



## Evaluation of a Mobile Highway Management System at Roadwork Zones

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### ABSTRACT

Road construction and maintenance activities cause traffic congestions and delays and present challenges for ensuring the safety of both motorists and road workers. While urban areas are well-equipped with traffic devices, in the case of highways our chances to collect traffic data and control traffic flows may be limited. Then the use of a temporary Highway Traffic Management System seems to be a suitable solution. Although the impacts of its deployment are addressed by many theoretical studies and demonstrated on traffic simulation models, there are not many references dealing with field tests. We provide results of the practical evaluation of the temporary Highway Management System installed and tested on the main highway in the Czech Republic during the road works period. Before-after analysis of collected traffic data was performed to prove the importance and positive impact of the proposed solution. We demonstrate an over 20% increase in the capacity of the roadwork zone and an almost 30 seconds decrease in average delay for one vehicle Highway administrators can use the results to justify investments into the temporary deployment of mobile traffic management systems.

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## 1. INTRODUCTION

The highway D1 is a backbone of the road network in the Czech Republic, running west-east and connecting the capital Prague with other major cities, Brno and Ostrava. In addition to being the longest, it is also the oldest highway in the country, with the highest traffic volumes. It was not until November 1980 that the final section, allowing highway travel from the capital to Brno, was completed. An average daily traffic volume is over 37,500 vehicles per day. The highest value reaches almost 90,000 vehicles per day and occurs near the capital city of Prague. The age of the highway and the high volume of traffic naturally lead to traffic problems. Driving comfort is limited due to the old road surfaces, which require regular maintenance. For these reasons, the Ministry of Transport of the Czech Republic together with the Roads and Motorways Directorate of the Czech Republic (RSD), have decided to invest in the complete renovation of highway D1. Responsible authorities had

to choose a suitable alternative from various solutions, taking into account different and conflicting criteria. The decision-making process concerned four basic alternatives – modernization, reconstruction, new construction, and zero alternatives:

A) *Modernization* concerns a solution where both directions of the highway are extended by 75 cm, i.e., change from the category D26.5 to D28 according to local classification regulations. This solution allows driving in four lanes in one work zone and assumes the laying of a new concrete surface.

B) *Reconstruction* consists of fragmenting the current concrete cover and laying a new asphalt carpet. In this case, category D26.5 remains unchanged.

C) *New construction* means a complete reconstruction of the 6-lane highway.

D) *Zero's* solution is to preserve and maintain the status quo.

All these alternatives were evaluated using the Statistic Failure Modes and Effect Analysis (SAFMEA)

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methodology [1]. Finally, the *Modernization* option was chosen [2]. The planned duration of the whole process was 7 years, while several work zones with a length of 5 to 7 km each were established at the same time. Each work zone used two lanes in each direction with limited width and the maximum speed limit of 80 km/h. Maintenance work was expected to be completed in 2021.

The principal question was how to manage highway traffic under those extraordinary situations. A Highway Traffic Management System (HTMS) is one of the important functional systems of Intelligent Transportation Systems (ITS) [3]. Its purpose is to collect data from roadside equipment, to provide more efficient services to highway users, and to prevent or react to hazardous situation occurrences. The latest HTMS usually relies on multiple technologies creating different installed sub-systems: variable message signs, portable information displays, emergency call boxes, incident detection systems, meteorological data systems, automatic traffic counters and classifiers, CCTV, speed enforcement systems, etc. [3]. While urban areas are well-equipped with traffic devices [4], our chances to collect traffic data and control traffic flows on highways may be limited. In case of exceptional circumstances, such as roadworks and maintenance works, permanent installations are not available and the only solution to the traffic situation is based on the deployment of a mobile version of the HTMS. Jacobson [5] discussed the main benefits of such solutions as identified in many international projects: travel time decrease 20 to 48%; travel speed increase 16 to 62%; highway capacity increase 17 to 25%; and others. This paper aims to provide results of the practical evaluation of the mobile HTMS temporarily installed and practically tested on the longest highway in the Czech Republic (D1) during the roadworks period. The evaluation is based on collecting data before and after deployment of the mobile HTMS to demonstrate how the capacity of the roadwork zone increases.

**1. 1. State-of-art** Speeding as a key factor causing rear-end and roadside accidents and collisions between vehicles and traffic facilities and construction personnel is analyzed by Cheng and Cheng [6]. A qualitative study of safety aspects introduced by Yang et al. [7], analyzing worker perceptions of common hazards and their mitigating measures in work zones. Methodological approaches to work zone safety were reviewed and assessed by Ackaah et al. [8]. It is well-known that any roadwork causes traffic problems, including traffic congestions, delays, and even increased safety hazards. While the theoretical effects and implications of HTMS are well known and broadly discussed. There are not so many literature providing practical results from real applications. At the same time, the implementations

differ concerning the boundary conditions as well as the actual implementation. We believe that the research presented here is significant in the way it provides results from a real-world study and not a simulation experiment. It follows the evaluation principles described by Sinha and, Fwa [9]. The following paragraphs analyze and compare the findings to the existing literature review.

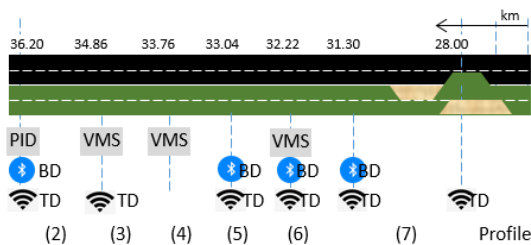
Requirements and limitations of HTMS are discussed by Harbord and Jones [10]. Speed harmonization project on the M25 Motorway in the UK, focusing on congestion management, led clearly to the reduction of the number of accidents by over 10%. The HTMS also caused a decrease in travel times in one direction while travel times in the other direction were increased. This is caused not only by imposed speed limits but also by more strict enforcement [11]. Also, further investigations on this highway could not demonstrate a statistically significant decrease in travel times [12]. Another experiment in Utrecht and Rotterdam (the Netherlands) led to an increase in the capacity of about 1 to 2 % [13]. It is worth mentioning that sometimes in the case of developing countries highway capacity analyses should be adjusted for prevailing traffic composition and driver behavior [14]. Interesting results of speed management on road arterials were provided by Talebpour et al. [15]. The authors addressed many different aspects and various scenarios that might have influence. However, the impact is demonstrated on a microscopic traffic simulation model in PTV Vissim. While authors explain the calibration procedure, their own experience in demonstrating the effects of speed harmonization is strongly dependent on drivers' compliance [16] and the results cannot be compared to real-world studies (as presented in this paper). Similar results were also discussed in literature [17-19].

An important study by Strömberg and Lind [20] presents the results of a field-test experiment on the E4 highway south of Stockholm. The authors reported on real implementation and evaluation during 18 months. Similar to our field test, they implemented their solution in two phases: first the queue warning was implemented and two years later the speed harmonization. The evaluation method was also similar: before-after analysis. One important result was a significant decrease in drivers' speed compliance after introducing the system. This significantly decreases the effectiveness of the system. The authors were dealing with a road segment where they had a maximum speed of 100 kph. Overall, the authors reached an increase in the maximum throughput of about 10%.

Astarita et al. [21] analyzed various technologies (Internet of Things, connected vehicles, new sensors, clouds, blockchains, etc.) applied to mobile systems and their impact on traffic management and safety. Many recent publications discuss the benefits of connected and automated vehicles in highway management. Most of the

studies however provide only theoretical foundations [22] or show the impact within a simulated environment [23-28]. The effects of connected, cooperative, and/or autonomous vehicles are discussed in literature [29-32]. The main control objective is the work zone throughput. Yulong and Leilei [33] proposed the control flow of Intelligent Lane Merge Control System with Intelligent Transportation System (ITS) techniques. The ITS is also considered by Jacob et al. [34], utilized reinforcement learning-based optimal control. Yanli et al. [35] presented research of adaptive speed control of freeway work zone to decrease the speed difference between the upstream and downstream vehicles. General recommendations for intelligent vehicle highway systems are available even reported by Nanda [36]. Traffic management systems being a part of smart cities may also implement other functionalities, such as prioritizing emergency vehicles [37] which was not our case. Ambros et al. [38] focus on the effectiveness of section speed control in highway work zones in the Czech Republic. We believe that the results presented within this paper set the basis for a better comparison of the real impact of connected vehicles.

**1. 2. Evaluation Framework** The main aim of the pilot project was to implement, test, and evaluate a comprehensive modular mobile telematics system for traffic management in road closures, or temporarily



**Figure 1.** The configuration of the temporary highway traffic management system (simplified)

**TABLE 1.** Legend to Figure 1

Profile No.	Position [km]	Sensors		Actuators
		Traffic detector TD	Bluetooth detector BD	PID/VMS
1	36.22	Yes	Yes	PID
2	34.86	Yes	No	VMS
3	33.76	No	No	VMS
4	33.04	Yes	Yes	-
5	32.20	Yes	Yes	VMS
6	31.30	Yes	Yes	-
7	28.00	Yes	No	-

exposed locations within the road network. The system was expected to harmonize traffic flow, inform about the situation, and/or respond to the actual traffic. The pilot field test was realized on the highway D5 in the Czech Republic (a work zone between 28.5 and 30.8 km on the D5 highway was selected). However, the results were used as an indicator for future purchase and implementation of more such systems for the planned modernization of the main highway D1.

**2. EVALUATION RESULTS**

**2. 1. Principle of Operation** Two major technological systems were tested within the evaluation process—the warning system and the speed harmonization system. Both of them belong to the field of mobile highway management, but they use different means to address a driver. It is rather well-known that sudden changes in the driving speed (i.e., quick deceleration) and interactions of vehicles with significant speed differences are risky [39-40]; that can cause shock waves [41-42].

The *Warning System*: reacts to the situation when the traffic flow increases, the drivers are affected by the adjacent traffic and must decrease their speeds. If the speed decreases to 30 km/h, the traffic sign “Warning – Congestion ahead” is activated about 6 km ahead of the work zone. This warns the drivers, but further does not limit their behaviors.

The *Speed Harmonization system* is similar to the previous system but it also addresses the problem of sudden breaking, large differences in speeds, and shock waves. It affects the traffic flow using changes in the speed limits, which are dynamically decreased based on the actual traffic flow conditions.

**2. 2. Evaluation Methodology** The methodology for the pilot testing was in advance accepted by the Roads and Motorway Directorate of the Czech Republic (RSD). Preliminary analysis of the data from highway D5 showed the necessity of collecting data and warning the drivers at least 5 kilometers ahead of the work zone. Technologies were installed ahead of the selected work zone as depicted in Figure 1. The overall length of the road equipped with the technology (both data collection and warning and speed harmonization) was 8.2 km. Portable Information Displays (PID) and Variable Message Signs (VMS) were used as actuators. The road network segment was also covered by the GPRS – 3G (i.e., wireless technology) as a preferred mode of data exchange. To allow better understanding and confirmation of the results, there were cameras placed on the entire length of the monitored area, and the visual information was transmitted to the National Traffic Information Centre (NDIC) located in the eastern part of the country (Ostrava city). This also brought a possibility

of manual intervention by road operators (not used during our measurements). There are different ways how to evaluate a certain measure in the transportation field. Morris et al. [43] mention modeling, simulation; or before-after analysis which does not place any assumptions on the underlying model nor requires detailed calibration. For that reason, three evaluation phases (see Table 2) were used to collect statistically significant data.

The transmission layer in each profile contains 2G-2,5G (GPRS-HSDPA) and WiFi communication. The power supply layer varies according to the required consumption: Profile 1 – 2x 180 Ah batteries connected in parallel; Profile 2 - fuel cell, 360 Ah backup battery, connection to the SOS system, 360 Ah backup battery; Profile 3 - fuel cell, 2x 360 Ah backup battery, connection to the SOS system; Profile 4 - fuel cell, 180 Ah backup battery, 420 Ah battery; Profile 5 - fuel cell, 180 Ah backup battery, 420 Ah battery; Profile 6 - fuel cell, 180 Ah backup battery; and Profile 7 – solar panel, 40 Ah backup battery.

The 1<sup>st</sup> phase (Sept 5 – Oct 3, 2016) was essential as it described the situation without any warning or speed harmonization. Only reference data were collected to make later comparison with all other modes possible. The 2<sup>nd</sup> phase (Oct 3 – Oct 22, 2016) clearly denoted a phase,

in which the warning system was activated, but there was no speed harmonization function. Finally, the 3<sup>rd</sup> phase (Oct 22 – Nov 11, 2016) covered the situation with the speed harmonization system activated. The overall traffic volumes for each phase were similar, i.e., 17541 Veh/day, 16954 Veh/day, and 18138 Veh/day for each phase, respectively.

Table 3 shows values of daily traffic volumes (given in vehicles/day) as observed during the 10-weeks. Their graphical representation is available in Figure 2.

To be sure that we can assume the daily volumes to be from the same distribution, we tested the hypothesis that the second and third phases have the same daily average flow as the first phase. Using an independent two-sample t-test, we got a p-value of 0.355 and 0.404 respectively. That means that we cannot reject either of the hypotheses on a confidence level of 95% (<https://www.scribbr.com/statistics/t-test/>) and can assume the same traffic volumes for all phases.

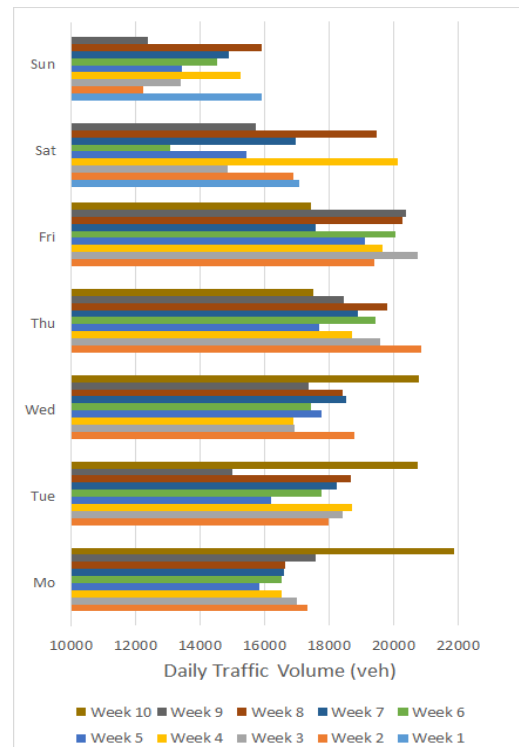
The control unit of the local control system works in principle according to the schematic diagram shown in Figure 3. The whole system works basically automatically. In case of certain extraordinary and emergency situations, it will be possible to control each actor via the local control system or from the superior level (NDIC). The principal functions of the local control system include in particular:

**TABLE 2.** Evaluation phases and scenarios

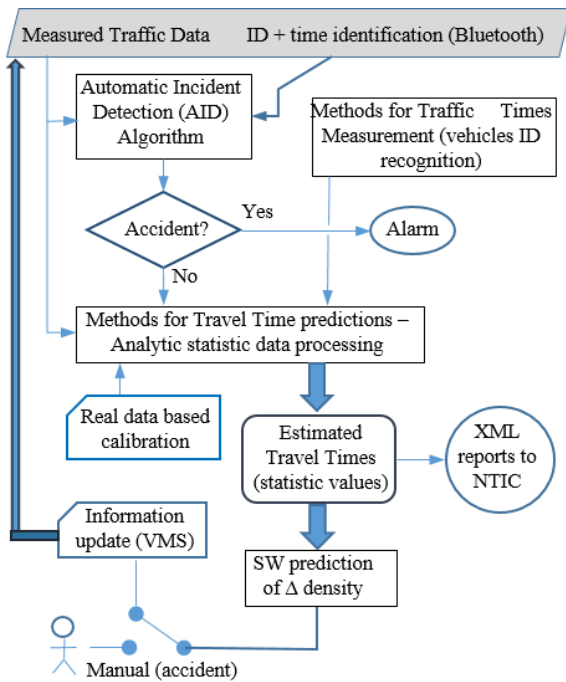
Evaluation Phase	Data Collection	Warning System	Speed Harmonization
1 <sup>st</sup> Before: Basic Scenario	ON	OFF	OFF
2 <sup>nd</sup> After: Active Warning Only	ON	ON	OFF
3 <sup>rd</sup> After: Active Speed Harmonization	ON	OFF	ON

**TABLE 3.** Daily traffic volumes [Veh/day]

Mo	Tue	Wed	Thu	Fri	Sat	Sun
-	-	-	-	-	17066	15925
17331	17975	18779	20870	19412	16893	12257
17003	18441	16951	19601	20758	14876	13390
16542	18704	16892	18718	19647	20136	15265
15833	16197	17757	17691	19130	15437	13438
16525	17757	17425	19458	20057	13059	14541
16618	18254	18517	18882	17599	16958	14892
16654	18690	18417	19821	20287	19462	15922
17597	14997	17372	18479	20386	15748	12403
21878	20759	20792	17518	17433	-	-



**Figure 2.** Comparison of aggregated daily volumes for particular days of the week



**Figure 3.** Schematic diagram of processes processed by the local control system

1. Communication between peripheral elements on the infrastructure (traffic detectors, driving time detectors, and at the same time all types of VMS);
2. Supervision of connected technology and sending status information to NDIC;
3. Data collection from detectors and their processing for the needs of control algorithms incl. sending selected information to NDIC;
4. Transmission of commands for displaying symbols on the VMS.

**3. RESULTS**

We provide selected results demonstrating its impact on traffic. In the pilot project, we focused on several aspects (variables) addressing the performance and impact of the mobile highway management system, particularly impact on road capacity; impact on the duration of traffic congestion, and impact on delay.

**3.1. Impact on Road Capacity** Table 4 provides the maximum and average flow per minute and average occupancy data.

**3.2. Impact on the Duration of Traffic Congestions** The traffic congestion was defined as the time when the average speed of the traffic flow is lower than 30 km/h

(based on speed reduction index as stated by Afrin and Yodo [44]) anywhere between the 1st and the 5th measurement points. In every evaluation phase, data were measured over 120 hours. The results are presented in Table 5.

**3.3. Impact on Delay** Another important parameter indicating the quality of the traffic management is delay (in seconds). The parameter was evaluated using floating car data from the project RODOS<sup>1</sup> where a large fleet of vehicles collected data and evaluated them. The data were collected and aggregated for segments 34 km – 32 km (i.e., profiles No. 3, 4, and 5).

Let us explain the parameter average delay. A delay of 0 seconds means, that a vehicle went through the segment with an average speed of 120 km/h so that the vehicle passed through the measured segment of 2 km in about 60 seconds. A delay of 30 seconds means that the vehicle passed through the segment in about 90 seconds, i.e., with an average speed of 80 km/h. The measurements from the RODOS vehicle fleet were collected for particular project phases as depicted in Table 6. The table indicates a significant improvement of 25.09 seconds already in the 2nd phase with an active warning system only. In the case of the 3rd phase with a speed harmonization system, the delay further improves by additional 4.58 seconds. The values and decrease of the average values can be seen in Figure 4.

**TABLE 4.** Resulting maximum and average flow per minute

Evaluation Phase	1 <sup>st</sup> Before Basic Scenario	3 <sup>rd</sup> After Active Speed Harmonization	Δ [%]
Max flow (Veh/min)	26.6	32.4	+21.8
Max flow (Veh/h)	1596	0.1	+21.8
Avg. flow (Veh/min)	21.4	21.7	+1.4
Avg. occupancy (%)	9.0	11.2	+24.4

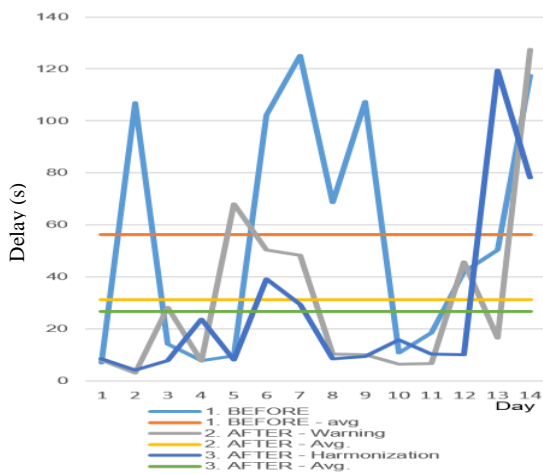
**TABLE 5.** Impact on the duration of traffic congestions

Evaluation Phase: Ratio of congestions to the total time	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>
Mo	11.5	8.0	5.5
Tue	17.0	6.0	11.0
We	23.5	32.5	8.5
Thu	35.0	31.0	33.0
Sat	11.0	4.5	0.0
Sun	22.0	9.0	6.0
Total	23.4	18.3	12.7

<sup>1</sup>[http://www.centrum-rodos.eu/about\\_the\\_rodos\\_center.aspx](http://www.centrum-rodos.eu/about_the_rodos_center.aspx)

**TABLE 6.** Impact on average delay for segments 34-32 km

1 <sup>st</sup> Evaluat. Phase		2 <sup>nd</sup> Evaluat. Phase		3 <sup>rd</sup> Evaluat. Phase	
Date	Avg daily delay [s]	Date	Avg daily delay [s]	Date	Avg daily delay [s]
10.IX	6.90	08.X	8.09	22.X	8.45
11.IX	106.99	09.X	3.09	23.X	4.14
12.IX	14.24	10.X	28.19	31.X	7.78
13.IX	7.79	11.X	7.61	01.XI	23.69
14.IX	9.53	12.X	68.21	02.XI	8.05
15.IX	102.27	13.X	50.41	03.XI	39.09
16.IX	125.20	14.X	48.21	04.XI	29.40
17.IX	68.48	15.X	10.28	05.XI	8.49
18.IX	107.55	16.X	10.07	06.XI	9.47
19.IX	10.84	17.X	6.40	07.XI	15.72
20.IX	18.45	18.X	6.56	08.XI	10.37
21.IX	41.98	19.X	45.72	09.XI	10.14
22.IX	50.24	20.X	16.39	10.XI	119.60
23.IX	117.48	21.X	127.51	11.XI	78.21
Average delay per phase [s]					
56.28		31.20		26.61	
Average daily improvements in delay between phases [s]					
25.09			4.58		



**Figure 4.** Delays and their average values as observed over 3 evaluation phases

We can observe a larger improvement between the 3<sup>rd</sup> phase (with active speed harmonization) and the 2<sup>nd</sup> phase (with warning system only). This is a significant contribution with a high positive impact on the overall traffic flow.

The achieved results demonstrate the importance of such a system deployment. The mobile highway

management system increased the road capacity by over 21%. Overall, there was a more than 5% decrease in the time of congestions for the 2nd phase. For the 3rd phase, this decrease reached over 10%. Similarly, the average daily delay decreased by almost 30 seconds.

#### 4. CONCLUSIONS

The major objective of this paper was to evaluate a pilot operation of the mobile highway management system consisting of warning and speed harmonization subsystems. A before-after analysis was conducted in 2016. With all other variables kept constant (mainly the traffic flow), the system measured various parameters. We described results dealing with the road capacity and the time in congestions, defined as the time when the speed was lower than 30 km/h.

Concerning the relatively short measurement period, we do not report on the impact of our system on road safety, even though quite important improvements could be expected there. During the 1<sup>st</sup> phase, there were 7 incidents reported, and during the following two phases only 2 incidents. This result could be expected, due to the speed harmonization. The results are however not statistically significant and require a long-term evaluation. Overall, the presented results have a huge impact, especially for a highway with such high traffic demand as D1. As the modernization of the highway takes years, such an increase has a major impact not only on the lost time but also on produced CO<sub>2</sub> emissions and fuel consumption. Without a doubt, an investment into a mobile highway management system for work zones has also a high societal impact.

In addition, the growth of cooperative vehicles will also influence the behavior of traffic flow in work zones. The cooperative vehicles can be used as further sensors measuring parameters of the traffic flow and simultaneously, they can be used as actuators. The control system can for example warn such vehicles in case of dangerous situations or provide recommendations for speed adaptation. This behavior will also be further investigated.

Based on the results and clear demonstration of savings the Roads and Motorways Directorate of the Czech Republic decided to order six sets of mobile highway management systems. They will be applied to future work zones on highways. This statement can be proved by tender-based information published in the tender area under the ID number VZ0084077 of the General Directorate of the Roads and Motorways Directorate of the Czech Republic (ŘSD ČR) and available online<sup>1</sup>.

<sup>1</sup> <https://tenderarena.cz/dodavatel/seznam-profilu-zadavatelu/detail/Z0003026/zakazka/310542>

We believe that our findings are important not only for researchers but also for highway managers as they support investments in new research as well as the implementation of mobile highway management systems in work zones.

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### Persian Abstract

#### چکیده

فعالیت‌های ساخت و ساز و نگهداری راه‌ها باعث ازدحام و تأخیر در ترافیک می‌شود و برای تضمین ایمنی رانندگان و کارگران جاده‌ای چالش‌هایی ایجاد می‌کند. در حالی که مناطق شهری به خوبی مجهز به وسایل ترافیکی هستند، در مورد بزرگراه‌ها، شانس ما برای جمع‌آوری داده‌های ترافیکی و کنترل جریان ترافیک ممکن است محدود باشد. سپس استفاده از سیستم موقت مدیریت ترافیک بزرگراه راه حل مناسبی به نظر می‌رسد. اگرچه تأثیرات استقرار آن توسط بسیاری از مطالعات نظری مورد توجه قرار گرفته و بر روی مدل‌های شبیه‌سازی ترافیک نشان داده شده است، اما مراجع زیادی در مورد آزمایش‌های میدانی وجود ندارد. ما نتایج ارزیابی عملی سیستم مدیریت موقت بزرگراه نصب شده و آزمایش شده در بزرگراه اصلی جمهوری چک را در طول دوره کار جاده ارائه می‌دهیم. تجزیه و تحلیل قبل و بعد از داده‌های ترافیک جمع‌آوری شده برای اثبات اهمیت و تأثیر مثبت راه حل پیشنهادی انجام شد. ما بیش از ۲۰ درصد افزایش در ظرفیت منطقه کار جاده‌ای و تقریباً ۳۰٪ کاهش میانگین تأخیر برای یک وسیله نقلیه را نشان می‌دهیم. مدیران بزرگراه می‌توانند از نتایج برای توجیه سرمایه‌گذاری در استقرار موقت سیستم‌های مدیریت ترافیک بسیار استفاده کنند.

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