A simulation study of using active traffic management strategies on congested freeways

Ramakrishna VADDE, Dazhi SUN*, Joseph O. SAI, Mohammed A. FARUQI, Pat T. LEELANI

Texas A&M University-Kingsville, Department of Civil Engineering MSC 194, Kingsville, Texas 78363, USA

Abstract: The main objective of this study is to evaluate the effectiveness of using active traffic management (ATM) strategies on freeways in terms of the driver's behavior and operational impacts. A few test beds were selected to evaluate the impacts of ATM such as speed harmonization, shoulder utilization, and ramp metering. Test beds used in this study were at places where an ATM is either proposed or previously implemented, i.e., where data exists for conditions prior to and after the implementation of ATM. Data collected from the test beds were used in a simulation model to evaluate the impacts of each ATM strategy on speed, travel time, and crash rates. Simulation results indicated that the implementation of speed harmonization on US 90 showed a 14% reduction in crashes and a 2%–3% increase in freeway speed; the implementation of hard shoulders on US 90 showed a 39% increase in travel time, 22% increase in freeway capacity and 60% decrease in delays; and the implementation of ramp metering on US 59 between Bissonnet St. and Fondern road showed a decrease of 23 % in freeway travel time, a 14% increase in freeway speed and 11% decrease in accident rates.

Key words: active traffic management; VISSIM; speed harmonization; hard shoulder; ramp metering

© 2012 JMT. All rights reserved.

1. Introduction

Current increases in population growth have resulted in an increased transportation demand worldwide. The growth in the transportation demand has created increased traffic congestions and accidents in urban freeways. The Texas Department of Transportation (TxDOT) and other transportation agencies have initiated innovative methods to reduce these congestion problems and improve the roadway safety. Operational strategies that have been developed to solve these problems include: HOV (high-occupancy vehicle) lanes, speed harmonization, ramp treatments, shoulder lane usage, and dynamic message signs.

Active traffic management (ATM) strategies are currently being used in Germany, Netherland, Denmark, United Kingdom, Singapore, etc., to alleviate traffic congestion problems. Several methods are being used as part of ATM to reduce congestion, travel time, accident rate, and pollution, as well as to increase traffic volume, density, speed, etc. The success of an ATM strategy has been found to depend on driver's understanding and compli-

ance to the ATM strategy being applied. Hence there is a need for more research on ATM to show when, where and how the management strategy should be applied.

Speed harmonization is one of the ATM strategies used to maintain a free flow of traffic. This method involves changing driving speed limits in real time according to traffic condition (variable speed limit or VSL). Previous studies (Table 1) have shown that the use of speed harmonization decreased accident rates, improved travel time reliability, and reduced congestion and emissions.

Shoulder utilization is the usage of hard shoulder during peak hours to alleviate traffic congestion. Most of the studies and implementation of this method were done in France, Germany, England, and Netherlands. Opening the hard shoulder to traffic during peak periods was found to improve travel time reliability significantly and decrease congestion levels. This resulted in about 26% accident reductions. The main advantage of shoulder lane usage is to increase the capacity of freeway and this was proved by successful implementations in several countries. For example, Netherlands and France found an increase of 7%–22% in road way capacity while 10% increase was found in United Kingdom (Table 2). These countries used shoulders by observing and controlling the whole network manually with video cameras, radars, as well as automated controlling algorithms. Real time speed data was

Received Dec. 7, 2011; revision accepted Apr. 14, 2012

*Corresponding author. E-mail: Dazhi.Sun@tamuk.edu (D.Z. SUN)

© 2012 JMT. All rights reserved

doi: 10.3969/j.issn.2095-087X.2012.03.008

used in the algorithms to determine when the shoulder should open or close to through traffic.

Ramp metering is used to control merging of vehicles on-ramp to a freeway. The commonly used three types of ramp metering are single lane, dual lane, and dual lane with transit lane ramp metering. Ramp metering was implemented in some countries such as Germany, Netherlands, New Zealand, United Kingdom, and the United States (Table 3). Fig. 1 shows the geometric design of ramp metering.

Table 1 Benefits of speed harmonization from past studies

Case study locations	Benefits of speed harmonization
Germany [1-2]	<ul style="list-style-type: none"> ● 3%–30% reduction in crashes with light property, heavy material damage and personal injury crashes
Netherlands [1]	<ul style="list-style-type: none"> ● 23% decrease in accidents ● 4%–5% increase in vehicle throughput ● Minimized total time vehicle spends in network
United Kingdom [1-2]	<ul style="list-style-type: none"> ● 5%–10% increase in freeway throughput ● 10% decrease in collisions ● 28% decrease in accidents
Minnesota, United States [3]	<ul style="list-style-type: none"> ● 7% increase in vehicle throughput ● 20%–60% increase in speed limits
Michigan, United States [3]	<ul style="list-style-type: none"> ● Minimal decrease in travel time ● 5% of speed is increased in freeway

Table 2 Benefits of shoulder utilization from past studies

Case study locations	Benefits of shoulder utilization
Hessen, Germany [4]	<ul style="list-style-type: none"> ● 16% increase in capacity ● 25% increase in speed
Netherlands/France [5]	<ul style="list-style-type: none"> ● 7%–22% increase in roadway capacity ● 7% increased in traffic volume
Oxford, United Kingdom [6]	<ul style="list-style-type: none"> ● 25% reduction in travel time

2. Selection of test beds

Locations were selected on freeways where ATM is either proposed or previously implemented, and have pre- and post- ATM implementation data. Data was collected from the test beds was used in a microscopic simulation model (VISSIM) to evaluate the impacts of

Fig. 1 Geometric design of ramp metering

Table 3 Benefits of ramp metering from past studies

Case study locations	Benefits of ramp metering
Germany [7]	<ul style="list-style-type: none"> ● 50% decrease in congestion during peak periods ● Average speed on freeway increased by 10 km/h during peak periods
England [7]	<ul style="list-style-type: none"> ● Freeway speed increased by 14%–18%
Oregon, Portland [8]	<ul style="list-style-type: none"> ● 22% decrease in travel time ● 18% increase in speed ● 6% reduction in fuel consumption ● 43% reduction in accidents
Minnesota, United States [8]	<ul style="list-style-type: none"> ● 16% increase in speed ● 7% reduction in pollutant emissions ● 24% reduction in accidents
Austin, Texas, United States [8]	<ul style="list-style-type: none"> ● Metering increased vehicle throughput by 7.9% and increased average mainline speed by 60%
Seattle, Washington [8]	<ul style="list-style-type: none"> ● 28% decrease in travel time ● 26% decrease in accident rates ● Traffic on surrounding routes decreased by 43% due to increase accessibility
Denver, Colorado [8]	<ul style="list-style-type: none"> ● 27% increase in speed in freeway ● 5% reduction in accidents.

each ATM. Various data such as number of lanes, traffic volumes and freeway speed, shoulder width, average annual daily traffic (AADT), and signal timing were collected and used in the simulation experiments

The two locations selected for this study were

(1) US 59 in Houston between Bissonnet St. and Fondren road for ramp metering study;

(2) US 90 in San Antonio for speed harmonization and shoulder lane study.

US 90 is a major east-west highway which is linked to IH-10 in which the AADT varies from 65 000 to 140 000 vehicles per day.

Traffic volume data was collected from the TxDOT website. The ramp traffic volume (vph) and freeway traffic volume (vph) of IH 10 in Houston were collected with the help of TxDOT, Houston office.

3. Simulation and results analysis

VISSIM simulation software was used to evaluate the impacts of using ATM strategies. VISSIM is a micro-

level traffic simulation software developed by Planung Transport Verkehr (PTV), which provides a powerful tool for evaluating the impacts of ATM strategies such as travel time, delay time, speed, queue lengths, vehicle throughput, etc. Three ATM strategies selected for this study were speed harmonization, shoulder utilization, and ramp metering.

3.1. Simulation of using speed harmonization on US 90 test bed

Safety benefits were evaluated by comparing the use of speed harmonization when it is active and inactive on US 90 in San Antonio. Speed harmonization was tested as a potential improvement on a 3 mile segment of highway US 90 in San Antonio, Texas (Fig. 2). VSLs were activated according to the traffic volumes detected. This freeway section has three lanes with a width of 11 feet. Detectors installed at an interval of 0.5 miles were used to collect observed traffic and vehicle speeds.

Fig. 2 San Antonio study area

The speed limits changes from 70 mph to 50 mph when traffic volume exceeds 1 600 vphpl but less than 2 000 vphpl. The speed limits will be lowered to 40 mph when traffic volume exceeds 2 000 vphpl. Data collected during study period is shown in Table 4.

Table 4 Required data for speed harmonization

No. of lanes	AADT (vehcles/day)	Actual speed limit (mph)	VSL (mph)
3	3 3000–7 0000	70	50

After setting all these data in VISSIM model, several simulations were run to observe the traffic conditions. Table 5 shows the collected VISSIM model simulation data for speed harmonization.

Summary of results of the simulation are listed below:

(1) Travel time is increased by 6% when speed harmonization is active.

(2) Accident rates are reduced by 14% when speed harmonization is active.

(3) Average travel speed is increased by 2%–3% when speed harmonization is active.

Table 5 Simulation results when VSLs are active or inactive

Total no. of lanes	Freeway Volume (vph)	Start simulation time (s)	End simulation time (s)	Avg. main lane travel time (s)		Average main lane delay time (s)	
				Inactive	Active	Inactive	Active
3	4 500	0	3 600	471.5	498	230.3	258.1
3	5 400	3 600	7 200	509.9	521	268.8	291
3	6 000	7 200	10 800	526	578	284.4	309
3	6 600	10 800	14 400	531	558	290.9	359
3	6 000	14 400	18 000	534	591	293	381

3.2. Simulation of using hard shoulder lane on US 90 test bed

Hard shoulder lane was tested as a potential operational improvement on a 3-mile segment of highway US 90 in San Antonio, Texas. The number of lanes was 4 including hard shoulder. The width of regular lanes was 11 feet and the hard shoulder width was 10 feet. Shoulder lane is activated only during peak periods when traffic volume on the freeway exceeds 1600 vphpl, and the speed limit on the shoulder lane is used the same as regular lanes when activated. The data shown in Table 6 was collected and used to calibrate in VISSIM model.

The safety impacts were evaluated when the shoulder lane is inactive (Fig. 3) vs. active (Fig. 4). Table 7 shows the simulation results of shoulder lane use.

Table 6 Required data for shoulder lane use

No. of lanes	Shoulder width (feet)	AADT (vehicles/day)	Displayed speed limit (mph)
3	10	33 000–70 000	70

The following are the benefits of using hard shoulder lane on US 90 in San Antonio:

- (1) Freeway travel time is decreased by 39% when shoulder lane is open.
- (2) Capacity is increased by 22% when hard shoulder lane is open.
- (3) Delay time is decreased by 60% when shoulder lane is open.

Fig. 3 Simulation scenario when shoulder lane is inactive

Fig. 4 Simulation scenario when shoulder lane is active

Table 7 Simulation results when shoulder lane is inactive or active

Total no. of lanes		Freeway volume (vph)	Start simulation time (s)	End simulation time (s)	Average main lane travel time (s)		Average main lane delay time (s)	
Inactive	Active				Inactive	Active	Inactive	Active
3	4	4 500	0	3 600	471.5	301	230.3	21.9
3	4	5 400	3 600	7 200	509.9	319.4	268.8	38.6
3	4	6 000	7 200	10 800	526	341.8	284.4	76.3
3	4	6 600	10 800	14 400	531	353.1	290.9	106.7
3	4	6 000	14 400	18 000	534	369.4	293	157

3.3. Simulation of using ramp metering on US 59 test bed

Ramp metering was tested on location US 59 southwest freeway between Bissonnet St. and Fondern road. It is a single lane ramp metering.

Ramp metering is activated only during peak periods when traffic volume exceeds 1 600 vphpl on freeway. The strategy used in this study is “single-lane one car per green” in which it allows only one car to enter the freeway during each cycle with capacity of 900 vph, and single-lane two cars per green strategy is used when capacity is increased to 1200 vph on ramp. It allows two

cars per green in each cycle. The length of the ramp is assumed to be 2 600 feet and the ramp metering was placed 400 feet upstream of the freeway [9]. The ramp control signals were modeled using Vehicle Actuation Program (VAP).

Table 8 shows the signal cycle timings that are used in the metering depending on the traffic volume on ramp.

After setting all geometric data in VISSIM model, several simulations were run when ramp metering is active and inactive to evaluate the benefits of using ramp metering. Figs. 5 and 6 show the simulation scenarios of ramp metering. Table 9 shows the simulation results of ramp metering when it is active and inactive.

Table 8 Recommended ramp metering signal timings [9]

Number of vehicles per green	Capacity (vph)	Cycle length (s)	Ramp signal interval timings (s)		
			Red	Amber	Green
1	900	4	2	1	1
2	1 018	7.07	2	1.70	3.37
3	1 103	9.79	2.32	2	5.47
4	1 182	12.18	2.61	2.22	7.35
5	1 125	14.40	2.86	2.41	9.13

Fig. 5 Simulation scenario when ramp metering is inactive

Fig. 6 Simulation scenario when ramp metering is active

Table 9 Simulation results when ramp metering is active or inactive

Total no. of lanes	Freeway volume (vph)	Start simulation time (s)	End simulation time (s)	Average main lane volume (vph)	Average street lane travel time (s)	Average main lane travel time (s)		Average main lane speed (mph)	
						Inactive	Active	Inactive	Active
3	4 500	0	3 600	4 326	4 980	190	140	52	59
3	5 400	3 600	7 200	4 398	4 997	196.1	142.1	57	60
3	6 000	7 200	10 800	4 400	4 870	199.4	147.9	51	60
3	6 600	10 800	14 400	4 250	4 750	201.3	151	51	59
3	6 000	14 400	18 000	4 429	4 836	201.9	151.5	55	58

The following are the summarized benefits of using ramp metering on US 59 in Houston between Bissonnet St. and Fondren road.

(1) Freeway travel time is decreased by 23% when ramp metering is used.

(2) Freeway travel speed is increased by 14% when ramp metering is used.

(3) Freeway capacity is increased by 12% when ramp metering is used.

(4) Accident rates are decreased by 11% when ramp metering is used.

4. Conclusions and recommendations

The study demonstrates that implementation of ATM strategies on congested freeways show positive impacts on traffic operation and safety, while enhancing the effectiveness of existing strategies. Simulations of ATM on congested freeways show that the use of ATM strategies improved safety operations on test locations. The study also indicated the following results:

- Implementation of speed harmonization on US 90 showed a 14% reduction in crashes and an increase in freeway speed of 2%–3%.
- Implementation of hard shoulders on US 90 showed a 39% increase in travel time, 22% increase in freeway capacity, and 60% decrease in delays.
- Implementation of ramp metering on US 59 between bissonnet St. and Fondren road showed a decrease of 23% in freeway travel time, a 14% increase in freeway speed, and 11% decrease in accident rates.

The success of ATM strategies mostly depends on the driver's understanding and behavior to the ATM method applied. So a few surveys need to be conducted on several ATM locations by considering how drivers

respond to these strategies, including noncompliance, presence of enforcement, and how information is communicated to drivers.

References

- [1] Federal Highway Administration, Active traffic management: the next step in congestion management, Washington D.C.: Office of International Programs, 2007.
- [2] M. Robinson, Examples of variable speed limit applications, In: *the Speed Management Workshop, 79th Annual Meeting of the Transportation Research Board*, Washington D.C., 2000.
- [3] B. Park, S. Yadlapati, Development and testing of variable speed limit logics at work zones using simulation, In: *Transportation Research Board 82nd Annual Meeting*, Washington D.C., 2003.
- [4] G. Riegelhuth, A. Pilz, Temporary hard shoulder use in Hessen: experiences and strategic planning, Technical Session 3.3: ERP achievements and results in traffic management, Aalborg: Pilz Traffic Centre Hessen, 2007.
- [5] S. Cohen, Using the hard shoulder and narrowing lanes to reduce congestion: some lessons from an experience on the Paris motorway network, In: *Proceedings of the 12th IEE Conference on Road Transport Information and Control*, London, 2004.
- [6] F. Middleham, State of practice in dynamic traffic management in the Netherlands, Rotterdam: Transport Research Centre, 2005.
- [7] R. Usath, Ramp metering: new experiences in NRW, http://www2.napier.ac.uk/euramp/workshop_proc/EURCAMP_workshop_usath.pdf, 11-11-2011.
- [8] G. Piotrowicz, J. Robinson, Ramp metering status in North America, Washington D.C.: U.S. Department of Transportation, 1995.
- [9] S.T. Waller., M.W. Ng, E. Ferguson, et al., Speed harmonization and peak-period shoulder use to manage urban freeway congestion, The University of Texas at Austin: Center for Transportation Research, 2009.

(Editor: Yao ZHOU)