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Prioritizing Initiatives and Geometric Designing for Improvement the Performance of Intracity Expressways (Case Study: Hemmat Exp)

Ali Paydar*, Mehdi Hashemi

Department of Civil Engineering, Malard Branch, Islamic Azad University, Malard, Tehran, Iran.

* Correspondence should be addressed to Ali Paydar , Department of Civil Engineering, Malard Branch, Islamic Azad University, Malard, Tehran, Iran. Fax: +982166985562, Tel: +989120590684, Email: a.paydar@iaumalard.ac.ir .

ABSTRACT

In this study, improvement of the Hemmae Exp-east, between the Haqhani Exp and Sayad Shirazi Exp, was investigated using the smartization implementation and geometric designing. The traffic volumes of passing vehicles through light and heavy detachments were collected, and traffic information involved the PHF and the peak hour were extracted from them. The speed of the vehicles, the number of transmission lanes, and the width of the lanes were taken and the improvement of delay indices, speed, travel time and distance traveled, fuel consumption, and pollutant emissions, were investigated by providing solutions in three scenarios. The first scenario was implemented on-ramp metering. In the second scenario, two lanes were added to the Hemmat Exp, and both of the scenarios were implemented in the third scenario. The Delay index was decreased by 22% in scenario 1. In the third scenario, the speed indicator increased by 77%. Compared to different scenarios, the improvement rate for delay indices, speed, travel time, fuel consumption, and pollutant emissions in scenario 3 had more improvement than the other two scenarios. After the software calibration, in which the results are more reliable, scenario 3 showed better results than the first and second solutions.

Keywords: Traffic simulation, Smartization, Hemmat Exp.

1. INTRODUCTION

Rapid developments of technology in the communication era have significantly affected societies [1-3]. Due to the growth of urbanization, car traffic has become an important issue. Traffic is the main source of city life because it is the backbone of capital flows, logistics, information, and various activities, which plays an important role in social stability, development, and improvement of community [4-7]. Green transportation is a low-carbon and environmental traveling mode [8]. The active promotion of green transportation is not only beneficial for intensive use of road resources, the ease of traffic congestion, the decrease of energy consumption, and the improvement of air quality but also, as a return to healthy and leisure lifestyles, essential for the improvement of citizen health [9].

Considering the transportation system of Iran during recent years, it has been figured out that despite micro-investment in constructing new roads, obstacles such as congestion, car accidents, and environmental pollution are increasing. The car traffic in metropolises of Iran has become a growing difficulty, and the current nonself-adaptive traffic control systems are not able to manage it. Proper investigation and monitoring must be used to make smooth traffic flow. Therefore, utilizing smart control systems is essential. In a smart traffic control system, the road traffic data can be used to understand the behavior of vehicles to manage the road traffic. These data can also predict traffic flow for different roads in a city [10].

In the case of proper transport systems, the public confidence in the transportation network will be increased. These systems will result in a significant economic saving for both people and the government. Besides, along with prioritization to specific cars, they cause easy access to relief. They also can increase overall productivity utilizing coordination between their components (Fig.1).

In this research, prioritizing model of smartization and geometric designing on intracity expressways (case study: Hemmat Exp) have been investigated, and the following questions answered to a great extent:

- Has smartization a positive impact on resolving the traffic problems of the Hemmat Exp?
- Is the Hemmat Exp ready to implement the smartization?
- How does smartization affect the safety as well as the efficiency of the Hemmat Exp?
- How effective are the ramp metering and the geometric designing to improve the traffic mods?

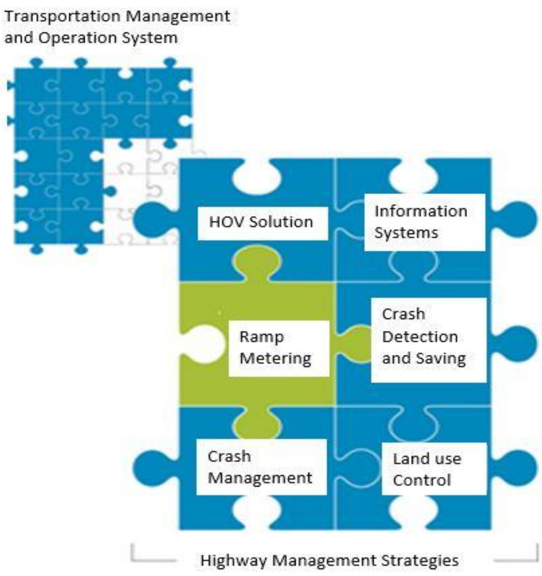


Figure 1. Transportation management and operation systems

In recent years transportation companies have provided smart ways to improve traffic conditions with the help of intelligent transportation technologies [11-13]. These technologies have been developed based on the multitude of researches that have been done around the world.

Alam and et al. (2018) gave a brief survey of researches on road traffic prediction and propose an innovative approach to estimate road traffic flow using regression analysis for the roads of Porto city (capital of Portugal). They have applied data preprocessing and feature selection techniques on the traffic data and then applied five (several) regression models to predict future traffic flow:

Linear Regression, SMO Regression, Multilayer Perceptron, M5P Regression Tree, and Random Forest. Their results show that prediction generated by M5P based regression tree tended to get the closest to actual traffic flow for different roads of Porto city, Portugal [14, 15]. Wang and et al. l. (2018), conducted a research project and published an article. In this article, they provided an overview of several promising research areas for traffic management in SIoV . Given the significance of traffic management in urban areas, they investigated a crowdsensing-based framework to provide a timely response for traffic management in heterogeneous SIoV. The participant vehicles based on D2D communications integrated trajectory and topology information to dynamically regulate their social behaviors according to network conditions. A real-world taxi trajectory analysis-based performance evaluation was provided to demonstrate the effectiveness of the designed framework [16].

Younes and et al. (2015) introduced an intelligent traffic light scheduling algorithm (ITLC). That algorithm utilized the vehicular ad hoc (VANET) technology to gather the real-time traffic characteristics of each surrounding traffic flow. The largest density first scheduled was implemented to set the phases of each traffic light cycle. The ready area was defined around the signalized road intersection to determine the maximum allowable time for each phase. The actual time set for each phase depends on the location of the farthest vehicle in each process of the traffic flow. From the experimental results, they inferred that the ITLC algorithm achieved better performance compared to algorithms that had previously been introduced in this field. In terms of the average delay taken for each vehicle to cross a signalized road intersection, ITLC decreased the delay by 25%. At the same time, ITLC increased the throughput of each road intersection by 30% [17].

Djahel and et al. (2016) provided a comprehensive study of the different phases of a modern TMS, emphasizing the main challenges and shortcomings of the systems and suggesting some directions to make the TMSs more efficient in future smart cities. First, they presented the different technologies used for traffic data gathering and highlighted the main new technologies that can significantly improve the accuracy of the collected data. They also surveyed the numerous routing protocols used in VANETs to disseminate the collected data among vehicles and showed their respective advantages and shortcomings. The congestion problem in VANETs, as well as the simulation tools, were also deeply discussed. Second, a critical discussion of data fusion and aggregation solutions was provided, along with a brief overview of the TMDD standard used by IBM. Third, routes planning and traffic prediction services were investigated with the main focus on highlighting the limitations of the algorithms and suggesting alternative directions for better accuracy and efficiency. Finally, they presented their vision on improving TMS's efficiency and robustness, which consists of leveraging smart vehicles capabilities and advanced parking systems to achieve the desired level of accuracy and control of the traffic [18].

Barkham and et al. (2018) investigated the urban management and real estate market and published a report. In this report, they discussed trends in applying big urban data and their impact on real estate markets. They expected such technologies to improve the quality of life and the productivity of cities over the long run. They forecasted that smart city technologies would reinforce the primacy of the most successful global metropolises at least for a decade or more. Their results show that a few select metropolises in emerging countries may also leverage these technologies to leapfrog the provision of local public services. In the long run, all cities throughout the urban system will adopt successful and cost-effective smart city initiatives. Nevertheless, smaller-scale interventions are likely to crop up everywhere, even in the short run. Such targeted programs are more likely to improve conditions in blighted or relatively deprived neighborhoods, generating gentrification and higher valuations there [19].

Shehada and Kondyli (2019) published a paper. In this paper, two well-known ramp metering algorithms, a local (ALINEA) and a system-wide (HERO), were evaluated considering several performance measures, including travel time reliability, queue lengths, throughput, and congestion duration. Travel time reliability was measured through the cumulative probability of travel times, travel time index, buffer time, and buffer index. In the context of this study, travel time reliability was found to be important for assessing the impact of ramp metering for a variety of demands. The evaluation was done through simulating in VISSIM an 8-mile long freeway facility in Kansas City, KS. The simulation results showed that travel time reliability for the entire facility did not exhibit significant improvement when a ramp metering strategy was implemented. However, the upper half of the facility underwent drastic improvement in travel time and travel time reliability. In contrast, the lower half of the facility experienced worse travel times and travel time reliability after implementing ramp metering strategies. The ramp meter on one street created a brief good impact on travel times, but it was overshadowed by the excessive vehicle demand incoming from the upper half of the facility. This suggests that although ramp metering might have positive effects on traffic operations and reliability, it might cause a new (possibly "hidden") bottleneck to occur downstream, thus diluting its overall benefits when looking at an entire freeway facility. In addition, it was also found that ALINEA generated better travel times than HERO; however, the difference was small. The benefits illustrated by the two algorithms in this research greatly depend on selecting the parameters used in ALINEA and HERO. It is possible that the selection of different parameters would likely yield different results in terms of reliability and performance [20].

Allan and et al. (2016) [21] surveyed and planned for management and traffic control through a smart transportation system. Congestion is a major problem in large cities. One of the main causes of congestion is the sudden increase in vehicle traffic during peak hours. Current solutions are based on perceiving road traffic conditions and re-routing vehicles to avoid congested areas. With this issue in mind, they proposed an intelligent traffic system called CHIMERA, which improved the overall spatial utilization of a road network and reduced the average vehicle travel costs by preventing vehicles from getting stuck in traffic. Simulation results showed that their proposal was more efficient in forecasting congestion and re-route vehicles appropriately, performing a proper load balance of vehicular traffic.

2. MATERIALS AND METHODS

2.1. THR RESEARCH PROCEDURE

At the first step, the Hemmat Exp-east between Haghani Exp and Sayad Shirazi Exp was investigated. The traffic volumes were mapped separately sorted by different vehicle weights, and traffic data, including PHF and peak hour, were obtained from the traffic volumes data. In the next step, the speed of vehicles, the number of lanes, and the lane's road width were mapped. In this research, Aimsun. 8 software was utilized [22].

After drawing the case of the research network, volumes of popular sedans, speed and capacity were used as the software input data. In order to evaluate the present situation, delay indices, speed, zero time, and distance traveled were considered. Then, smartization strategies, ramp input to Hemmat Exp scheduling, and the network safety strategies were evaluated. After that, the improvement of the cumulative index and the level of susceptibility of these proposed solutions were investigated. Finally, the queue length using the coefficients in the transport and traffic organization of Tehran municipality was calibrated. At this stage, the results of calibration were compared, and the following outcomes were taken:

Time (S/Km), speed (Km/h), average travel time (S/Km), total travel time (h), and distance traveled (Km)

Fuel Consumption (Liters)

Pollutant emission rate CO2 (Kg), PM (Kg), NOx (Kg)

2.2. THR STEPS OF SIMULATION

First, the network of the research area, including the roads and the accesses to the Hemmat Exp within the investigated area, was drawn.

Second, the direction of motions and the specifications of the public ways (e.g. speed, traffic passing capacity in one hour, and lanes width) and the methods for current traffic nodes controlling were determined according to the traffic laws (e.g. preemption and priority stop). Then, the specifications of the passing vehicles based on the local conditions of Iran and the properties of systems which have been calibrated based on Iran University of Science and Technology bylaws (length and width of the vehicles, the maximum and minimum rate of speed, and the acceleration of the vehicles), were entered into the software as inputs.

Also, sedans in the peak hour in an O-D matrix, the input and output accesses, and the making U-turn were entered. In order to determine the outcomes, dynamic and mesoscopic scenarios were defined. Then, based on the number of simulation performances, numerical and graphical outputs (e.g. delay, harmonic speed, the total and average time of travel, distance traveled, fuel consumption, and pollutant emission) were extracted from the software. According to the definition of the level of service based on the HCM2016 bylaw, the level of service of public ways separately sorted by width as well as output V/C were extracted, too. The research process is listed in Fig.2.

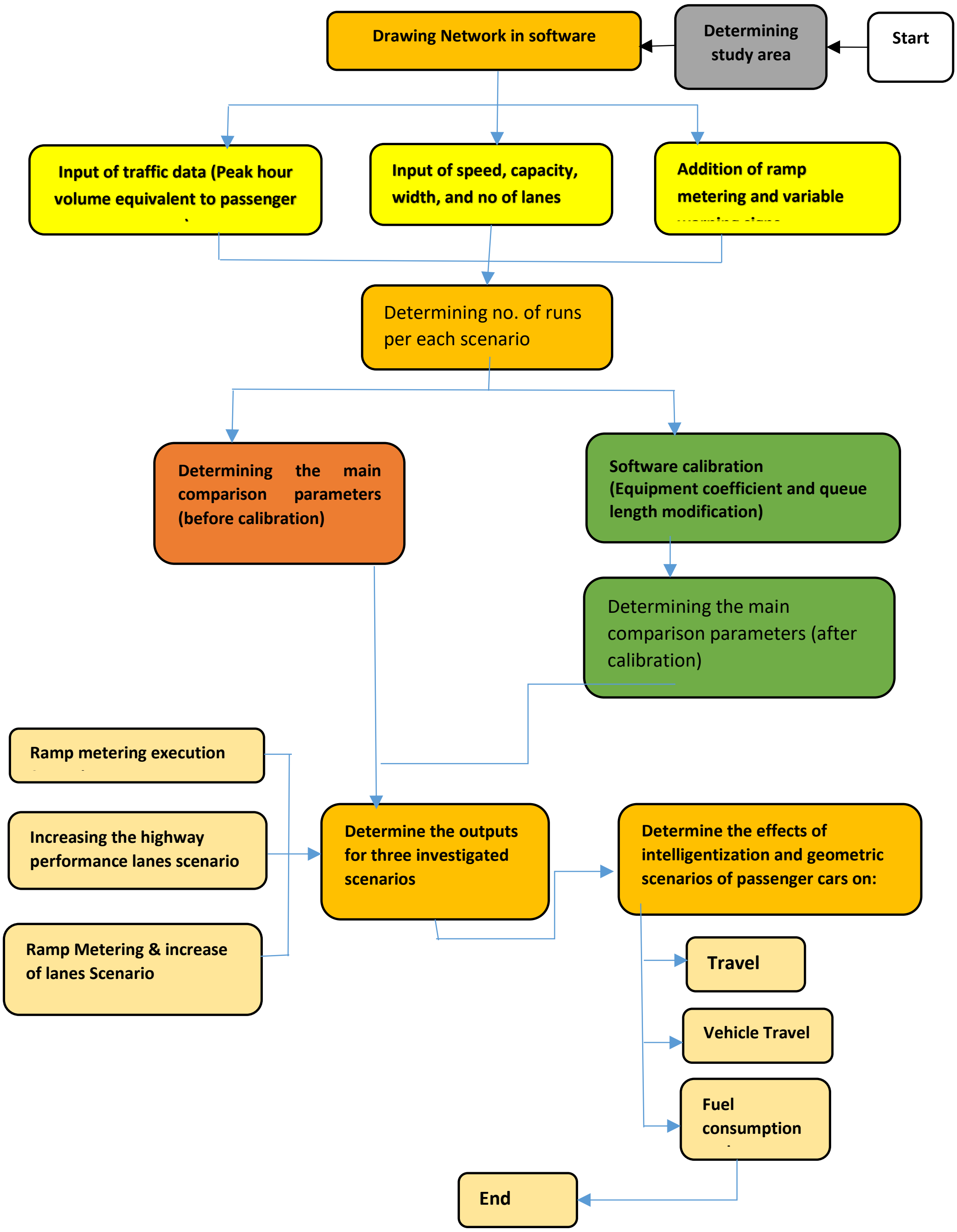


Figure 2. Research procedure (simulation and outputs from the software- Aimsun)

The investigated area is the Hemmat Exp-east between Haghani Exp and Sayad Shirazi Exp (Fig.3 and Fig.4). There is a ramp input with two lanes on the Hemmat Exp-east after Pasdaran Avenue that enters many vehicles into the highway (Fig.5).

Figure 3. Interference of high traffic between West-East of Hemmat path and High traffic of entrance ramp after Pasdaran passage

Figure 4. Aerial view of the study area

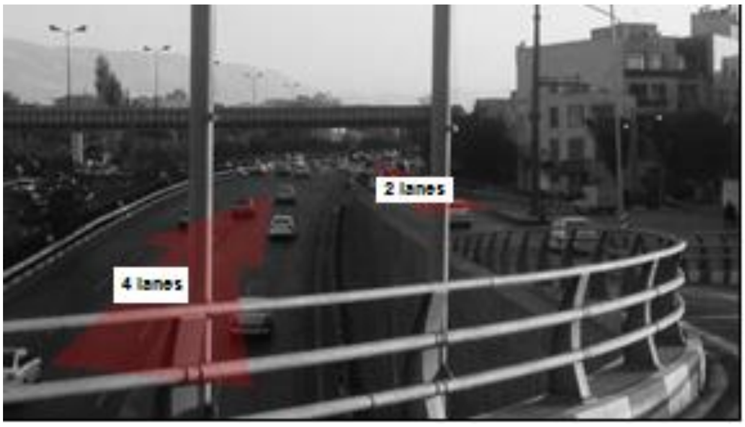


Figure 5. A view from the entrance ramp to Hemmat Highway (reduced lanes from 6 to 4)

The results of our mapping showed that the time between 17:00 to 18:00 should be considered as the peak hour. The investigated volumes in the mentioned peak hour have been shown in Fig.6 .

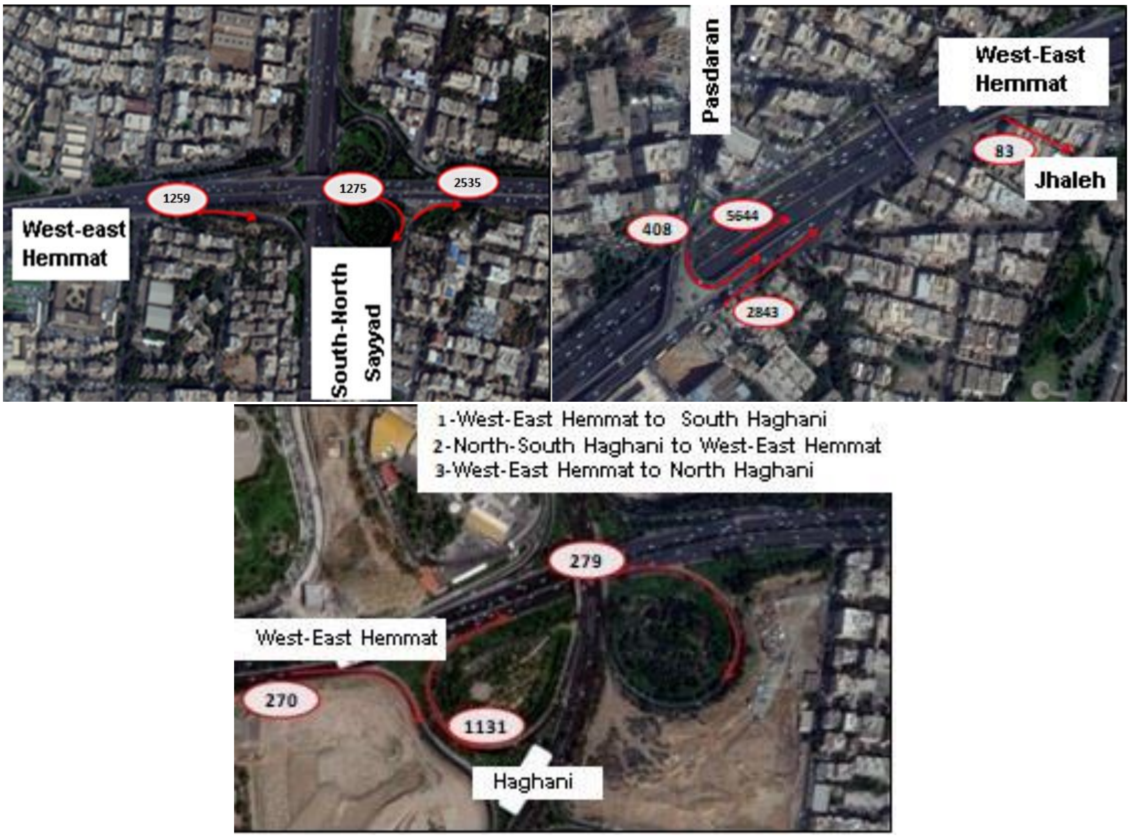


Figure 6. Measured traffic volume at the peak hour (17:00 to 18:00) evening

Our feasibility study led us to propose 3 scenarios to organize and improve traffic congestion. Then, these scenarios were simulated, and the results were compared:

Scenario 1: ramp metering operation for input ramp to Hemmat-Exp.

Scenario 2: adding a lane to the Hemmat Exp in the Mehran garden region (from the ramp input after Pasdaran to the ramp output to the Sayad Shirazi Exp-south), and adding a lane to the Hemmat exp in the Sayad Shirazi cross (after output loop to Sayad Shirazi Exp-north to input ramp from Sayad Shirazi Exp-north

Scenario 3: adding a lane to the Hemmat exp in the Mehran garden region (from the ramp input after Pasdaran to the ramp output to the Sayad Shirazi Exp-south), adding a lane to the Hemmat exp in the Sayad Shirazi intersection (after output loop to Sayad Shirazi Exp north to input ramp from Sayad Shirazi Exp-north, and ramp metering operation for input ramp to Hemmat Exp.

3. RESULTS AND DISCUSSION

The results are presented for the status quo and ramp scheduling scenario and the line increase, given the arrival of the correcting factors and controlling the length of the lining and the simulated queue.

The simulation results of the proposed scenarios are presented in Table 1 and Table 2, considering the correction factors for the status quo and ramp scheduling scenarios and the line increment.

Table 1. The simulation results of the proposed scenarios (traffic indicator)

Index		After calibration			
		Current Situation	Scenario1	Scenario2	Scenario3
Km/s	delay	8.343	7.294	1.290	7.257
Km/h	speed	8.170	9.260	0.220	5.310
Km	traveled distance	8.193	0.236	7.204	6.235
h	total travel time	0.160	8.138	9.129	4.107
Km/s	travel time	8.390	4.341	2.335	0.307

Table 2. The simulation results of the proposed scenarios (fuel consumption index and pollutant)

Index		After calibration			
		Current Situation	Scenario1	Scenario2	Scenario3
h	total travel time	0.1595	8.1379	9.1291	8.1035
l	fuel consumption	8.3000	4.2000	8.2000	9.2495
Kg	CO_2	8.7518	1.6614	8.6666	7.5394
Kg	PM	1.8523	1.2842	1.5049	0.7302
Kg	NO_x	11.5650	12.2890	11.1790	11.5450

Figure 7. Graphic delay index (an increase of lanes number and ramp metering solution) –After calibration

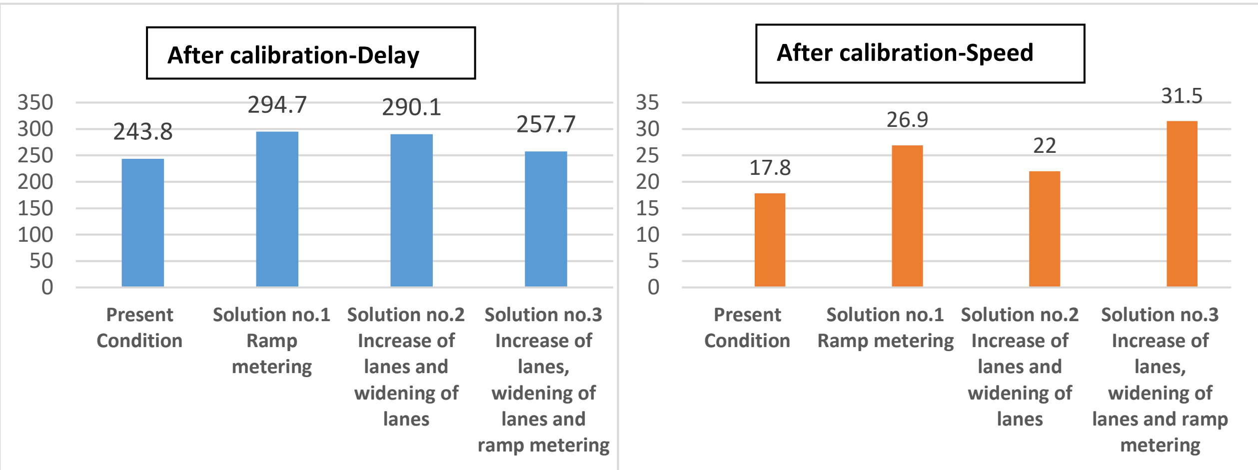


Figure 8. Comparison between the delay and speed indices-after calibration

In the following, the percentage variation of each performance indices is documented for the effect of the calibration (Table 3):

Table 3. The percentage changes of the results before and after the calibration

Index after calibration		Scenario1	Scenario2	Scenario3
Km/s	**delay**	**-14%**	**-16%**	**-25%**
Km/h	**speed**	**51%**	**23%**	**77%**
Km	**traveled distance**	**22%**	**6%**	**22%**
h	**total travel time**	**13%**	**19%**	**33%**
Km/s	**travel time**	**13%**	**14%**	**21%**
l	**CO2**	**38%**	**28%**	**38%**
Kg	**PM**	**12%**	**11%**	**28%**
Kg	**NOx**	**31%**	**19%**	**61%**
Kg	**CO2**	**6%**	**3%**	**0%**

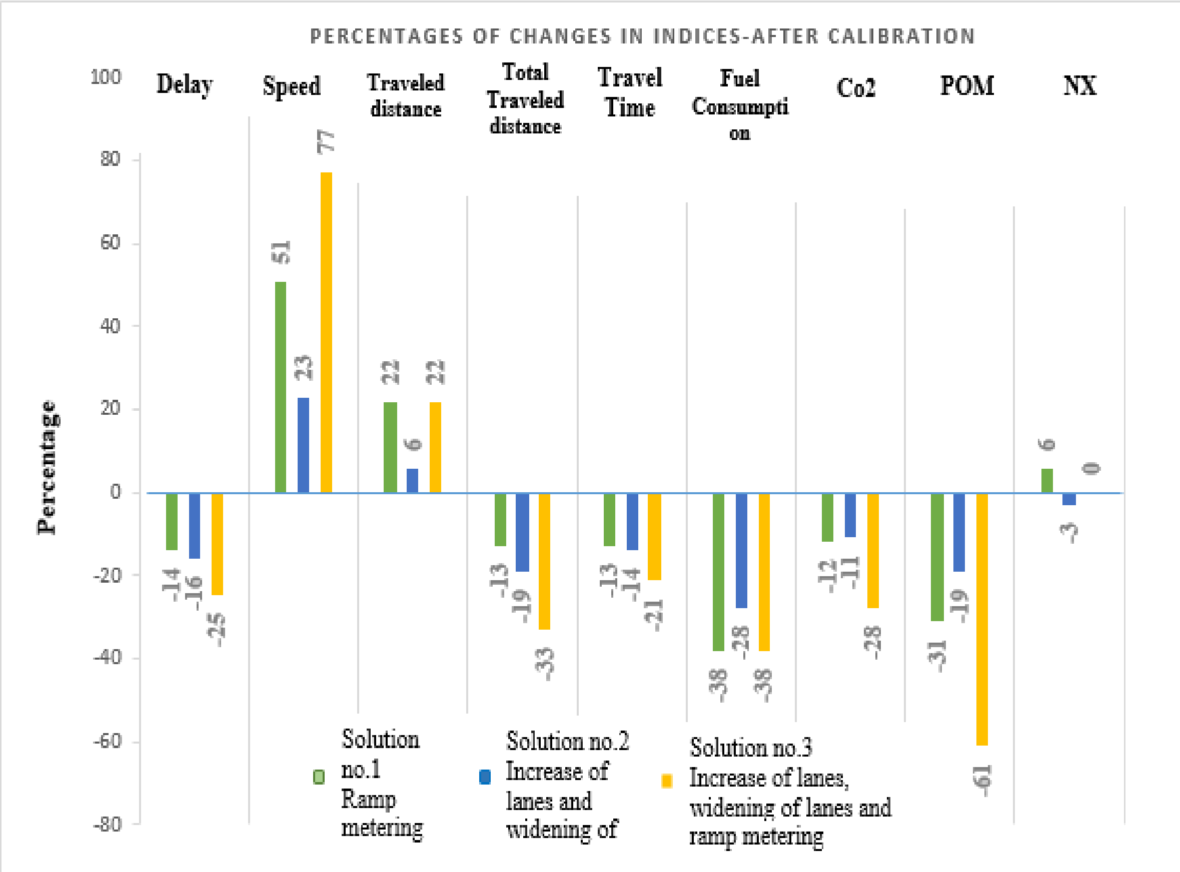


Figure 9. Comparison between percentages of changes in indices for scenarios no. 1 and 2(After calibration)

For all three scenarios, all indices of delay, speed, travel time, fuel consumption, and pollutants have improved. However, the distance indicator in the network has increased, and performance has been weaker.

Compared to the proposed solutions, the improvement of the delay index in the third scenario (adding lanes and ramp metering) has been more improved than the first two scenarios. Also, the improvement in speed indices, travel time, fuel consumption, pollutants, and delay index in the third scenario have been more improved than the first two scenarios.

For the pre-calibrated software, the solution performance of scenario 1 is better than that in scenario2, and scenario 2 has better functions than scenario3. In the post-calibrated software in which the results are more reliable, scenario 3 has better results than scenario 2, and scenario 2 has better results than scenario 1. The general indicator is defined as follows (Table 4 and Table 5):

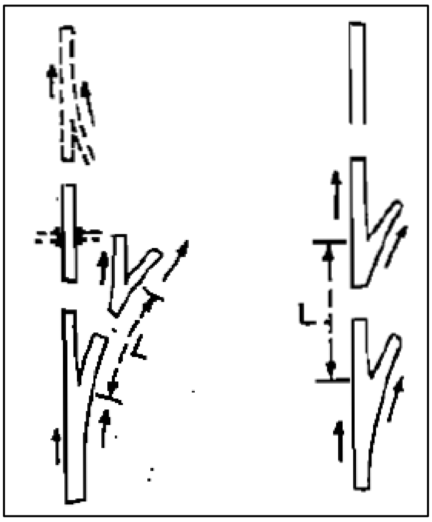
The general indicator = (delay×4)–(speed×3) + (average travel time×2) + (distance traveled×2) - total travel time

Table 4. Cumulative index (after the calibration)

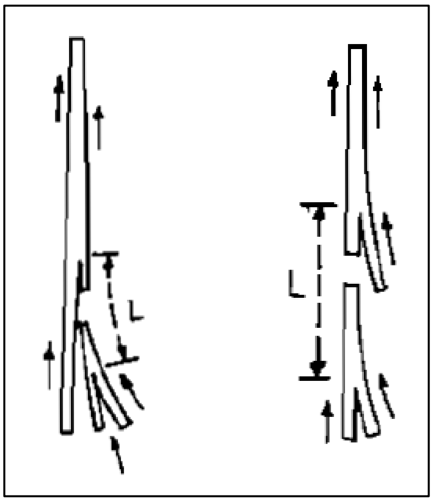
Solution	Scenario1	Scenario2	Scenario3
Cumulative index*	-2.0	-1.7	-3.6

Fig. 7 to Fig. 11 show the graphical indicator of the delay, comparison of the delay and speed index, comparison of the percentage variation of indicators for scenario 1 and scenario2, the input and output forms, and the distances between the accesses, respectively.

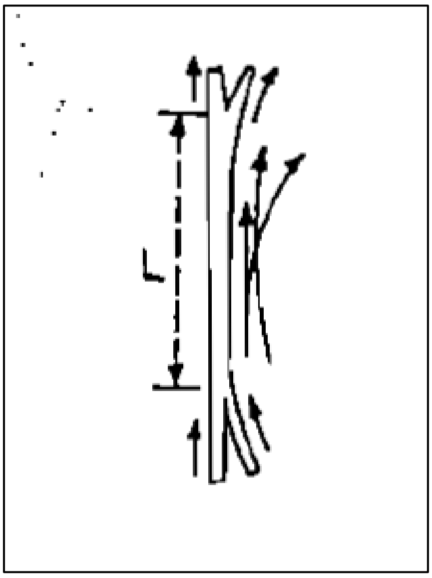
According to Section 5 of the Code of urban roads, interchanges, during the exchange situation and its interfaces, at least the distance between the inputs and outputs from each other on arterial roads is at least 250 meters in the output mode after the input (interference) on the highways. According to the comparison between the minimum distance of 250 m between the accesses on the highways and mapped distances in the range of research are accepted.



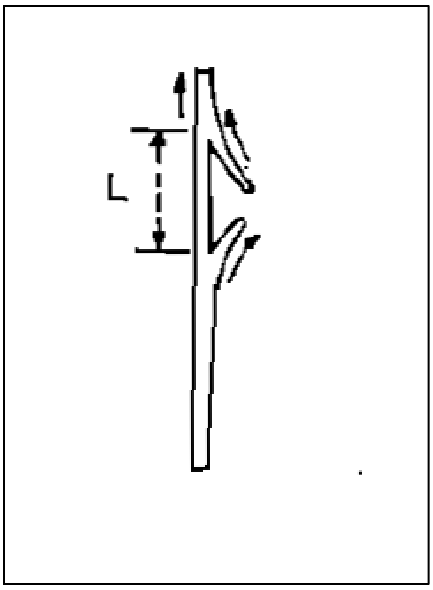
B) Two consequent exists



A) Two consequent entrances



D) Exit after entrance (Interference)



C) Entrance after exit

Figure 10. Types of entrances and exits

Table 5. The distance between the inputs and outputs

Situation	**L= The minimum distance between the inputs and outputs (m)**	
	Expressway	**Highway**
A	200	300
B	200	300
C	100	150
D	250	400

Figure 11. Distances between access points based on the Enactment No.32 of the supreme council for traffic coordination of Iran ministry of road and urban development

According to resolution 32 of the supreme council of traffic coordination of the Ministry of the Interior, the gaps of the accesses and other specifications of each functional class are listed in two main criteria and complementary specifications in Table 7. Considering the mapped information, the distances between the Haghani Exp and Hemmat Exp crossings is equal to 1390 m which, according to Table 7, the minimum limit of access intervals at the operational level of the highway is 2500 m, which does not observe that distances of the interchange ramp accesses are followed the rules.

Table 7. Main criteria for streets operational classification

Passing way	Dislocation role (%)	Access role (%)	Role in city network	Communication between the streets	direct access to peripheral applications	Speed (Km/h)	Allowed speed (Km/h)	minimum crossing distance	Shell width (m)	Number of lanes	Lane width (m)
Expressway	>90	<10	Between main zones	Main streem, highways and expressways	Does not have	90-120	80-110	1000	45	At least 2 lanes	3.25-3.50

Fig.12 shows the location of the identifier (Hemmat Exp-east before the Pasdaran ramp), and Fig.12 to Fig.15 show the general trend of the speed of vehicles passing through the Hemmat Exp within the area before the Pasdaran input ramp before and after the smartization process. The speed, time headway, the identifier of the detector (Occupancy), and the number of devices passing through the detector are shown as well.

Figure 12. Position of detector (West-East Hemmat before Pasdaran ramp)

According to Fig. 13, the average speed of the transit vehicles before smartization is 1/17 Km/h and after application of the solutions is 1/19 Km /h, which indicates an increase of 10%.

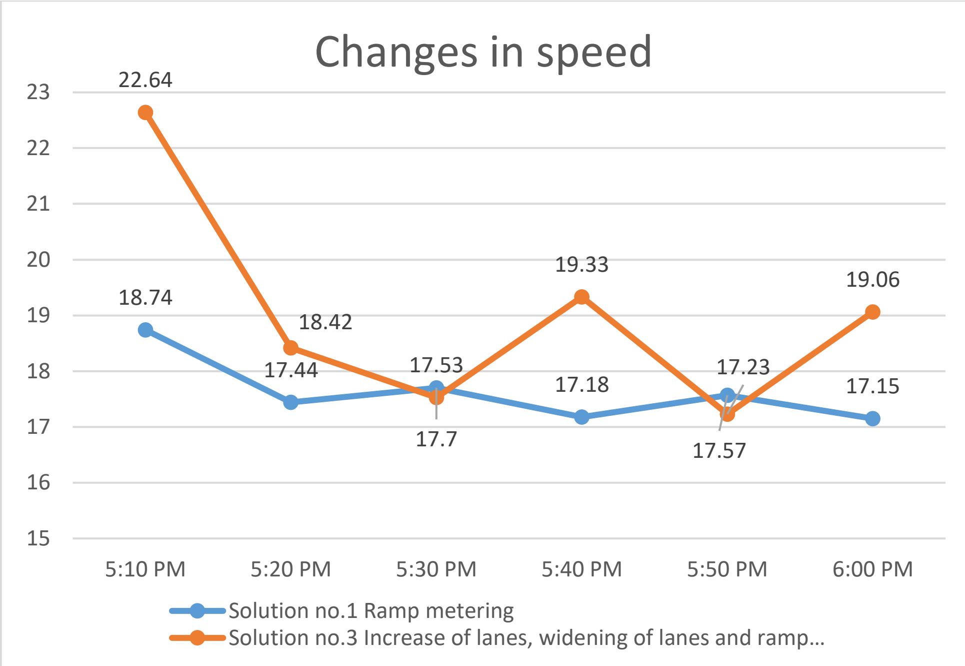


Figure 13. Changes in the speed before and after applying the intelligentization solutions

It is shown in Fig. 14 that the time headway before smartization is 83/0 Km/h. After applying the solutions, it is 62/0 Km/h, indicating a decrease of 25% and represents a gradual improvement.

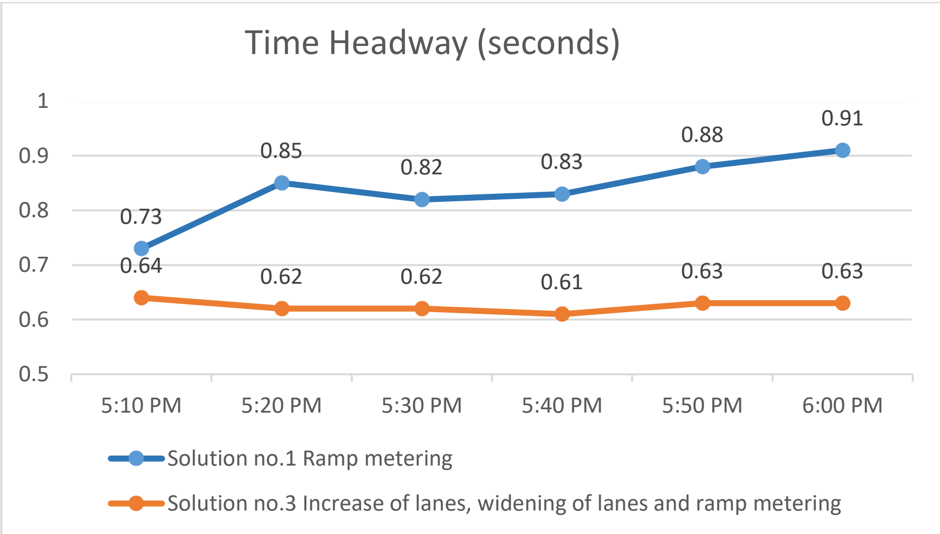


Figure 14. Changes in the time headway before and after applying the intelligentization solutions

As it is observed in Fig.15, the number of devices passing through the detector before implementation of the smartization, is 4312 vehicles per hour and after application of the solutions is 5761, which represents an increase of 34 percent and indicates an improvement in the throughput of devices from the indicator of the Hemmat Exp.

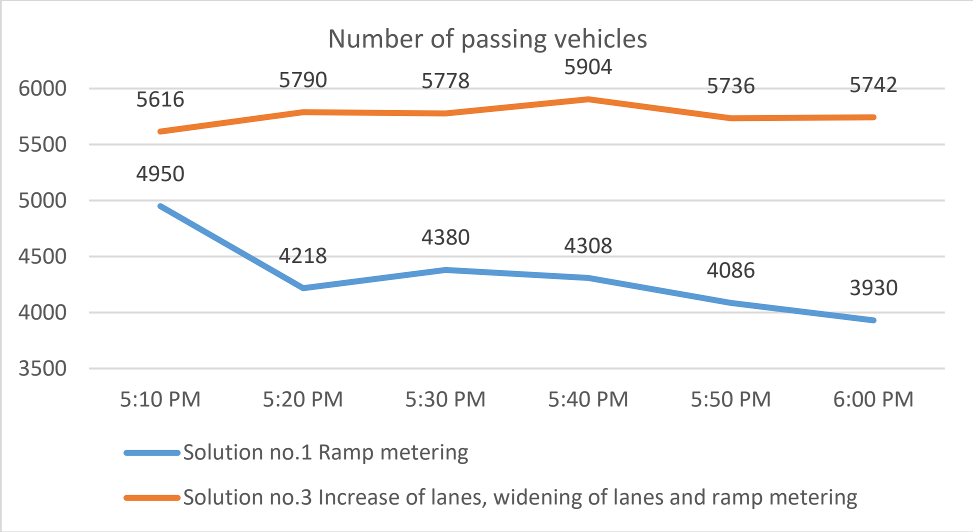


Figure 15. Changes in the number of vehicles passing the detector, before and after applying the intelligentization solutions

4. CONCLUSION

According to the simulation results of the proposed solutions, after applying the implementation of smartization strategies, the following are observed in comparison to the before and after applying the implementations:

Safety
Reducing the lane changing and thereby reducing the probability of car crashing and increasing the level of the safety in the region of fast and slow lanes overlap （As a result of a 7% reduction in lane change in the region of slow to fast, the safety level will increase)

The level of changes of speed and travel times compared to the current state (without applying the smartization process)
Decreasing delay by 25%
Increasing the speed level (speed up) to 77%
Reduction of the total travel time (hour) to 33% and decrease average travel time (second per kilometer) to 21%.

Fuel consumption and pollutant emission
Reduction of fuel consumption by 38%
Reduction of CO_2 production by 28%
Reduction of PM production by 61%

According to the study, the following modes are proposed to create ramp scheduling and increase the number of lanes crossing the main path. The reason for the use of ramp metering in critical sections is to increase the routing capacity of the main path.

The distances between the two inputs (entries) and two outputs must be less than 250 meters.

In case of similar creations of the ramp metering management system in access to the maximum volume of vehicles entering in an hour and the distance of the entry light to a radical is offered to be 10 m (two sedans). The advantages of using the ramp metering system were discussed in the previous section. Furthermore, in case of re-opening the node in the case study, using mentioned solutions, it is possible to transfer the critical point in the macro network to the main range of the research area. If applicable, the proposed solutions should be investigated.

According to the results, compared to each of the network links for the level of service indices, V/C, and the delay of each link, it is observed that in the present state, 14 links have the level of service F. In the following mode, six links have an F level of service and indicate performance improvement.

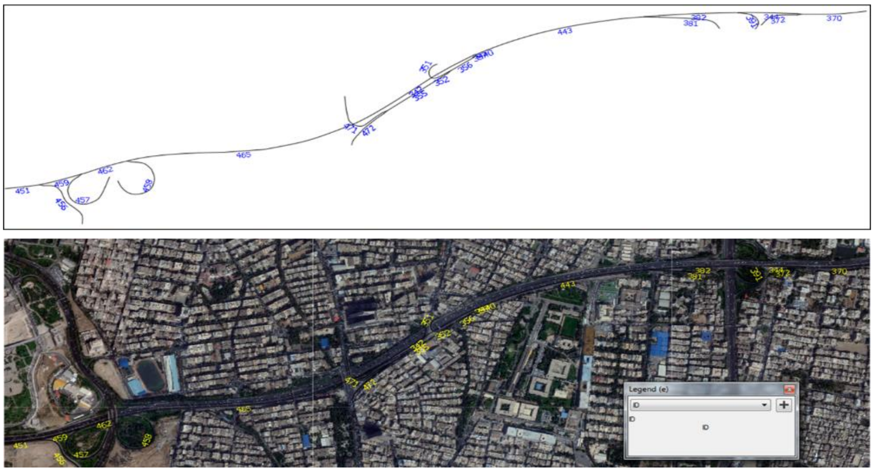


Figure 16. Position of each studied link for comparing the indices

In the present state, 14 links with higher V/C than one, and in the following mode, the application of smartization strategies has six links with V/C higher than one. This indicates an improvement in the overall network performance. The delay variation of each network links to the present state and, after applying the smartization guidelines, indicates a delay in 15 links from 23 links.

According to the results of the research in the case of the multiplicity of accesses in major cities, if it is not possible to remove the accesses, applying the ramp metering will improve the procedure of the main road. The results will show the improvements in transit, delay reduction, increase in traffic congestion, and increasing speeds. Also, it will be used at intervals of less than 250 meters, and it will prevent the locking of the network and the number of vehicles in the main avenue, as well as the accesses in peak traffic hours.

The followings are the answer to our questions:

1. Implementation of smartization has a positive impact on resolving the traffic problems of the Hemmat Exp.
2. The Hemmar Exp is not suitable for traffic, but it is ready to implement the smartization process.
3. The smartization process of Hemmat Exp is possible using ramp metering and improving the geometric design, including enhancement of the number of operating lines and increscent the width of the lines.
4. Each smartization proceeding affects the safety of the highway.
5. Smartization process of transportation increases the efficiency of the highway.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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