehran and implement plate number rationing. After that, authors try to review the method of implementation and results they have given. So Bogota, Mexico city and Beijing are selected for reviewing the effect of traffic demand management schemes.

2.1. Mexico City, Mexico

In 2009, Mexico City had over 8.8 million people [5] and 4 million vehicle registered. On average, 160000 vehicles are registered annually in this city [5]. Plate number rationing in Mexico City has implemented since November 1989. This scheme which is known as "Hoy No Circula", prohibits vehicles that have two specified numbers for the last digit of their plate to enter congestion zone, therefore, it is expected that this scheme decreases 20% of daily traffic.[6] This scheme was organized to be used in winters, when thermal inversion happened and caused an increase of air pollutions, but this scheme was permanently used from 1990 to 2000.[7]

Implementation of plate number rationing in Mexico City persuade people to buy another vehicle. Therefore, this scheme increased car ownership and traffic congestion. Using old vehicles and traffic increase in weekends have been reported as a disadvantage of this scheme. Studies illustrate that this constraint had more social costs instead of benefits

expected such as decreasing traffic congestion and air pollution. Mexico City authorities plan to use 8000 new cameras and 100 radars to monitor traffic violation in the future.[6]

2.2. Sao Paulo, Brazil

Central part of Sao Paulo had over 11 million people in 2011 and had more than 7 million registered vehicles until 2011[8]. Plate number rationing in Sao Paulo was used in the central part of this city for decreasing pollution from dangerous level since 1995 [9]. Statistics show that, after implementation of this scheme weather quality has been improved and traffic congestion has been decreased. So that, carbon monoxide has been decreased to 530 ton per day and buses average speed has increased from 16 km/h to 20 km/h and finally number of bus travels has been increased by 2% [10].Results of polling showed that 57.7% of people want to continue this scheme. After successful experience of this scheme in 1995, it was used again during 1996 to 1998. At that time, plate number rationing scheme was implemented in the morning peak hour from 7a.m. to 10 a.m. and in the evening peak hour from 5p.m. to 8p.m.[6] Studies show that plate number rationing loses its effectiveness and people in the central part of Sao Paulo tend to have a private car. Therefore, the desirability of public transportation decreased about 12 percent and the desirability of private cars increased about 3 percent, although road networks did not change at all [10].

2.3. Bogota, Colombia

Approximately 20 percent of people use their private cars [12]. In Bogota, plate number rationing is known as “Picoy place.” This scheme is implemented since 2000, causes about 30-40% decrease of vehicles that are circulating in urban roads network. This restriction is implemented from Monday to Friday, 6-9 a.m. and 4-7p.m. [11] Bogota authorities know that the implementation of the restriction in all hours of day persuades people to buy another vehicle. In addition, pattern of restriction changes annually. [6]

The “Picoy Place” is being used in companion with the BRT system and extending bike paths. Thus, this restriction supports public transportation. So, the effect of plate number rationing cannot be measured for each policy. A package of policies has made some benefits such as increasing desirability of using public transportation and bicycle, reducing daily travel times about 1 hour, improvement in average speed about 58 percent and reduction of air pollutions about 10 percent. In addition, BRT operations offer 32 percent improvement in travel time than other transit modes, and 9 percent shift from private vehicles to BRT systems. [12]

2.3. Beijing, China

Beijing had over 19 million people in 2010 with 3.3 million vehicles that are circulating in this city. This city was host of summer Olympic in 2008. Therefore, Beijing authorities implemented road space rationing and restricted the entrance of 50 percent of vehicles based on last digits of their plate number. This scheme was executed in July 2008 for decreasing air pollutions during Olympic Games and continued during Paralympics. Beijing

authorities were expecting that this scheme could decrease about 45 percent of circulating vehicles; also, 300000 pollutant vehicles prohibited to enter this zone [13].
Pollution level reached its standard level during the Olympic Games. Thus, Beijing authorities used modified restrictions after Olympic Games. This scheme has restricted 20 percent of vehicles from the entering to the special zone; also, they used other restriction for freight vehicles that want to enter Beijing and prohibit pollutant and old cars to enter downtown. Beijing authorities use cameras for executing of these schemes [14].
Studying the experience of using plate number rationing illustrates that other cities except Beijing did not use any intelligent transportation system (ITS) technologies for enforcement of plate number rationing scheme. The enforcement of this scheme in other cities accomplished with the police presence. Although, enforcing of congestion pricing in the whole world is accomplished with ITS technologies. Thus, the cost to enforce plate number rationing in Latin American cities is equal to law enforcement costs of monitoring vehicles, issuing violations and collecting the fines [6].

3. COST-BENEFIT ANALYSIS

The purpose of cost-benefit analysis (CBA) is to estimate the money value of benefits and costs of the project to establish whether it is advisable or not.[15] Cost-benefit analysis is a powerful, widely used and relatively easy tool for deciding whether to make a change or not. The method imposes accounting framework to measure benefits and costs and aggregates them. In the public sector planning, the cost-benefit analysis is being used as a tool for choosing among a range of alternatives, and for comparing projects.[15] when a project is analyzed, we should compare costs and benefits that may appear in different times. This ratio is calculated by discounting future financial benefits and costs to a reference date (usually time of the decision to implement the project), using a given annual discount rate. [16]
Based on ideas back to the French engineer Jules Dupuit in the mid nineteenth century, formal cost benefit analysis was first used in practical planning in the USA in the 1930's as a result of the impetus provided by the Flood Control Act of 1936. In order to control federal spending, this act specified that the U.S. Corps of Engineers could carry out projects for the improvement of the waterway system only ‘if the benefits to whomsoever they may accrue are in excess of the estimated costs’. It was not until about twenty years later (in the 1950s) that economists attempted to develop a rigorous, consistent set of methods for measuring benefits and costs and deciding whether a project is worthwhile.[17]
Following the principle of discounting, benefits and costs of transportation projects occurring in the future is discounted to their present values using a specific discounting rate. This rate varies in every country. For instance, the recommended discounting rate for transportation project is 6 percent annually in the United Kingdom, 7 percent in the United States and Australia, 8 percent in Norway, 10 percent in Canada [18] and 12 percent annually for the projects evaluated by the World Bank [19]. The discounting rate in Iran is determined as 20 percent annually. [20]
Experiences of Tehran in implementation of ITS technologies for enforcement of congestion pricing in first cordon shows that ANPR technology had good effects on recognition of

violation and helped the policy makers to manage the traffic congestion. Therefore, in this paper we assumed this technology would have a good effect in traffic management for second cordon and this system is selected for cost-benefit analysis and so on this technology has been cosen for enforcement of this scheme.

In this paper, authors try to compare costs and benefits of ITS technologies for enforcement of plate number rationing to illustrate if the implementation of this technology is worthwhile or not. First, costs and benefits are determined. Then, costs are classified in two groups: costs that one can calculate and costs that one cannot. And benefits are also classified in these groups too. Calculable costs consist of buying technologies and setting them up and hiring some people for controlling and maintaining these technologies. Calculable benefits consist of reduction in the police presence, reduction in human resources needed in official process and recognition of more violators. However, there are other effective costs and benefits but we cannot calculate them, these costs and benefits are such as resident and police healthy, time worth and improving traffic characteristics, fuel consumption, traffic congestion and air pollution. These parameters should be studied in detail after implementation of ITS technology for enforcement of plate number rationing scheme in a before-after study. For studying worthiness of this project, benefit-cost ratio method is chosen.[21] In this method, difference between the current situation and the alternative situation benefits that are calculated in technologies lifetime, should be divided into the difference between the current situation and the alternative situation costs that is discounted to the net present worth based on technologies lifetimes and the discount rate. If this ratio were determined as more than 1 it illustrates that the project would be worthwhile if the supposed situation are happened in future. This ratio would be calculated based on the following equation:

$$\frac{\mathrm{B}}{\mathrm{C}} = \frac{\mathrm{Benefits}}{\mathrm{Costs}} = \frac{\mathrm{PWB}}{\mathrm{PWc}} \quad (1)$$

4. CASE STUDY (TEHRAN EVEN-ODD ZONE)

Tehran as the biggest city of Iran that has over 9 million residents with more than 4 million registered vehicles but only 2.5 million vehicles are circulating in this city daily. On average, 280000 vehicles are registered in this city annually.[22] Tehran is now controlling its traffic on congested areas with a multi-layer cordon pricing. The first layer constraints the entrance of vehicles into downtowns and second layer which is around it constraints the entrance of vehicles upon the last digit of their plate numbers. Because plate numbers in Iran do not contain zero number, number of vehicles with odd plate is 11 percentages more than even plates.[23]

The second restriction layer has expanded due to air pollutions and increasing traffic from 2005 and known as even-odd zone. Even-odd scheme restricted some vehicular traffic from entering to the special cordon and covered a 120 square-kilometres area and had 97 entrance gates. Vehicles that the last digits of their plate are not in accordance with weekdays could not travel in this zone. Therefore, even plate numbers could enter on Saturdays, Mondays and Wednesdays and odd plate numbers could enter on Sundays, Tuesdays and Thursdays [23] (figure1)

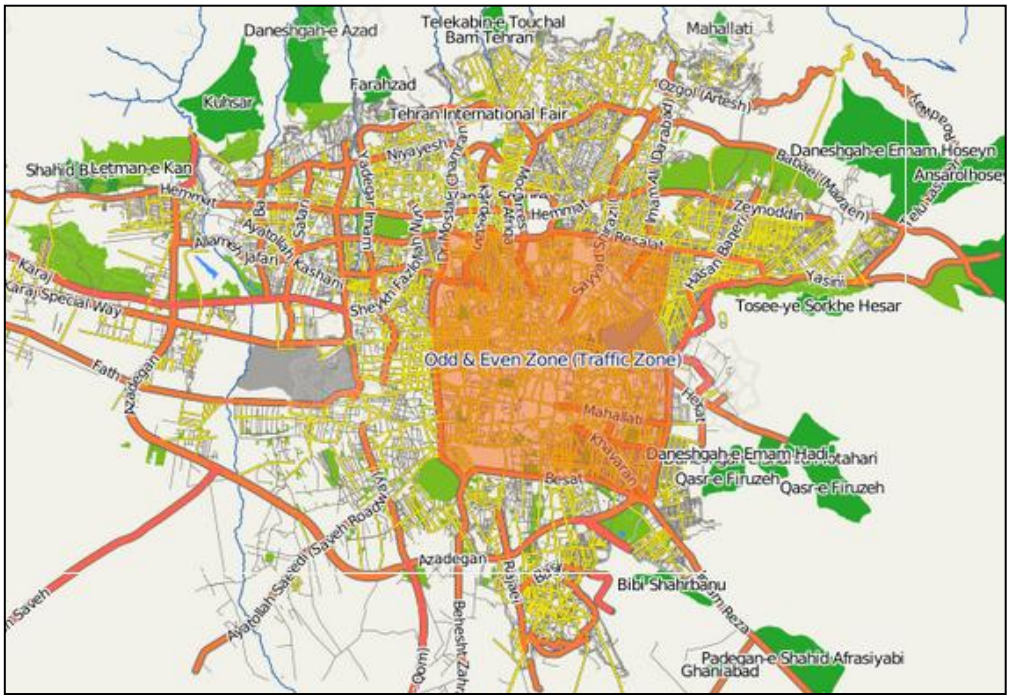

Figure 1-Tehran even-odd zone map

4.1. Technical evaluation of using ITS technologies

In this part, authors decided to compare police presence and ITS technologies from the technical point of view. So, for reorganization of violators and recording traffic volume, more than 120 actuaries were employed and 9 cameras were setup for recording the highway traffic volume during the start to end of this scheme (6:30-19:00) in two weekdays (Monday, Tuesday). After, the data were gathered and volumes databank was provided, rate of violating was calculated and types of road hierarchy were determined. Finally, correlation between types of road hierarchy and their violating rate are reviewed.

As shown in figure 2, second cordon divided into four border line based on its geographic position (east, south, west and north) and types of road hierarchy defined, percent of road types in any side border line are different. On average, 48.45 percent of road hierarchy are arterial roads, 30.93 percent are collector roads and 20.62 percent are local roads.[23]

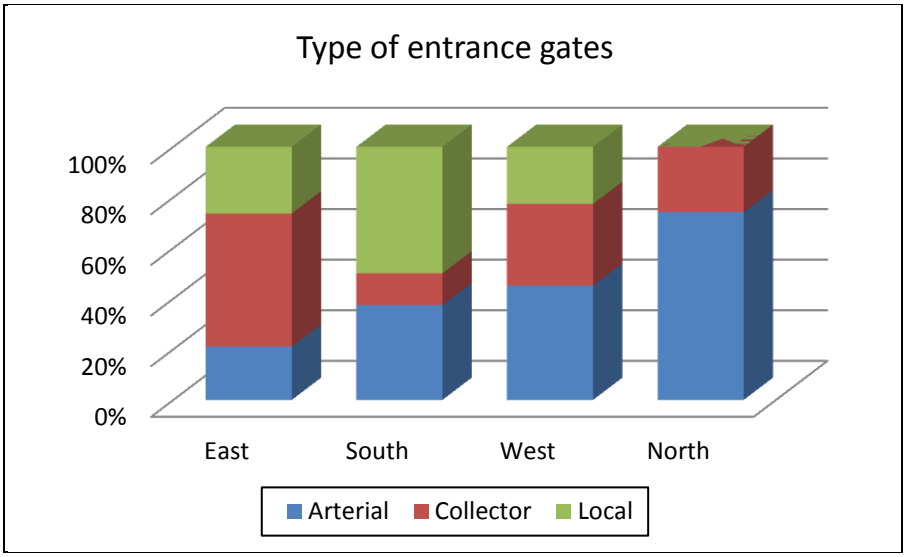

Figure 2-share of road hierarchy in each border line

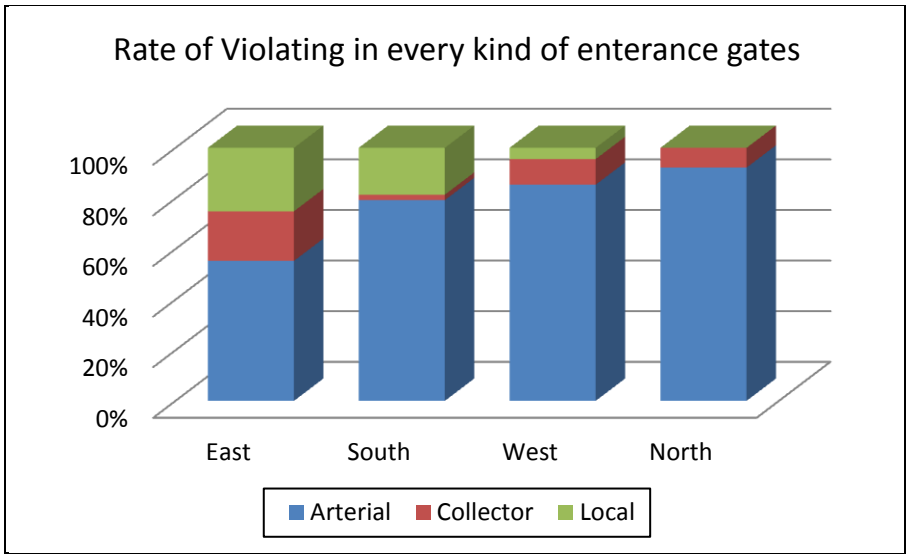

Figure 3- Rate of violations by hierarchy of roads

For studying the rate of violation in every border line and studying the necessity of using ITS technology for enforcement of Even-odd zone, this rate calculated based on the hierarchy of entrance roads and its geographic positions. As shown in figure 3, rate of violating in arterial roads is more than other types of roads. On average, rate of violating in arterial roads is 79.73 percent; rate of violating in collector roads is 14.52 percent and rate of violating in local roads is 5.75 percent. [23]

Comparing between figure 2 and figure 3 illustrate that rate of violation in arterial roads is more than other types of roads. Thus, police presence is not suitable and could not control violation in arterial roads and ITS technologies should be applied for enforcement of Even-Odd zone in Tehran. Therefore, ITS technologies are more effective than police presence from the technical point of view.

4.2. Economical evaluation of using ITS technologies

Because Tehran had some experiences in implementation of ITS technologies for enforcement of congestion pricing project, authors assumed that effect of this policy on Tehran even-Odd zone is the same as implementation of ITS technologies on traffic congestion zone that was performed. However, traffic congestion zone only restricted to downtowns but even-odd zone restricted to more residential areas. Before and after studies of enforcement congestion zone via intelligent transportation system illustrate that after implementation of this policy, vehicle violation rate would be decreased about 17 percent at once, and the total volume that enter to congestion zone decreased about 56 percent at once.[24] However, we could not specify that which percentage of these changes related to congestion pricing because congestion pricing performed simultaneously with other policies such as fuel rationing and extension of public transportation networks (BRT, Metro); also, these changes happened in even-odd zone. Based on congestion pricing experiences, after enforcement of the congestion zone via intelligent transportation systems violation rate would be decreased 8 percents annually although traffic demand would be increased 2 percents per year.[24] Calculable costs and benefits that related ITS technologies enforcement even-odd zone determined above. Now, authors try to calculate these cost and benefits in detail and after that benefit-cost ratio would be calculated with net present worth method.

4.2.1. Benefits of reduction in police presence

Costs of police presence should be calculated according to the number of policemen and patrolmen who are responsible for enforcement of this scheme in current situation. According to statistics of Tehran traffic police, 223 policemen are responsible of controlling entrance gates and 351 patrolmen are responsible of controlling inner zone. So, costs of police presence in current situation were estimated about 2,328,408 US$ annually and these costs would be about 1,399,440 US$ after using ITS technology because only entrance policemen would be omitted. Therefore, enforcement of even-odd zone via ITS technologies would have some benefit because of reduction of police presence. In addition, there are some other costs that related to police presence but we could not estimate them such as costs of their healthy, costs of their cars, fuel consumptions and other cost that related to their equipment.

4.2.2. Benefits due to less human force needed in official process

Currently, traffic restricted zone is being enforced via intelligent transportation systems (ITS) by Traffic Organization of Tehran Municipality. Annually, specified numbers of permits are given to qualified vehicles. Although, specified number of daily and weekly permissions were published and were disturbed between drivers who are not permissible to enter this zone but these permissions let drivers enter to even-odd zone even thought that day was not accordance to last digit of their plates. As a result, this process that contains publishing and selling these permissions in 60 stations around Tehran even-odd zone have some cost for the Traffic Organization of Tehran Municipality that should be considered in our calculation. According to Traffic Organization of Tehran Municipality's statistics 29 people are working in traffic congestion permission's sector and 60 people are responsible of selling these

permissions around Tehran even-odd zone. So, Costs of traffic congestion Permissions' employees in current situation were estimated 503,004 US$. These costs would be 187,385 US$ after using intelligent transportation systems. So, reduction of 60 people who were responsible of selling permissions around even-odd zone has benefits for our calculation.

4.2.3. Benefits of recognition of more violators

As cited above, because of Tehran experiences in using ITS technologies for enforcement of congestion traffic zone, authors decided to extend traffic congestion results to even-odd zone. Thus, violation rate would be decreased 17 percent at once by using ITS technologies although total traffic volumes would be decreased too. Based on congestion pricing studies, after the enforcement of congestion zone via intelligent transportation systems, violators annually would decrease 8 percent, although traffic demand would increase 2 percent per year. A 10 US$ fine had been accounted for violators entering even-odd zone in weekdays. This fine has been increased to 15 US$ recently. This fine is 6 to 13 times more than Tehran's in other countries which has implemented plate number rationing. In Mexico City this fine is equal to 200US$, 107US$ in Bogota and 100US$ in Sao Paulo. Benefits of recognition of more violators would be calculated based on current violators and percentages that cited above in ITS technologies lifetime and calculate its worth with fines would be taken by Tehran Traffic Police. So, Benefits of recognition of more violators were calculated and shown in table 1.

4.2.4. Costs of ITS technologies

ANPR/ALPR technology is chosen based on Tehran traffic congestion experiences. These technologies working based on images taken from vehicle license plates, so we need to use cameras. Some systems use front and end-rear located cameras and the other one only use the one of them, in Tehran for improving driver's privacy images should be taken by rear-end cameras. In addition, because of technical restrictions, these cameras are able to cover only two lanes and because of financial restrictions, Tehran Municipality plan to setup these technologies only in entrance gates. Therefore, cost of cameras had calculated according to the number of entrance gates. After that Traffic Organization should be hire some experts for setting them up and maintaining these technologies. Finally, some experts required for controlling them and recognition of violators.

Number of cameras and related technologies determined based on the number of entrance gates and number of their lanes. According to surveying and current restrictions east border need 31 cameras and related technologies, south border need 23 cameras and related technologies, west border need 28 cameras and related technologies and north border need 25 cameras and related technologies. Totally, Tehran even-odd zone need to 107 cameras and related technologies for mechanized control of even-odd zone. Unit price of any camera and related technologies are equal to 50000 US$ including mechanical and electrical equipment and operations, cost of devices and OCR software. Therefore, the ultimate cost of buying ITS technologies for all of entrance gates estimated 5,350,000 US$. After buying these technologies, Traffic Organization of Tehran Municipality needs to hire expert people

for setting these technologies up. If 10 people takes part in this project, set up these technologies would be last about 6 months, so their costs would be equal to 69,231 US $. Finally, we should estimate costs of annually maintenance. Costs of annually maintenance estimated 895,384 US $

4.2.5. Benefit-Cost Ratio

After calculation of costs and benefits, The benefit-cost ratio would specify that enforcement of plate number rationing scheme with ITS technologies is worthwhile from the economical point of view or not. Therefore, net present worth of costs and benefits for a 10 year period are determined and illustrated in table 1.

Table 1- Benefit-Cost analysis

Costs(US$)		
	Current situation	After implementation
Buying ITS technologies	---	5,350,000
Set up ITS technologies	---	69,231
Maintenance of ITS Technologies	---	9,849,224
Benefits(US$)		
Reduction in police presence	23,284,080	15,858,324
Reduction human forces in official process	5,533,044	2,219,045
recognition of more violators	*288,362,644*	*811,410,428*
Benefit-Cost Ratio	***34.96***	

5. RESULTS

Results of this study show that more than 76 percent of violators in Tehran even-odd zone related to arterial roads while, these roads only have 49 percent of even-odd entrance gates. Characteristics of arterial roads are so that police presence cannot control violations and cannot punish violators; also, manual enforcement did not have desired effects in decreasing emission level and travel demand because police cannot control the entrance gates fully. In the other hand, successful experience of using ITS technologies for enforcement of Tehran congestion pricing zone leads Tehran authorities to use this technological surveillance for execution of even-odd zone.

Evaluation of using ITS technologies for enforcement of plate number rationing in Tehran even-odd zone by cost-benefit analysis in 10-year period with discount rate of 20 percent show that benefit-cost ratio is equal to 34.96. This high ratio indicates that benefits of this scheme could compensate its costs in a short time. This result can be attributed to recognition and punishment of violators in arterial roads that police cannot recognize them in manual enforcement. Because plate number rationing scheme restricted 50 percent of vehicles from entering the cordon in each day, there will not other important alternative if it fails on operation. Therefore, by using ITS technologies, control of the entrance gates would be more accurate and traffic characteristics might be improved. At a result, using ITS technologies for enforcement of plate number rationing in Tehran even-odd zone is advisable from technical and economical points of view.

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