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Collective assessments of active traffic management strategies in an extensive microsimulation testbed

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Abstract

Regarding the daily congestions on the transportation networks, fresh Active Traffic Management (ATM) policies (including an innovative combination of existing ones) could be considered a potential and affordable solution to improve traffic network performance. Any fresh idea needs to be carefully evaluated before real-world deployment to avoid potential risks on the budget and time. And microsimulation approaches have been considered a custom and dependable method for evaluating traffic improvement scenarios in recent decades. Considering available tools in traffic microsimulation software, developing a large-scale well-calibrated model complying with real-world circumstances to some acceptable levels could be challenging and time-consuming, requiring taking some initiatives. This study includes the development of a 34 miles roadway network consisting of 41 signalized intersections in VISSIM software, probing to well-fitting ATM policies and potential combinations of them, and evaluating their deployment through VSSIM's COM interface.

1. Introduction

Most urban highways are facing daily traffic congestion, especially during peak hours. Hence, related institutions intend to deploy innovative policies to improve roadway traffic flow. Referring to the recent development in vehicular and infrastructural communication technologies, new ATM policies could be considered a potential and affordable solution to improve the traffic network performance in the bottleneck sections. To avoid potential risks on the budget and time, any traffic management policy must be carefully evaluated before deploying on the roadways.

In recent decades, simulation approaches have been noted as a standard and dependable method for evaluating traffic improvement scenarios. Developing a well-calibrated model complying with real-world circumstances to some acceptable levels could be considered an essential requirement in traffic and transportation studies. Based on the study goals, traffic/transportation simulation could be done either in macro or micro circumstances. Since micro simulator software is not equipped with sufficient tools to deal with big networks, modeling a relatively large network in microsimulation circumstances could be a challenging task that takes time and requires some initiative. This study aims to develop a large microsimulation network platform to be used as a reference for various ATM policies evaluation. To reflect all potential aspects, such a network should include various types of roadways, such as Interstates, principal arterials, minor arterials, and collectors. It also should cover various types of traffic control infrastructures, such as traffic signals and stop or yield signs. Another goal of this study is to find the most well-fitting ATM policies and innovative combinations, considering the network characteristics and initial simulation results for each scenario.

This paper is organized as follows: a brief literature review of related ATM policies, including Hard Shoulder Running (HSR), and Variable Speed Limits (VSL). Design of a large-scale traffic microsimulation testbed in VISSIM (mostly used microsimulation software in the USA) including dynamic assignment module deployment and travel time calibration based on ground truth travel time data from INRIX. Finding well-fitting ATM policies by considering the network characteristics, base condition simulation, visual observation, and numerical results. Defining proper evaluation measurement to compare the results of base condition with proposed scenarios. Evaluation of an innovative combination of proposed policies based on each policy's simulation results and the network characteristics.

2. Material and Method

2.1. Active traffic management strategies

ATM is the ability to manage recurrent and non-recurrent congestion based on prevailing dynamic and predicted traffic conditions. ATM policies are primarily focused on trip reliability by maximizing the effectiveness and efficiency of the facility. The most common ATM policies are Adaptive ramp metering, Adaptive traffic signal control, dynamic junction control, dynamic lane use control, Hard Shoulder Running (HSR), Variable Speed Limits (VSL), queue warning, and transit signal priority [1]. These solutions could be deployed singularly or combined, such as a combination of HSR and VSL or a combination of ramp metering and VSL. When implementing an ATM policy, besides the purpose of the system, the control algorithm complexity level is also essential. ATM policies are desired to have a control algorithm that can reflect the specific purpose of the system, simultaneously having a straightforward algorithm to be implemented quickly. It means the required control input should be easy to measure and interpret, and the control algorithm should be able to run in real time without potential delays (such as calculation delay) [2]. Based on the scope of this study, real-world deployed algorithms of HSR and VSL are briefly reviewed in this section.

2.2. Hard shoulder running

HSR could be considered as a subclass of managed lanes policies. This policy is based on deploying the hard shoulder as an extra lane in case of congestion at the specific section and increment of the roadway capacity at the bottleneck section. Various algorithms have been proposed for HSR, some of them more on the academic side and never used in real-world circumstances, and others more practical with records of deployment in real-world roadway sections.

The opening and closure criteria of the hard shoulder on the French A4-A86 motorway is based on the following algorithm:

If OCCj ≥ 20%: Open the hard shoulder.
If OCCj ≤ 15%: Close the hard shoulder.

Where OCCj is the occupancy measured in section j (the bottleneck section) [3]. The time interval of data collection and Hard shoulder-opening/closure interval could be defined based on the length of the hard shoulder and other traffic characteristics of the roadway.

2.3. Variable speed limits

Variable Speed Limit systems consist of a series of VSL signs and associated detectors collecting traffic data. The speed limits shown on the VSL signs are based on the traffic data collection close to the sign (normally a downstream section and both downstream and ups stream sections in a few algorithms). The same as HSR, several algorithms have been developed for the VSL trigger system and the optimum advisory speed. The VSL control system could be based on thresholds for a single variable, such as speed, or multiple variables, such as a combination of volume, occupancy, and speed [2].

The MCS algorithm (implemented in Sweden) uses speed thresholds for lowering and increasing the speed limits. The speed limit on the upstream sections is based on the detector speed measurements in the congested section. The MCS algorithm speed limit updating scheme for a highway with a speed limit of 120 km/hr is presented:

- If $V_{t,j} \leq 45$ km/h:
    - The speed limit at detector station j is set to $V_{t,j} = 60$ km/h.

  - Lead-in speed limits at two upstream detector stations are set to $V_{t,j-1} = 80$ km/h and $V_{t,j-2} = 100$ km/h, respectively.
- If $V_{t,j} \geq 45$ km/h:
  - The speed limit at detector station j, $V_{t,j}$, and the associated lead in speed limits, $V_{t,j-1}$ and $V_{t,j-2}$, are reset to 120 km/h.
  - Where $V_{t,j}$ is the mean speed detected at section j and time t [3].

2.4. Simulation test bed design

As mentioned in previous sections, modeling a relatively extensive network could be challenging and time-consuming due to available tools in micro simulator software. This section briefly describes the selected network's characteristics, and the main steps followed to develop its simulation testbed in VISSIM software.

2.5. Network cope

A section of I 80 between two interchanges with us 46 in New Jersey has been selected as the main simulation testbed, which undergoes heavy traffic in peak times due to its proximity to New York City. To evaluate the widespread deployment of ATM policies, the adjacent parallel roadway (US 46) and the significant roadways between US 46 and I 80, and all arterials and most collectors between US 46 and I80 are also added to the model. The total length of the modeled network is 34 miles consisting of 41 signalized interactions, mostly semi-actuated. Stop signs, yield signs, priority rules, conflict areas, reduced speed areas, and desired speed decisions are also monitored throughout the network and applied to the model. Figure 1 indicates the network created in the VISSIM simulation software.

2.6. Dynamic assignment add-on module

According to the network scale, the dynamic assignment add-on module in VISSIM is deployed for traffic assignment in the network. Dynamic assignment module deployment requires taking some initiative according to network characteristics which are described:

2.7. Zoning and relative flow adjustment

Considering the extent of the network, it is divided into 18 zones. The optimal zoning (which maximizes the seed OD matrix volume without congestion) is based on the network's physical characteristics and the roadways and traffic control systems' characteristics. The optimal zoning is achieved after several trials and errors as illustrated in Figure 1.

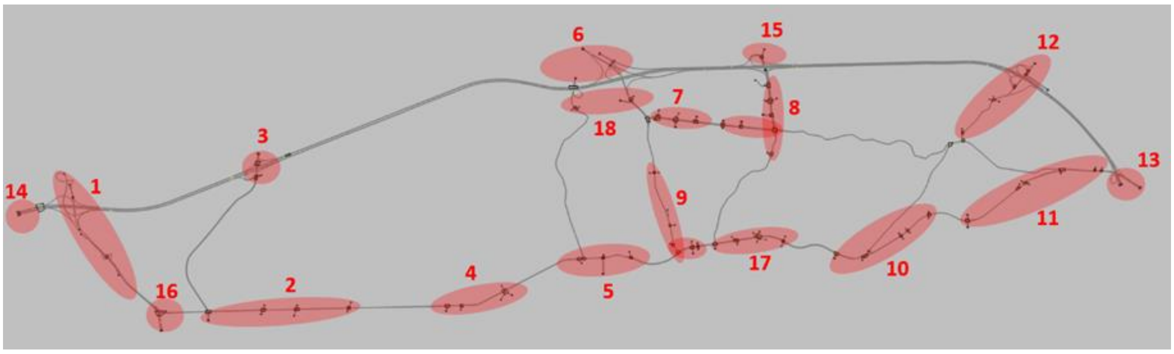

Figure 1. Network zoning

In VISSIM's dynamic assignment module, each zone consists of several virtual parking lots, and vehicles are entered/exited into the network through this spot. VISSIM software's default algorithm evenly distributes the entering volume to all parking lots in the same zone [5], which may not comply with real-world conditions. To make the model more compatible with the real world, an engineering judgment has adjusted the relative entering flow from different virtual parking lots in each zone based on immediate roadways and traffic control system characteristics.

2.8. Initial travel time equilibrium

Based on the selected zoning in the previous section, a seed OD matrix with a total demand of 9487 veh/hr is assigned to the model. A 3-hour simulation is run 15 times till travel time convergence for 90% of paths with a tolerance of 15% is achieved. To avoid fluctuations in simulation results, the simulation random seed is kept constant through all iterations, otherwise the equilibrium will never be achieved.

2.9. Matrix correction

To correct the OD matrix based on the available ground truth volumes, all available volumes for 2016 to 2018 from NJ traffic count stations (35 sections including ramps and loops), have been assigned to the links for three consecutive hours in the pm peak (17:00 to 19:00). And the matrix correction module (available in recent versions of VISSIM) is applied separately for each hour in pm peak time (3hours). The final estimated matrix ranges from 16916 to 19697 veh/hr for 3 hours pm peak.

2.10. Assignment of the estimated matrix to the network

As the last step of OD estimation, 40% of the estimated matrix is assigned to the network, and a 3hr simulation was run 60 times while increasing the seed OD by 1%; after 60 simulation iterations, the travel time in the network was converged for 90% of paths with a tolerance of 15%. The initial matrix reduction factor (40%) and the increment rate (1%) are achieved through several trials and errors (a maximum value that does not cause congestion in the network through each simulation iteration).

To evaluate the accuracy of the estimated matrix, counted volume in the simulated network (after convergence) is compared with the ground truth data on 30 sections, as shown in Figure 2. Ground truth and simulation volume count are reasonably compatible except for a few sections. Meanwhile, rezoning or seed matrix reconfiguration may change the result; it requires several trials and errors and running all dynamic assignment steps for each trial, which is highly time-consuming, while a more consistent result is not guaranteed. Moreover, a model calibration based on travel time is also considered in the steps.

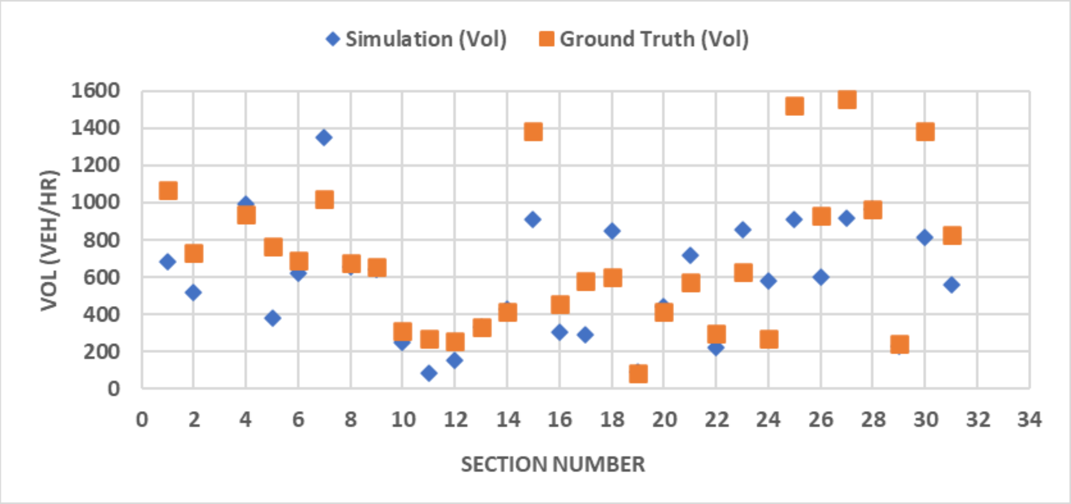

Figure 2. Ground truth vs. simulation results (volume on the links)

2.11. Dynamic assignment conversion to static routing

Despite travel time convergence, the result of a dynamic assignment simulation run could be different in each iteration. Additionally, running simulations through the dynamic assignment module takes longer than a static assignment. The created dynamic assignment routes are converted to static routing to save time and avoid potential fluctuations. This process removes only routes with 0.00 relative flow or 0.00 absolute flow, and no constraint is set on the maximum number of routes per destination. As a result, up to 1100 static routes are created between each origin-destination pair.

2.12. Model calibration

To make sure the simulation is complying with the ground truth facts [6]. The median of INRIX travel time data in 8 sections on I80 (4 in each direction) for 12 days (September 2018, Tuesday, Wednesday, and Thursday, 16:00 to 19:00) is compared with the simulation travel time results. The number of days is based on engineering judgment and available resources for this study. In case of a noticeable difference between INRIX and simulation travel time data, manual adjustments on static routes and volumes (for a time interval of 15 minutes) are made to make it compatible as much as possible.

2.13. ATM strategies deployment

ATM policies developed in this section could be considered an inspiration for future large-scale and more comprehensive ITS and traffic management studies on the network. Considering the network characteristics and initial simulation results, HSL, VSL, and a combination of them are considered the most well-fitting traffic management policies to be evaluated.

2.14. Variable speed limit

VSL system is deployed at a congested section in the network; speed detectors are placed 500 meters upstream to the center of the congested section on lanes 2,3 and 4 (lane one was skipped because it was observed line is formed on this lane to access the exit ramps). Two variable speed signs are located 0.5 miles and 1 mile upstream. The speed at the downstream section is monitored every 5 minutes, and the upstream VSLs are updated based on the MCS algorithm. Since the default desired speed on I80 is 65 mph, reduction to 35 mph in two steps (VSL deployment at two upstream sections showing 50 mph and 35 mph). As it is expected the VSL to affect the travel time in the bottleneck and upstream sections, travel time is collected in a section with 2.2 miles (0.5 miles downstream and 1.7 miles upstream of the interchange, shown in Figure 3.

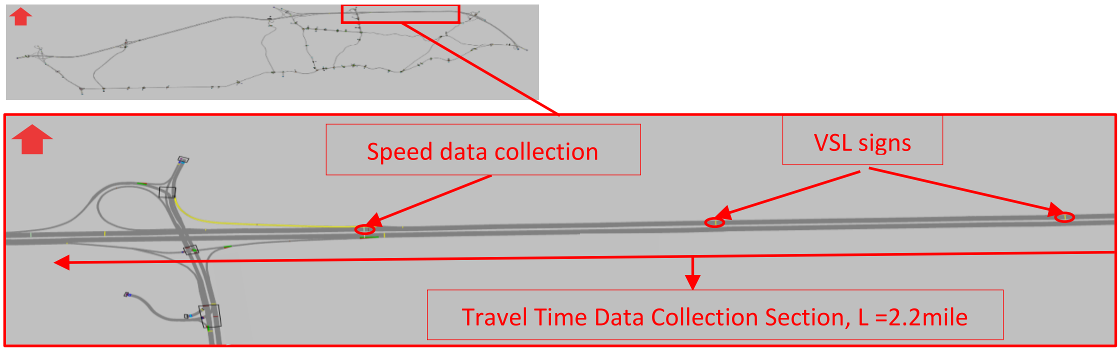

Figure 3. VISSIM network configuration for variable speed limit through non-automated circumstances

Real-time Data Collection and VSL algorithm deployment are applied by developing an application in Python and coupling it with the traffic simulation software (VISSIM) through its Computer Object Model (COM) interface, as shown in Figure 4.

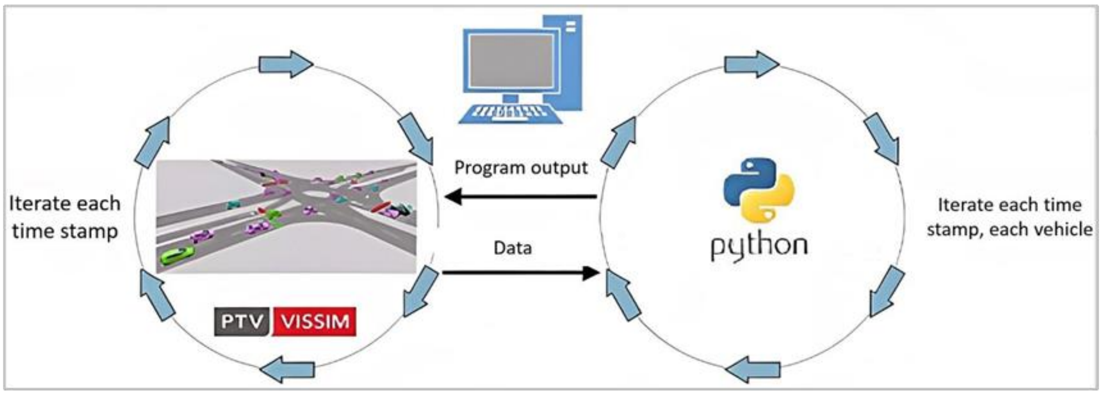

Figure 4. Coupling the Python application with the VISSIM traffic microsimulation software

2.15. Hard shoulder running

Same section, direction, and time as VSL deployment is selected for HSR performance evaluation. To deploy French A4-A86 HSR algorithm, a section with 0.3 miles length is selected as the potential bottleneck section for occupancy monitoring. And a Hard shoulder with a length of 1 mile, which is capable of being run in case of occupancy higher than the occupancy threshold at the downstream, is deployed in the model. As it is expected the HSR to affect the travel time in the bottleneck and downstream sections, a travel time collection section with a total length of 2.8 miles is defined, which includes 0.6 miles upstream and 2.2 miles downstream to the occupancy measurement section, which triggers HSR. The travel time data collection section includes two adjacent downstream intersections to reflect the upstream throughput increment effect on downstream sections entirely. Real-time Data Collection and HSR logic deployment are applied through the VISSIM COM interface by Python scripts.

2.16. Combination of HSR and VSL

Based on the simulation results of the previous scenarios (presented in the next sections of the paper). Combined deployment of HSR and VSL is also considered as a scenario. Speed detectors are located at 4 observed bottleneck sections downstream to the HSR section to detect congestion in downstream sections. The VSL triggers if the speed in any downstream sections is less than the threshold in the MCS algorithm. No adjustment has been made to the HSR configuration (developed in a previous scenario). The network's physical configuration for this scenario is shown in Figure 4.

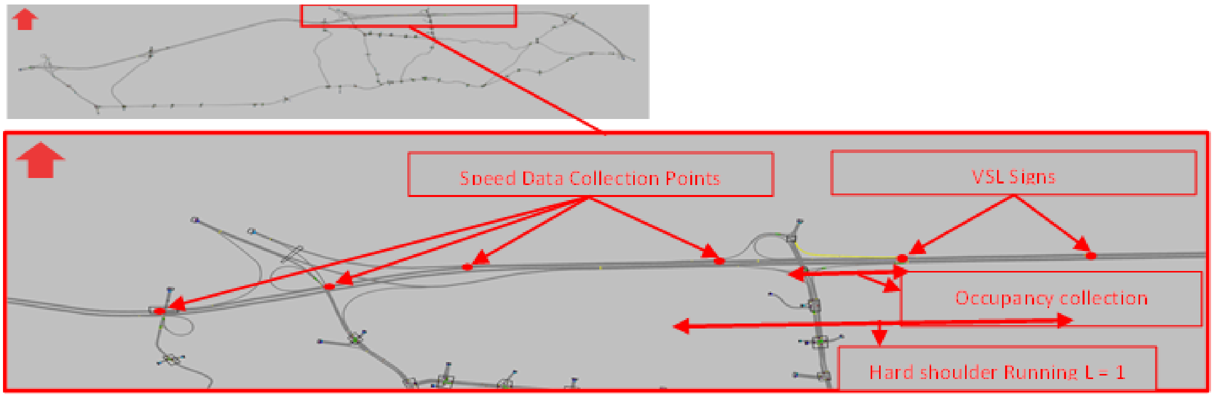

Figure 4. Vissim network configuration for combination of VSL and HSR

3. Results

The simulation is run three times with different random seeds, and the average travel time results with 15-minute collection intervals are collected for all scenarios. HSR deployment compared with the existing condition are shown in Figure 4. Referring to the results, VSL deployment has an unsteady travel time reduction/increment impact on the network. It reduces travel time by up to 30% at the second travel time peak (70000 simulation seconds). Meanwhile, it causes travel time to increase up to 15% right after the second congestion peak (90000 simulation seconds). Overall, it seems that VSL deployment can decrease travel time through the section.

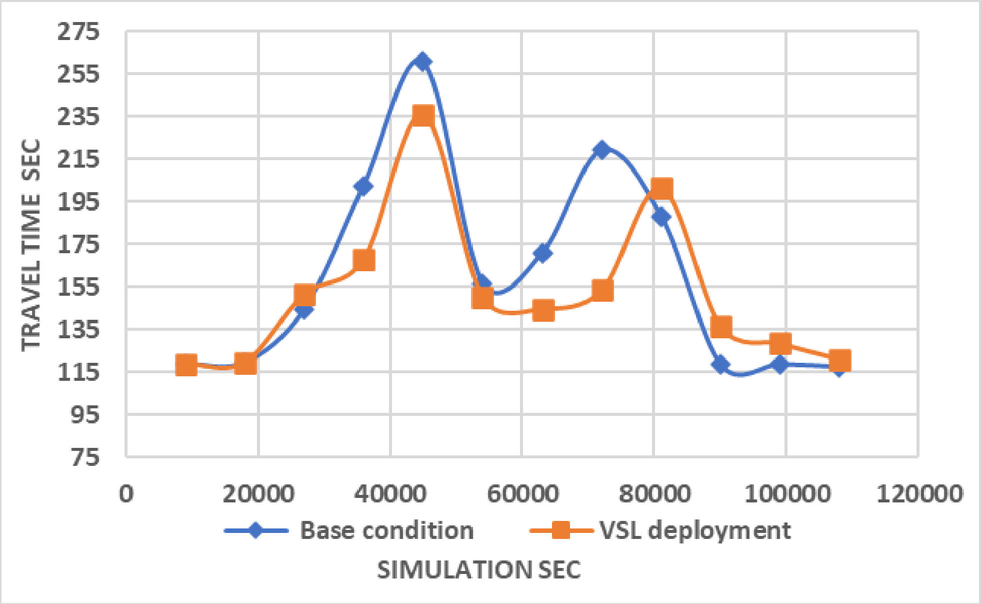

Figure 4. Travel Time Comparison (base condition vs. VSL deployment)

Results of HSR deployment and the combination of HSR and VSL compared with the base scenario are shown in Figure 5.

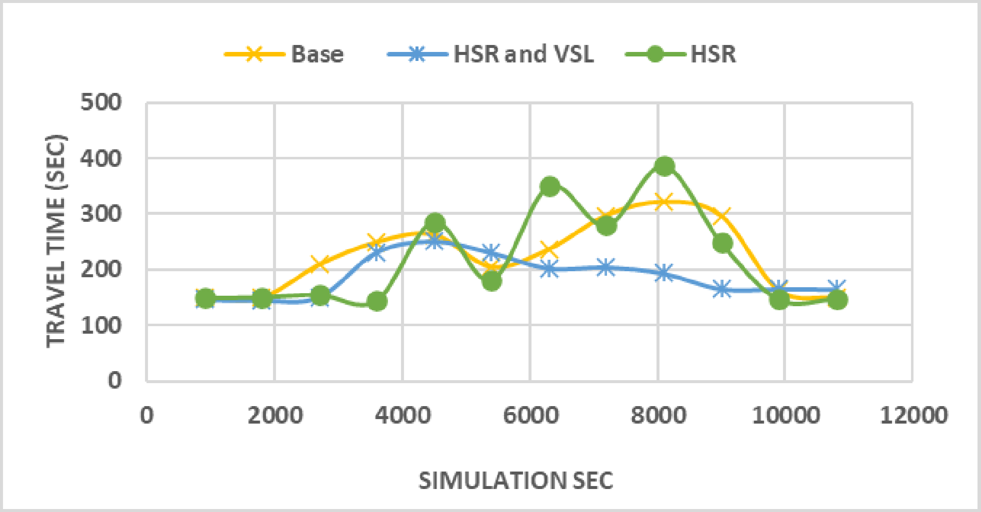

Figure 5. Travel time comparison (base condition vs. a combination of HSR and VSL deployment)

Referring to Figure 5, HSR deployment results in a noticeably fluctuated travel time. Travel time reductions are observed initially (between 20000 to 40000 seconds of the simulation). Meanwhile, as time goes on the travel time noticeably increases. According to the visual observation of the simulation, the reason is congestion in downstream sections. All in all, HSR deployment could leave a negative impact on the network in the 3 hours.

According to Figure 5 again, a combination of HSR and VSL could decrease travel time through the focused network section. According to the various unpredicted factors affecting the results, no straightforward interpretation could be made in Figure 6. Meanwhile, since no noticeable improvement is made in the first peak time (around 40000 sec of the simulation), it seems it takes time for this combined ATM policy to affect the network. All in all, a noticeable improvement in travel time (up to 40% reduction) has been made in the network through this scenario.

4. Conclusion

Referring to the available tools in micro simulator traffic software, developing a relatively large-scale network could be a challenging and time-consuming task requiring some initiatives. A well-calibrated 34 miles roadway network consisting of 41 signalized intersections is developed in this study to be used for a variety of ATM policies evaluation. The developed simulation test bed also evaluates the deployment of ATM policies including VSL, HSR, and an innovative combination of ATM and VSL. Simulation results reveal that VSL deployment could cause minor improvement in traffic flow at peak time, and deployment of HSR could noticeably increase travel time on the network due to the congestion on downstream sections. Meanwhile, the extension of HSR to downstream sections could cause congestion in farther sections; the fresh scenario consisting of a combination of VSL and HSR dramatically decreases the travel time through the network. The finding from this study is that the deployment of innovative combined ATM policies could be noticeably effective in some cases and should be considered before the extensive deployment of a single ATM policy.

Widespread deployment of HSR and VSL through the network and evaluation of its impact on adjacent corridors is the next step of this study. An innovative combination of other ATM policies, such as queue warning, adaptive ramp metering, dynamic lane reversal, and dynamic merge control, could also be considered. Considering the imminent appearance of connected/autonomous vehicles on the roadways, another recommendation for future studies is to evaluate the impact of vehicle-to-vehicle or vehicle-to-infrastructure communication in ATM policy deployment. For instance, in the case of different market penetration of autonomous vehicles, the VSL messages could be directly dispatched to individual vehicles, and the self-driving vehicles will maintain the exact recommended speed, which potentially could change the results.

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Author contributions

Ardeshir Mirbakhsh: Methodology, Software, Validation, Formal analysis, Original draft preparation; **Joyoung Lee:** Supervision, Conceptualization, Methodology; **Ravi Jagirdar:** Review and editing; **Hyun Kim:** Software; **Dejan Besenski:** Resources.

Conflicts of interest

The authors declare no conflicts of interest.

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