Intelligent Highway Management System for the City of Wichita

Final Report
August 2018

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Midwest Transportation Center
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16. Abstract

The researchers at Wichita State University collaborated with the Kansas Department of Transportation's Traffic Management Center in Wichita, Kansas, to develop an Intelligent Highway Management System (IHMS). The functions of the IHMS were to conveniently extract specific incident-relevant record data from high-dimensional, high-volume time series datasets; autonomously analyze online traffic-related data (e.g., volume and speed) for incident diagnosis/identification; and create autonomous optimization that facilitates traffic control decision making to reduce average incident clearance and traffic recovery time.

The IHMS integrates multiple technologies to improve traffic flow and safety. It also streamlines vehicular operations by managing congested traffic, which has become a major problem, as it leads to issues in safety, productivity, and environmental performance. In this study, the researchers developed a transportation system simulation methodology that could be used to reduce traffic congestion, as well as restore traffic to its normal conditions, by allowing vehicles to reroute and avoid congested roads, in turn dipping the speed profile for a faster and quicker recovery. The created simulation system was customized for the City of Wichita and implemented in Simulation of Urban Mobility (SUMO). Simulation results indicate that this approach reduces traffic congestion, provides for quicker incident recovery, and is a solution to ongoing safety, productivity, and environmental performance issues.

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EXECUTIVE SUMMARY

The researchers at Wichita State University are collaborating with the Kansas Department of Transportation through the Traffic Management Center in Wichita, Kansas, to develop an Intelligent Highway Management System (IHMS). The functions of the IHMS were to conveniently extract specific incident-relevant record data from high-dimensional, high-volume time series datasets; autonomously analyze online traffic-related data (e.g., volume and speed) for incident diagnosis/identification; and create autonomous optimization that facilitates traffic control decision making to reduce average incident clearance and traffic recovery time.

The IHMS integrates multiple technologies to improve traffic flow and safety. It also streamlines vehicular operations by managing congested traffic, which has become a major problem, as it leads to issues in safety, productivity, and environmental performance. In this study, the researchers developed a transportation system simulation methodology that could be used to reduce traffic congestion, as well as restore traffic to its normal conditions, by allowing vehicles to reroute and avoid congested roads, in turn dipping the speed profile for a faster and quicker recovery. The created simulation system was customized for the City of Wichita and implemented in Simulation of Urban Mobility (SUMO). Simulation results indicate that this approach reduces traffic congestion, provides for quicker incident recovery, and is a solution to ongoing safety, productivity, and environmental performance issues.

1. INTRODUCTION

Traffic congestion has become a major problem in the modern era, resulting in three major issues: safety, productivity, and environmental performance. Every year, incidents occurring on highways, streets, and other roads, have caused tremendous suffering and loss of life, as well as costing the nation billions of dollars (Pina 2017). Most of these incidents occur due to the start and stop nature of vehicles in congested traffic. Congestion can also lead to productivity issues, as it causes disruptions to traffic flow, which results in delays in the supply chain and hence overall reduced productivity and increased costs. Also, the start and stop nature of vehicles tends to cause an increase in fuel consumption and greenhouse gas emissions when compared to normal conditions. However, all of these issues can be reduced to a noticeable extent with the use of an Intelligent Highway Management System (IHMS).

To achieve this, three major factors must be taken into consideration: traffic intensity, incident duration, and proportion of lane blockage (Saka et al. 2008). Traffic intensity is the ratio between volume and capacity (with a range from 0 to 1), incident duration is the amount of time the incident lasts, and proportion of lane blockage is the number of lanes that are blocked during the incident. All of these factors are directly proportional to each other, thus impacting the entire scenario. If traffic intensity increases, the duration of the incident also increases, thus increasing the recovery time.

In collaboration with the Kansas Department of Transportation (KDOT) and its Traffic Management Center (TMC) in Wichita, Kansas, the researchers developed an IHMS in order to improve resilience of the transportation system (Cox, et al. 2011, Yodo and Wang 2016a, Yodo and Wang 2016b, Yodo et al. 2017), as shown in Figure 1.

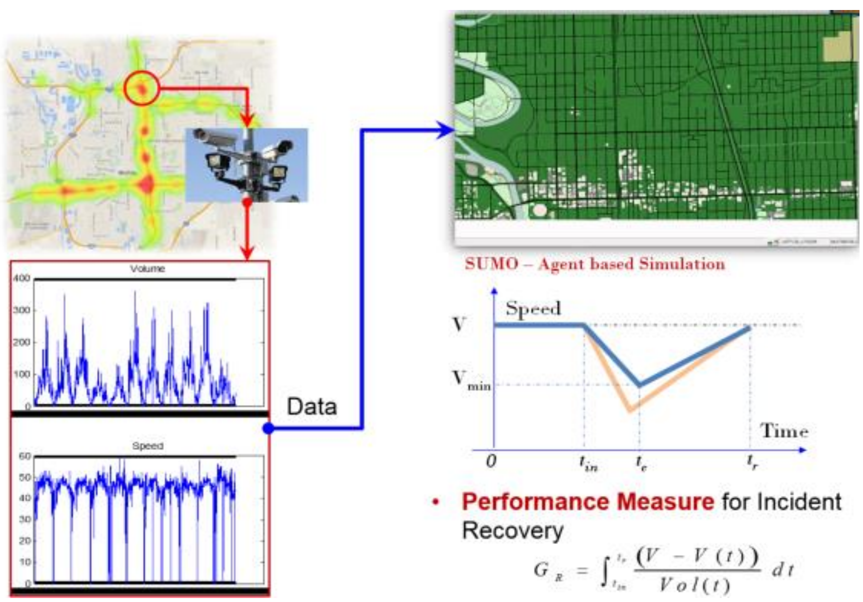

Figure 1. Data-driven highway incident management through predictive traffic control and agent-based simulation

The functions of the IHMS were to conveniently extract specific incident-relevant record data from high-dimensional, high-volume time series datasets; autonomously analyze online traffic-related data (e.g., volume and speed) for incident diagnosis/identification; and create autonomous optimization that facilitates traffic control decision making to reduce average incident clearance and traffic recovery time.

The next section includes a discussion about a case study that was implemented in Simulation of Urban Mobility (SUMO)—a micro simulation software—and how the data from KDOT were transformed into simulation parameters. The results and conclusion were drawn from this case study.

2. WICHITA HIGHWAY TRAFFIC DATA

2.1. Background

One of the primary objectives of this study was to find a way for a vehicle to achieve a faster and quicker recovery time after an incident. Currently, the data from KDOT's upstream sensors correspond to highways I-235, I-135, US 54, K-96, and Airport Road, as shown in the heat map in Figure 2.

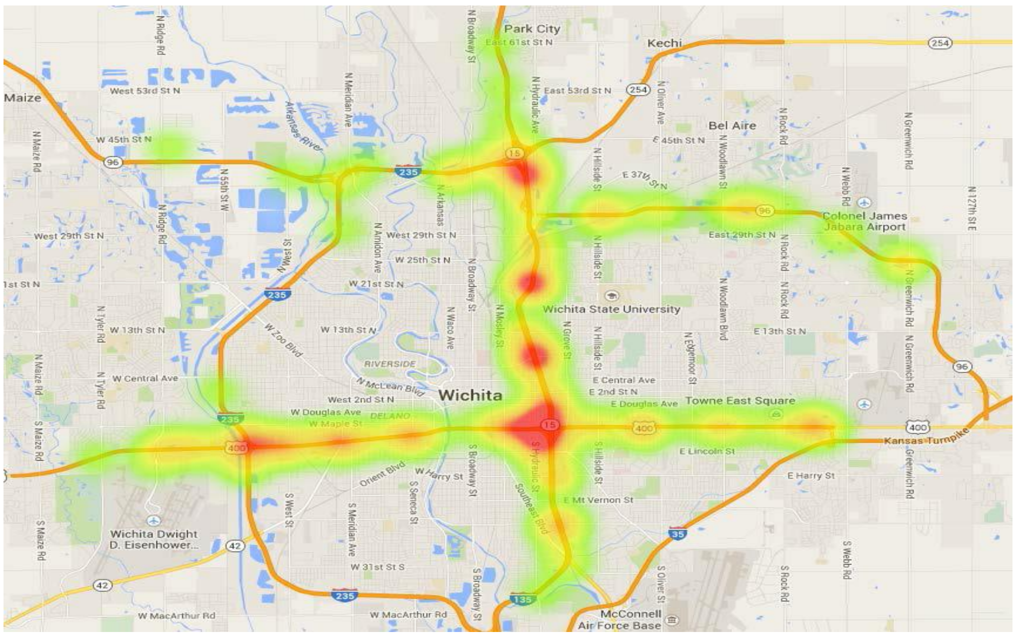

Figure 2. Distribution heat map of traffic incidents during April 2015 in Wichita, Kansas

As can be seen in Figure 3, each data point reflects a 15-minute average for a vehicle passing from one upstream sensor to another (implying one segment). Each data point reflects the detector ID (i.e., the unique identification number of the upstream sensor), detector name, date and time (i.e., when and where the data were recorded), volume (i.e., the total number of vehicles crossing one segment), long volume (i.e., the total number of vehicles that are not passenger-like trailers, trucks etc.), speed of the vehicles (in miles per hour), occupancy (i.e., the percentage of time one particular area was occupied), fail state (i.e., whether the upstream sensors were online or offline), and summary period (i.e., the time that one data point was observed during one segment).

	A	B	C	D	E	F	G	H	I	J
1	Detector Id	"Detector Name"	Dt	Time	Volume	Occupancy	Speed	Long Volume	Fail Stat	Summary Period
2	235015322	"I-235 at Broadway-SB-L2"	4/1/2015	0:00:00	40	0	56	40	ONLINE	15
3	235015322	"I-235 at Broadway-SB-L2"	4/1/2015	0:15:00	32	0	58	28	ONLINE	15
4	235015322	"I-235 at Broadway-SB-L2"	4/1/2015	0:30:00	12	0	59	12	ONLINE	15

Figure 3. Original data set in Excel

In this study, a total of 182 actively logged incidents, as Figures 1 and 2 show, along with traffic information from multiple online monitoring facility units during April 2015 in Wichita, were used to facilitate model and technology development.

2.2. Traffic Monitoring Information

Gathering information is the most important part of any project, as further analysis of the data reveals problems associated with it and how to tackle and reach an optimal solution. After the data were gathered, monitoring of the information and systematic and purposeful observation was done to graphically interpret the data. Due to the massive amount of associated data points, it would have taken a tremendous amount of time to discover which data points were creating the incidents or were part of the incident. So, to sort the data points, a formula was developed in Excel:

IF (AND (G3<45, G3>0, G3<(G2-10)), G3,"NOT INTERESTED") (1)

The above formula checks two particular cells adjacent to each other while also checking for all limitations associated with the formula, and upon going through the entire formula decides whether that particular data point is an incident or not. If it is labeled as an incident, it would display the cell name; if it was not an incident, it would simply display as “not interested.”

Figure 4 helps to show a better understanding of the formula. The formula first checks the cell G3 (i.e., the speed if it is less than 45 mph) and then if the speed is greater than zero (to avoid any data points that do not include vehicles during a 15-minute duration). It then checks if the speed at this instance is 10 mph less than the previous value, noticing if a sudden drop in speed has occurred. If all of these conditions are met, then the cell G3 is displayed implying an occurrence of an incident. If even one condition is not met, the cell would display “not interested,” thus implying a normal traffic condition. From Figure 4, it is clear that cell G3 is following normal traffic conditions.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Detector Id	“Detector Name”	Dt	Time	Volume	Occupancy	Speed	Long Volume	Fail Stat	Summary Period		
2	235015322	“I-235 at Broadway-SB-L2”	4/1/2015	0:00:00	40	0	56	40	ONLINE	15		
3	235015322	“I-235 at Broadway-SB-L2”	4/1/2015	0:15:00	32	0	58	28	ONLINE	15	NOT INTERESTED	

Figure 4. Formulation of data set in Excel

Using this scenario, the researchers considered speeds below 45 mph as an indication that an incident has occurred. The formula can be further tweaked to satisfy other conditions and speed limitations.

For this study, scenarios only included Highway I-235. Upon using the developed formulation for some 6,500 data points, spread across 12 days, it was found that 16 incidents had occurred, lasting from 30 to 60 minutes (each time step is 15 minutes long) (see Table 1).

Table 1. Number of incidents and associated speed variations

	Speed															
Time	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
0	56	57	56	65	64	57	50	55	57	54	56	57	54	70	47	54
1	26	39	41	44	41	39	26	38	44	43	43	44	38	44	36	37
2	32	39	58	49	50	43	63	64	60	55	56	44	49	53	59	57
3	47	65				48						48				
4	56					56										

The incidents were also plotted with respect to speed versus time, as shown in Figure 5.

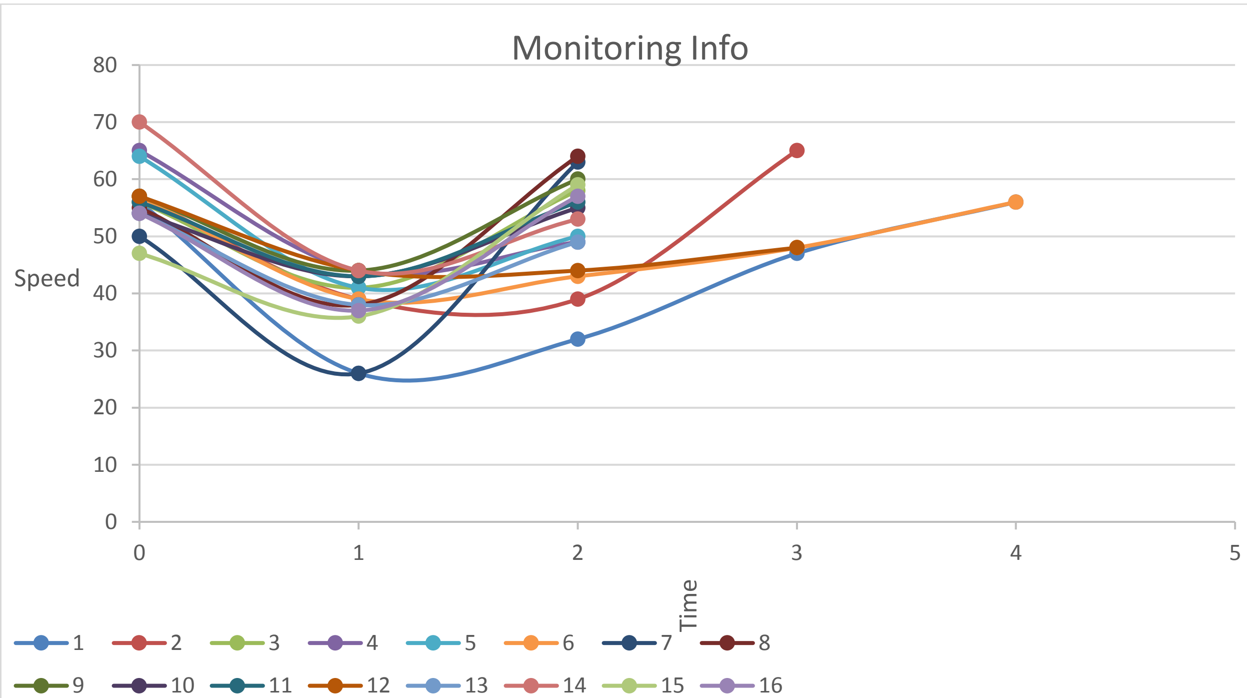

Figure 5. Speed profiles for different incidents

All 16 incidents were plotted to get a better idea of each individual speed profile, how they behave, and how the recovery time of these incidents could be reduced. Upon keen observation, it can been seen in Figure 5 that in all the speed profiles, the incident profile falls lowest in the first time step and then recovery begins. To reduce the time of recovery, the dip in the speed profile needs to be lowered, thus offering a faster and quicker recovery. This can be achieved by lowering the traffic intensity, which would result in less traffic to deal with overall while achieving a faster recovery time. Reroutes can also be used to achieve an intermediate goal of low traffic intensity, which could help to dip the speed profiles overall.

3. SUMO SIMULATION ANALYSIS

3.1. Modelling Assumptions and Parameters

A simulation model was developed in SUMO, which is a microsimulation (microanalytic) that involves highly detailed analytic simulation. For modelling, a very limited amount of assumptions were made, thus keeping the simulation as close to reality as possible. The following were the assumptions:

- As the vehicles approach their destination, they are transported out of the simulation and are not allowed to reappear in a continuous loop.
- All the vehicles follow basic traffic laws, implying that only vehicles allowed by law on a highway are permitted to use that road.

The simulation parameters were based on the metric system; hence, the speed is in meters per second instead of miles per hour and the simulation time step is in seconds instead of minutes.

3.2. SUMO Simulation Model

3.2.1. Creating the Scenario

All the incidents that occurred were on Highway I-235 at Broadway Street; hence, that particular portion of the map was imported from OpenStreetMap. The .osm file that was imported included water bodies, zebra crossings, railroad tracks, traffic signals, and other aspects that were part of the map, thus making it a real-life scenario. Hence, a polygon file was created to recognize all aspects of the map, which was integrated with the .osm file and formed the entire scenario. Figure 6 shows the intersection at Highway I-235 at Broadway Street (the left arrow [facing west] points south and the right arrow [facing east] points north).

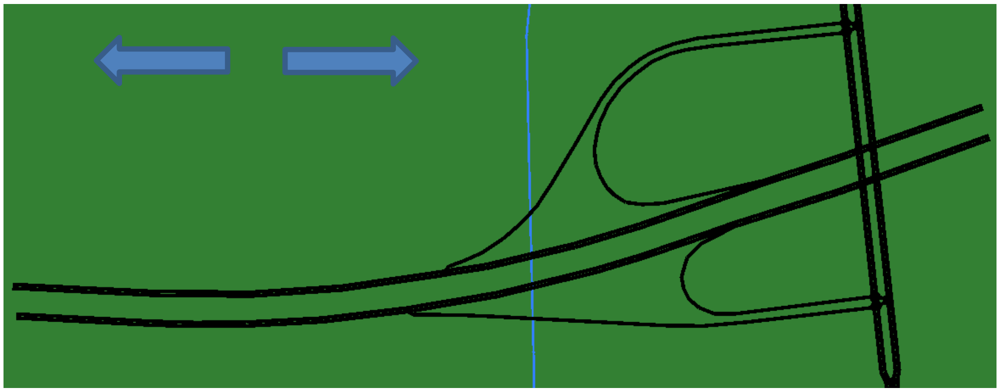

Figure 6. Highway I-235 at Broadway Street

3.2.2. Establishing Vehicle Flow

For establishing vehicular flow, a route file was generated with respect to the map. While converting the map from OpenStreetMap, default routes were generated that followed basic traffic laws. Apart from the default route, four extra routes were added to test the theories for reducing recovery time. The flow of vehicles was created as per the simulation, from 0 to 1000 seconds, deploying a vehicle every 10 seconds.

The highlighted path in Figure 7 represents the path of the vehicle that was taken into consideration while observing the incidents and new approach.

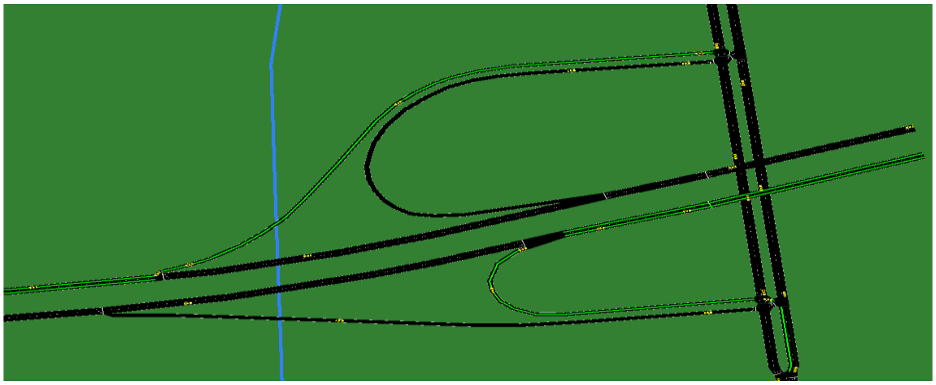

Figure 7. Flow of vehicles in the simulation

3.2.3. Proposed Approach

To reduce recovery time, reroutes were added. So, whenever there was an incident, the vehicles would be rerouted to a different path, thus allowing traffic intensity to fall by a tremendous amount while paving the way for emergency vehicles and returning traffic flow to its normal condition in a faster amount of time.

Figure 8 represents a reroute. Each reroute can be set from 0% to 100%, indicating the probability the vehicle will choose to reroute when a situation or incident occurs.

Figure 8. Representative reroute in simulation

3.3. Simulation Results

Figure 9 represents a situation where reroutes are not being used and traffic congestion keeps increasing until the incident has been cleared, which leads to a longer recovery time due to high traffic intensity and a higher proportion of lane blockage.

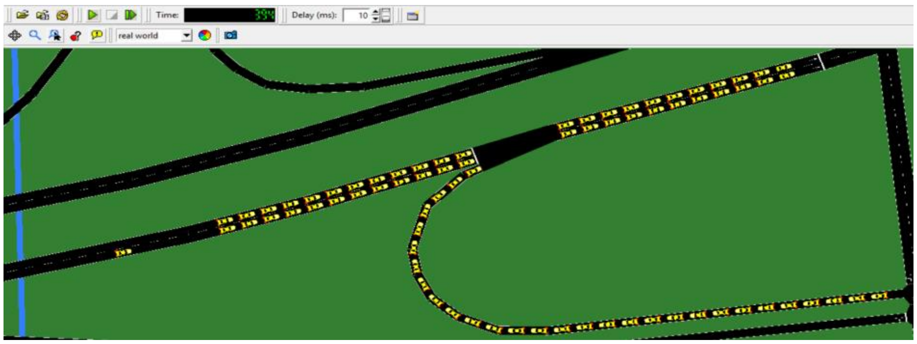

Figure 9. Traffic incident without reroutes

Figure 10 represents the same traffic flow but with reroutes in place. Both Figures 9 and 10 are time stamped almost at the exact same spot, and the difference is clearly noticeable. With the help of reroutes, traffic intensity is lowered drastically, which would help emergency vehicles get access to the incident and provide a faster and quicker recovery for traffic, leading to a smaller incident duration and overall achieving a dip in the speed profile.

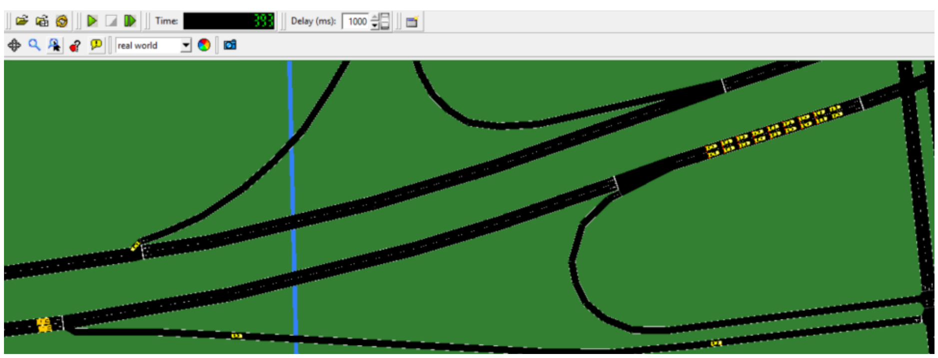

Figure 10. Traffic incident with reroutes

4. RESULTS AND ACCOMPLISHMENTS

4.1. Objective and Results

In this study, the researchers aimed at developing an IHMS through analyzing high-dimensional, high-volume, time series traffic monitoring data in collaboration with KDOT's TMC in Wichita, Kansas. The research team conducted the analysis for one month and extracted traffic-related features (e.g., volume and speed) from the raw data over time. These features were further analyzed to determine a set of the most effective features, so a relationship between highway incidents and data features could be built. The researchers worked with the TMC to develop autonomous data processing algorithms and user interfaces to automate the data analysis process that had been mainly done manually.

Further, by using the extracted features, the researchers developed a classification system that was capable of identifying highway incidents and their severity levels. A preliminary validation study of the classification system was conducted, and the study results showed very good effectiveness of the developed system.

In order to further study how the developed system would affect traffic flow during the occurrence of a transportation incident, the researchers developed a simulation framework for the traffic incidents and real-time controls. This framework was based on an agent-based simulation, while each vehicle was modelled with an independent agent in the transportation system. The researchers implemented this simulation platform in SUMO and developed a simulation platform specifically for the highway systems located in the City of Wichita, which would show how the developed highway traffic control strategies influence the resilience of highway traffic flow performance studied in the developed simulation platform.

4.2. Opportunity for Training and Development

The researchers have incorporated their research findings into graduate courses through course modules and projects and into other training opportunities:

- The principal investigator (PI) has incorporated the developed agent-based simulation tool based on the SUMO simulation platform in the course IME-864: Risk Analysis. Specifically, students were able to leverage the simulation tool for the identification and forecasting of highway incidents while being able to employ traffic control strategies to evaluate risks and associated traffic flow performances.
- Leveraging their collaboration with KDOT's TMC, the PI has trained engineers at the TMC about signal processing and automated highway incident management systems.
- The PI has incorporated the resilience concepts for complex transportation systems into the course IME-754: Reliability and Maintainability by providing materials and tools for students to conduct risk and resilience analysis of transportation systems through the development of resilience models and by conducting resilience analyses for different risk scenarios.

- The PI has provided training seminars to a broader range of students and professionals through the IME colloquium, which graduate students from the College of Engineering at Wichita State University, local industrial professionals through the local chapter of the Institute of Industrial and Systems Engineers (IISE), and area industrial advisory board members were invited to attend.
- The PI has also shared research at invited seminars atArgonne National Laboratory and Kansas State University.

4.3. Dissemination of Results

The researchers have actively disseminated the research results through presenting papers to relevant technical conferences, such as the 2017 Annual Industrial and System Engineering Research Conference (ISERC).

Meanwhile, the researchers have tried to disseminate research results through collaborations with industry and national laboratories. Specifically, the researchers have worked with a leading electronics testing company (Integra Technologies, LLC) and KDOT's TMC to develop research collaborations and disseminate research results.

The researchers have also established an industrial collaboration with Medtronic to disseminate research results through seminars while also obtaining internship opportunities for graduate students.

There are various ways through which a dip in the speed profile can be achieved. In this study, the researchers generated a simulation model that closely resembled an incident and used reroutes to achieve a dip in the speed profile by deviating traffic away from the path where the incident took place; hence, a faster and quicker recovery from incidents was achieved.

The reroutes increased overall productivity and safety, reduced the start and stop motion of congested traffic, and reduced fuel consumption and greenhouse gas emissions.

4.4. Broad Impacts

Highway incidents are one of the most critical factors that contribute to the interruption of continuous traffic flow and traffic jams. Appropriately and effectively handling these incidents requires not only the resources for removing the vehicles that are involved in an incident, but also effective information technology that could efficiently identify incidents while facilitating the optimized decision making of traffic controls so that incident management activities can be efficiently carried out.

5. CONCLUSION AND FUTURE WORK

In this study, the researchers developed a simulation study for highway incident management using data analytics for transportation traffic control decision making and applied it to the City of Wichita based on original traffic monitoring data. The results will open up a new research venue for researchers to further use data analytics and transportation informatics to improve the efficiency and effectiveness of transportation infrastructure systems. In addition, this study offers unique research and educational experiences for future researchers across the fields of transportation systems, data analytics, information systems, and signal processing, as it will allow students and professionals to be trained in an interdisciplinary learning environment.

Future work can include studies on how traffic incident management could develop new intelligent optimization approaches for traffic incident rerouting optimization and traffic control optimization to maximize the resilience of transportation networks.

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