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Dynamic Reroute Modeling for Emergency Evacuation: Case Study of Brunswick City, Germany

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Abstract**—**The human behaviors during evacuations are quite complex. One of the critical behaviors which affect the efficiency of evacuation is route choice. Therefore, the respective simulation modeling work needs to function properly. In this paper, Simulation of Urban Mobility's (SUMO) current dynamic route modeling during evacuation, i.e. the rerouting functions, is examined with a real case study. The result consistency of the simulation and the reality is checked as well. Four influence factors (1) time to get information, (2) probability to cancel a trip, (3) probability to use navigation equipment, and (4) rerouting and information updating period are considered to analyze possible traffic impacts during the evacuation and to examine the rerouting functions in SUMO. Furthermore, some behavioral characters of the case study are analyzed with use of the corresponding detector data and applied in the simulation. The experiment results show that the dynamic route modeling in SUMO can deal with the proposed scenarios properly. Some issues and function needs related to route choice are discussed and further improvements are suggested.

Keywords**—**Evacuation, microscopic traffic simulation, rerouting, SUMO.

I. INTRODUCTION

THE global weather change effects and human-caused major incidents such as terrorist and nuclear incidents have made crisis management one of today's important issues. Lots of attention has already been paid to it. Many research studies have also been performed to model different evacuation situations, to establish and develop the corresponding frameworks, to examine and solve existing problems and obstructions, and to develop, merge and evaluate possible solutions. Different simulative and operational tools for crisis management are already developed as well. In order to efficiently and effectively execute and manage different activities during crises, it is necessary to coordinate existing crisis management tools and to have exercises and trainings as preparation for successful crisis management. Several European research projects, such as ACRIMAS, CRISIS, DRIVER and CRISMA, have also aimed and continue to achieve the above mentioned goal for years.

Human behaviors during evacuations are quite complex. It is thus a challenge to model such behaviors properly, especially when empirical data are often not available. Such behaviors influence many aspects in traffic modeling and simulation, such as traffic demand, selected traffic modes, trip-making decision, departure decision, route choice decision, driving behaviors and so on. A review of the current evacuation modeling works can be found in [1].

The microscopic traffic simulation program, Simulation of Urban Mobility (SUMO), has extended its functions so that the traffic simulation can be performed not only for normal daily life but also for evacuation. The extended functions related to dynamic route modeling, trip-making decision and destination decision. Some related issues have been investigated in [2]. Following the results in [2] the focus is not only put on SUMO's dynamic routing modeling but also on the consistency between the simulation and the reality in this paper. A real case study is conducted to analyze possible traffic impacts of different traffic management strategies and examine SUMO's rerouting modeling during an immediate evacuation (bomb alert). Such a case happens several times in Germany every year and often results in an immediate evacuation which impacts the corresponding traffic system and the evacuation activities. Therefore, it is necessary to understand the possible traffic impacts of the proposed evacuation and traffic management strategies for better decision support.

II. CURRENT DYNAMIC REROUTE MODELING DURING EVACUATION IN SUMO

SUMO is an open source, highly portable, microscopic and continuous road traffic simulation package and is designed to handle large road networks. It has been continuously developed for more than 15 years and has be extensively successfully applied in different projects related to urban traffic management, traffic emission, Vehicle-to-Everything (V2X) and other diverse traffic issues [3], [4].

The dynamic route choice during evacuation is modeled with use of the rerouting function in SUMO. In the rerouting function, four mechanisms for location-based rerouting of vehicles are supported. When vehicles pass a pre-defined set of edges (referred to as rerouting roads) during a pre-defined time interval, they can take one or more of the following actions with the respective user-defined probabilities on each rerouting road.

1) Pick a new route from a pre-defined distribution of routes.
2) Pick a new destination from a pre-defined distribution of destinations and then take the fastest route to the new destination.
3) Terminate their routes immediately.
4) Compute and use the fastest route to their original destination that avoids a pre-defined set of closed roads (if the original route does not include the closed roads, no

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action is taken).

Mechanism 2, mechanism 3 and mechanism 4 can be combined and then vehicles that are affected by the closed roads can either pick a new destination and take the fastest route that avoids the closed roads or terminate their routes. Terminating a route can happen in the beginning of the trip, i.e. trip cancellation, or during a trip. According to the given probabilities, decisions can be made at each time when drivers are on a certain rerouting road. The fastest route is computed automatically with use of the Dijkstra-algorithm. The computed route starts at the edge the vehicle is located at and ends at the new/original destination. The following travel times can be considered for routing (the first applicable value is used):

- The current (smoothed) edge travel times in the network. This is meant to model vehicles with a modern navigation aid that uses up-to-date traffic data. In SUMO, this is accomplished by equipping vehicles with a so-called `rerouting device'.
- Subjective edge travel times for the current vehicle as set by an external application. This is accomplished via the TraCI command "change edge travel time information".
- Global edge travel times which are loaded via the SUMO option – weight-files.
- Empty network travel times (driving at the speed limit).

The last three edge travel times can be used to model various assumptions that drivers might take when facing a road closure or other information that would prompt rerouting. In addition, there are two special destination values:

- keepDestination: the vehicle continues on its current route; and,
- terminateRoute: the vehicle leaves immediately the simulation and is counted as arrived at its current position on the rerouted edge.

More corresponding information can be found at the SUMO-Rerouter website [5].

III. REAL CASE STUDY

The bomb alert case, which happened on July 20th, 2015 in Brunswick, Germany, is chosen as the real case study.

A. Basic Data

Brunswick is a city with around 250,000 residents. The city area is 192 km^2. In order to simulate the bomb alert scenario in Brunswick, Germany, the respective digital road network, traffic demand, and information about bus and the related traffic infrastructure are collected. With the consideration of the rerouting possibilities, the analysis network covers not only the evacuation area but also the major roads, highways as well as the corresponding ramps in Brunswick. Based on the results of the DLR's fundamental research projects AIM [6] and VABENE++ [7], [8], the analysis network is adjusted and the corresponding traffic demand, i.e. vehicular routes, in the analysis network are extracted from the original traffic demand in Brunswick. The layout of the analysis network is shown in Fig. 1. Furthermore, the information of the bomb alert case on July 20th, 2015 is collected and considered in the simulation as much as possible, in order to closely reproduce the traffic situation during the evacuation of the bomb alert case.

To sum up, the evacuation area is 1 kilometer around the found bomb close to the main railway station. Some railway services were therefore adjusted or canceled during the evacuation. Buses and trams were allowed to run in the evacuation area without stopping. The evacuation began at 17:05 and the total evacuation duration is 6.5 hours (from 17:05 to 23:36). More than 11,000 residents are evacuated. The evacuation area is also shown in Fig. 1 (indicated with a circle).

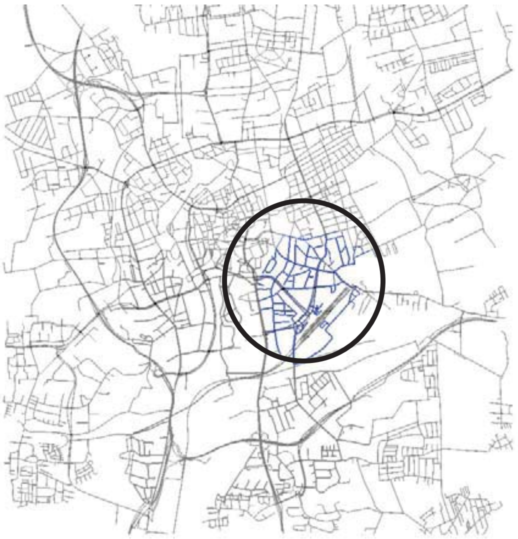


Fig. 1 Analysis network of the bomb-alert scenario

B. Link Flow Analysis

In addition to the basic data, the detector data, deployed in the analysis network, is collected as well. According to the detector data the changes of the traffic loadings before, during and after the evacuation as well as some evacuation behaviors can be further explored. In order to avoid other influences on traffic, such as weather, vacation time and other activities, only the data on Mondays, including the bomb-alert Monday, in July is collected.

In the following, the changes of the average traffic loading due to the bomb alert are firstly analyzed according to the different impact areas, i.e. the 1-km closed area and the analysis network excluding the closed area. The time series of traffic flows on the detectors within the closed area are then observed in detail to catch some behavior data for achieving a more realistic simulation.

The hourly average traffic volumes for a normal Monday are calculated with use of the data collected on July 6th, 13th and 27th, 2015 and used as the base values. Furthermore, the flow ratios between the hourly average traffic volumes for a normal Monday, for each analyzed Monday and for the bomb-alert Monday are calculated and indicated in Fig. 2. The flow ratio patterns of the three normal Mondays are quite similar to each other between 05:00 and 17:00. The deviation of the flow ratios for 2015-07-06 and 2015-07-27 are much higher (more than 10%) between 24:00 and 04:00. It is mainly since the traffic volumes are quite low during that period and the calculated ratio values become much more sensible. On the bomb-alert Monday, the flow ratio pattern is generally similar to that of the average normal Monday before the bomb was found. After 17:00, the hourly flow ratios decrease considerably due to the area closure. The impact of the bomb alert on the closed area is significant, especially during the rush hours in the evening. After 23:36, the area was open again and the respective flow ratio increases. Due to the effect of the small traffic volumes the flow ratio for 23:00 becomes extremely high. In addition, the flow ratios during the area closure period are quite low, but not zero. It indicates that some drivers violated the order and still traveled within the closed area. Such behavior cannot be represented in the simulation yet and needs to be adjusted in the simulation.

The impact of the bomb alert on the traffic in the investigated network (outside the closed area) is further examined. The result in Fig. 3 shows that the flow fluctuation on the bomb-alert Monday is quite similar to that on the other Mondays between 05:00 and 17:00. Like the other Mondays, the flow fluctuation between 24:00 and 05:00 on the bomb-alert Monday is higher. It is mainly due to the fraction effect of the small traffic volumes. Between 18:00 and 21:00, the average link flow on the bomb-alert Monday is higher than that on the other Mondays. It shows that the area closure impacted the surrounding traffic to a certain degree, but not extremely significant. Such impact is mainly from the rerouted traffic. The rerouted traffic results in a higher average traffic loading in the analysis network, where the rerouted traffic includes the trips really affected by the bomb alert and the trips which make rerouting only due to the drivers' expectations. At 23:36, the area closure was over and the people involved in the evacuation left for home or other places. Thus, the flow ratio between 23:00 and 24:00 becomes much higher than that in the normal situation.

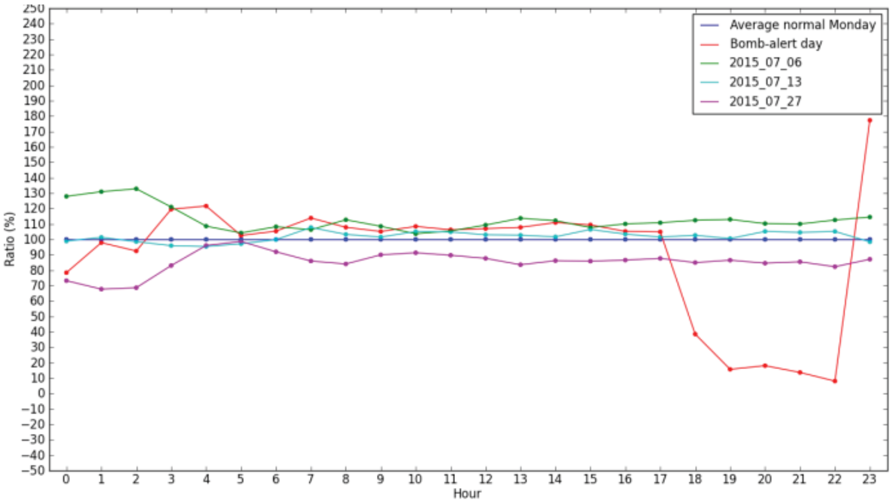


Fig. 2 The time series of the mean link flow ratios within the closed area on the different Mondays in July, 2015

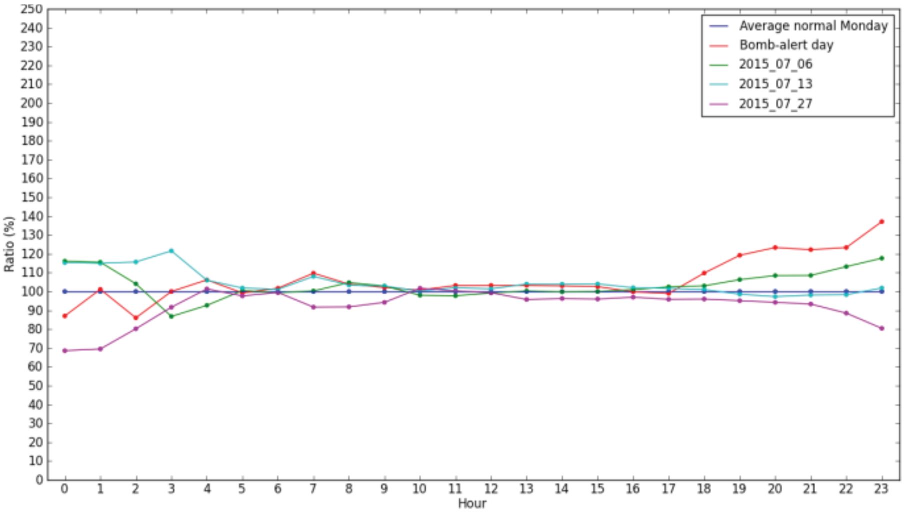


Fig. 3 The time series of the mean link flow ratios outside the closed area on the different Mondays in July, 2015

According to the collected data, an area of one kilometer around the found bomb was closed. When checking with the detector data, it is found that some roads at the border of the closed area were not really closed. Traffic was still detected at the corresponding detector locations during the evacuation. It is mainly because these roads are on the border and connect the closed area to other roads/areas. Thus, they were not closed during the evacuation. The above mentioned phenomena and behaviors will be considered in the simulation (see Section V).

IV. SCENARIO DESCRIPTION

Four influence factors, i.e. time to get information, probability to cancel a trip, probability to use navigation equipment and rerouting and information updating period, are considered to analyze possible traffic impacts and to examine the rerouting function in SUMO.

Besides the normal case (Base), five scenarios are developed to analyze the impacts of the following factors:

1) The time when the road closure information is available to the drivers,
2) The probabilities to cancel a trip due to unreachable destination, and
3) The probabilities to cancel a trip in order to avoid the expected traffic congestion on traffic with SUMO.

A. Base Scenario (The Normal Case)

The bomb alert in Brunswick happened on Monday. Thus, the traffic scenario on a common Monday without the bomb alert is chosen as the base scenario. The corresponding simulated edge travel time information will be used as reference traffic state in the proposed scenarios so that the rerouted vehicles will use this travel time information for route searching instead of the free-flow travel time information. The respective route searching result should be more realistic.

B. Scenario 1 (S1)

It is based on the normal case. All drivers receive the road closure information right after the road closure. The probability to cancel a trip on the way is 100% only for drivers who cannot reach their destinations when they are on the defined rerouting roads. Furthermore, some drivers may cancel their journeys in order to avoid the expected traffic congestion. In this case, the probability to cancel a trip on each rerouting road is defined as 5%.

C. Scenario 2 (S2)

It is based on Scenario 1. The probability to cancel a trip on each rerouting road is defined as 10% for avoiding the expected traffic congestion in this scenario.

D. Scenario 3 (S3)

It is based on Scenario 1. All drivers receive the road closure information right after the bomb alert, i.e. 15 minutes before the road closure, in this scenario.

E. Scenario 4 (S4)

It is based on Scenario 1. However, all drivers receive the road closure information right after the bomb alert, i.e. 15 minutes before the road closure, in this scenario. The probabilities to cancel a trip on the way and to go to a new destination are both 50% only for drivers who cannot reach their destinations when they are on the defined rerouting roads. Drivers, who decide to change their destinations, choose a new destination from a pre-defined destination set.

F. Scenario 5 (S5)

It is based on Scenario 4. However, the probability to cancel a trip on each rerouting road is defined as 10% for avoiding the expected traffic congestion in this scenario.

G. Scenario 6 (S6)

It is based on Scenario 1. However, the probability to cancel a trip for avoiding traffic jams is zero in this case.

H. Scenario 7(S7)

It is also based on Scenario 1. Furthermore, the probabilities to cancel trips with unreachable destinations and for avoiding traffic jams are both zero in this scenario. All vehicles with unreachable destination choose a new destination from a pre-defined destination set.

Moreover, from the collected data, the behaviors found in the Section III Link Flow Analysis and some common phenomena during the road closure and the evacuation are also considered in order to establish the simulation environment close to the reality. Firstly, drivers in the evacuation area are allowed to leave there in the first 2 hours of the road closure period. Secondly, drivers, who cannot leave the evacuation area in the first 2 hours of the road closure period, need to park their vehicles in the evacuation area and leave the area by foot or by shuttles provided by the rescue team. The later one will not be considered in the simulation. Thus, no vehicle should move in the evacuation area after the first 2 hours of the road closure period. The applied data in the simulation are summarized in Table I. The impact of using navigation devices on the traffic during the evacuation is investigated in each proposed scenario. Two factors are considered here:

1) Two navigation deployment rates: 25% and 75%.
2) Two rerouting and information updating periods: 300s and 600s.

V. IMPLEMENTATION

To implement the above mentioned scenarios and phenomena in the simulation, the rerouting function in SUMO is used. The evacuation begins at 17:05. In order to capture the traffic phenomena of the evacuation, the simulation starts at 15:00 so that the traffic state corresponds to the normal traffic situation when the evacuation starts. Furthermore, different roads are defined as “rerouting” roads at different time intervals according to the scenarios. Once a driver is on a rerouting road, he receives the road closure information and has the opportunity to reroute the trip. When a driver decides to cancel his trip, the respective vehicle will be immediately removed from its current location. According to the scenarios, two rerouter styles “Closing a Street” and “Assigning a new

Destination” in SUMO are applied.

TABLE I
FACTORS CONSIDERED IN THE SCENARIOS

Scenario	Time to get the information right after		Probability to cancel a trip with unreachable destination		Probability to cancel a trip for avoiding traffic jams	
	Road closure	Bomb alert	50%	100%	5%	10%
Base	-	-	-	-	-	-
S1	X			X	X	
S2	X			X		X
S3		X		X	X	
S4		X	X		X	
S5		X	X			X
S6	X			X		
S7	X					

In order to describe the situation in the simulation of drivers who cannot leave the evacuation area in the first 2 hours of the evacuation period, the method terminateRoute in the rerouting function is used. With this method, the respective drivers terminate their routes immediately and are removed from the simulation.

Although SUMO can simulate traffic closely to the given reality, there are currently still some limitations when simulating drivers' “flexible” behaviors, for example standing in a wrong lane, reverse driving or driving to the roadside in order to provide enough gaps at intersections so that dead-lock situations can be prevented. Such flexible driving behaviors happen much more often during evacuation. Otherwise, many dead-locks will appear at the borders of the evacuation area or some major intersections with heavy traffic loads. Furthermore, it is also observed in the Section III Link Flow Analysis that some journeys are still undertaken although the area is already closed. Therefore, the SUMO-option “teleporting” is used in addition to allowing U-turns at intersections. Three hundred seconds are set as the time to teleport vehicles in order to deal with the above mentioned issues and, at the same time, be still able to capture the overall traffic congestion phenomenon during the evacuation.

Table II shows the applied data and definitions in the simulation for each scenario.

VI. RESULT ANALYSIS

A. Without Navigation Effect

1) Travel Length and Travel Time

There are, in total, 146,976 vehicles during the normal situation. Table III shows that 80% of the travel lengths are between 1 km and 7.5 km, where 50% of the vehicles have a travel length between 1 km and 4 km. Furthermore, 14% of the trips have a travel length less than 1 km and only 6% of the trips have a longer travel length between 7.5 km and 15 km. The average travel length is around 3.5 km. The shorter average travel length is because the City Brunswick is a midsize city and the development area is not widely dispersed. Furthermore, only the trips with routes in the analysis network are considered.

TABLE II
OVERVIEW OF THE APPLIED DATA IN THE SIMULATION

Item	Content	Note
Simulation start time	15:00	
Traffic demand.	146976 vehicles	
Time to start the evacuation and the road closure.	17:05	
Time to disallow vehicles to drive within the evacuation area.	18:30	no moving vehicles in the evacuation area
Time to start rerouting.	see Table I	
Rerouting roads.	all roads	except the closed roads and the mainlines on the highways
Possibility to cancel a journey during a trip on each rerouting road (for drivers who cannot reach their destinations.	see Table I	
Possibility to cancel a journey on each rerouting road.	see Table I	
Time to teleport.	300 s	
Possibility to activate the navigation rerouting.	25% and 75%	for all scenarios
Updating and rerouting periods of the navigation rerouting.	300s, 600s	for all scenarios

TABLE III
TRAVEL LENGTH DISTRIBUTION IN THE NORMAL SITUATION

Kilometers	Percent	Kilometers	Percent
0.0-0.1	1.40	3.0-4.0	18.09
0.1-0.5	6.22	4.0-5.0	11.39
0.5-1.0	6.67	5.0-7.5	17.22
1.0-2.0	18.09	7.5-10.0	5.28
2.0-3.0	14.68	10.0-15.0	0.98

The proposed scenarios with the above mentioned parameter settings are executed with SUMO (Version: dev-SVN-r21514). The simulated travel information is analyzed and summarized in Table IV. Due to the nature of the proposed scenarios, i.e. the possibility to cancel a trip, the total number of vehicles varies in each scenario. Naturally, this variation also influences the average travel duration and the average travel length. As mentioned above, there are trips with very short travel distances and they will have great influence on average values. Thus, only trips with a travel distance greater than 0.5 km are considered when calculating the average travel duration and distance. In comparison to the normal case (Base), all other scenarios have more travel times and travel distances on average.

The higher possibility to cancel a trip for avoiding the expected traffic congestions results in the reduction of the number of vehicles that are not really affected by the road closure. The ratio of the vehicles that are truly impacted by the road closure and have longer travel times and distances increases in the whole vehicle population. Thus, the average travel duration and distance are higher in S2 and S5 than S1, S3 and S4. However, S2 and S5 have lower total travel durations than other scenarios due to fewer vehicles in the network. It also shows that an earlier bomb-alert notification (15 minutes earlier) only results in a limited reduction in total travel duration when comparing S1 and S3.

The average travel duration with an earlier bomb-alert notification is higher than that without an earlier bomb-alert notice. This is because more vehicles search for suitable routes and the respective route choices and travel durations are impacted when the bomb-alert notification is given earlier. The results of S6 and S7 further indicate that the average travel times increase significantly when no trip is canceled to avoid expected traffic jams. In addition, it is noticed that some vehicles have a route length of zero in all evacuation scenarios. Their travel duration is 1 second. It means that they cancel their entire trip in order to avoiding the expected traffic congestion. It also explains why the total numbers of vehicles in S2 and S5 (with 10% of probability to cancel a trip) is less than the other scenarios. Such trips are not considered in the result analysis. Moreover, Fig. 4 shows the distribution of the travel lengths in all scenarios. It is obvious to see that there are more trips with a travel distance less than 2 km in the scenarios from S1 to S5 than in the base scenario. The possibility to cancel a trip results in that some vehicles cancel their journeys while on their way.

The corresponding travel distances therefore become shorter. Once a trip cancellation is decided, the corresponding vehicle is immediately removed from its location. In addition, the trip cancellation possibility is defined on each rerouting road. The longer a trip is, the higher the respective possibility to cancel a trip will be. Therefore, more long-distance trips are canceled. When there is no trip cancellation, i.e. the cases S6 and S7, the trip proportions with a travel distance less than 3 km are similar to those in the base scenario. The trip proportions with a travel distance longer than 7.5 km become higher. It is mainly due to the rerouting behaviors.

TABLE IV
SIMULATED TRAVEL DURATION AND LENGTHS FOR ALL SCENARIOS

Scenario	Total number of trips	Total travel duration[a] (h)	Average travel duration[a] (min/veh)	Average travel length[a] (km/veh)
Base	146976	11988	5.77	4.05
S1	137495	9748	7.21	4.26
S2	134460	7732	7.98	5.01
S3	136582	9635	7.46	4.29
S4	137733	9655	7.30	4.22
S5	134509	7276	8.11	5.09
S6	140475	60704	32.33	4.26
S7	142187	66064	33.99	4.21

[a] Only trips with a travel length greater than 0.5 km are considered for avoiding the effect of trips with very short distances on the average value.

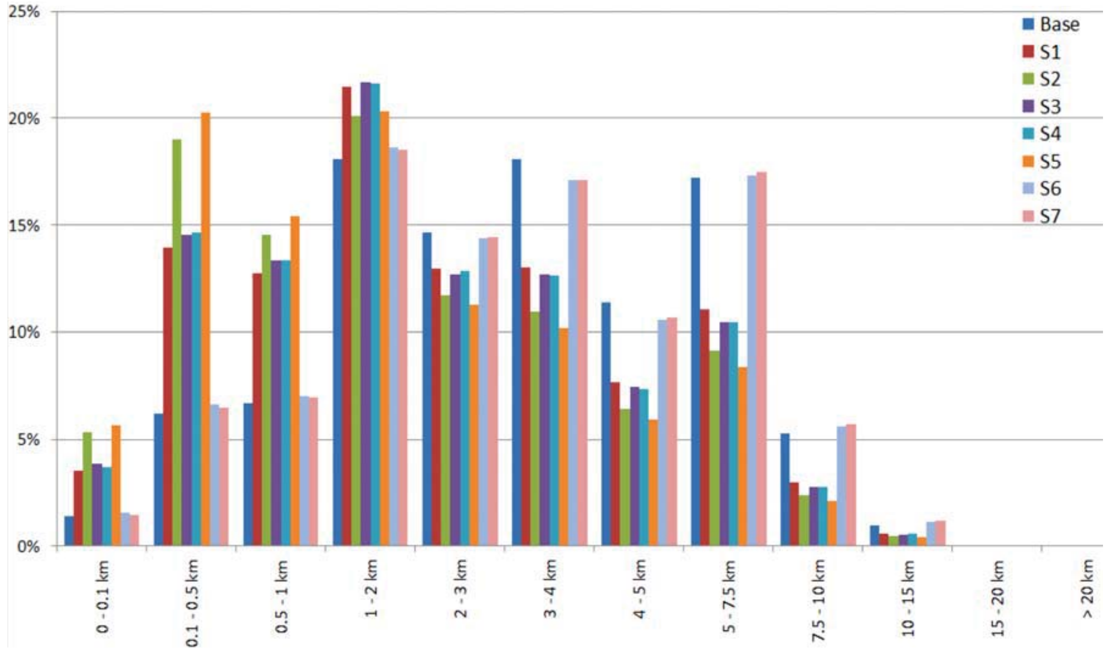


Fig. 4 Travel length distributions

Regarding the travel time distribution all vehicular travel times in the base scenario are within 25 minutes. Fig. 5 shows that the range of the travel time distribution becomes much wider when the bomb alert occurs. When trip cancellation for avoiding the expected traffic jams is possible, a few of vehicles have a travel time longer than 150 minutes. Around 1.2% of the vehicles travel longer than 25 minutes and 0.7% of the vehicles travel more than 60 minutes. Trips with shorter travel times become more in number due to the trip cancellation factor that causes not only trips with shorter travel distances, but also the network with less traffic load. S2 and S5 have a higher trip cancellation factor (10%), so that there are more trips with a travel time less than 5 minutes than other scenarios. When trip cancellation is not possible, 16.5% and 12.5% of the vehicles then travel longer than 25 minutes and 60 minutes, respectively. This indicates that the bomb alert has an influence on traffic, but only to a certain degree.

2) Emissions

It is known that there is an apparent relationship between travel speed and the amount of emissions [9], [10]. The more the driving speed deviates from the respective ideal driving speed, the larger the amount of emissions will be. Traffic jams occur during the road closure. Drivers who decide to continue their trips often experience lower travel speeds compared to the base case. The amount of the respective emissions should increase accordingly. Therefore, the influence of the evacuation on emission production is also examined in addition to the travel distance and travel time. The emission analysis, shown in Fig. 6, supports this thought. Two emissions CO and HC are chosen as indicators here. The amounts of the observed emissions for passenger cars and trucks in all scenarios are higher than those in the normal situation (Base). When observing each scenario, S2 and S5 produce more emissions on average than scenarios S1, S3 and S4. As mentioned before, the main reason is that the ratio of the vehicles that are really affected by the road closure increases due to the reduction of the vehicles that are not truly impacted by the road closure. The amounts of emissions for passenger cars in S3 are slightly higher than those in S1, where drivers get the information before and after the road closure in S3 and S1, respectively. It indicates that more vehicles in the network are affected by the evacuation when the respective information is earlier available. Such an outcome corresponds to the mentioned results of the average travel time and distance for S1 and S3. Also, S6 and S7 have high emission productions because there is no trip cancellation.

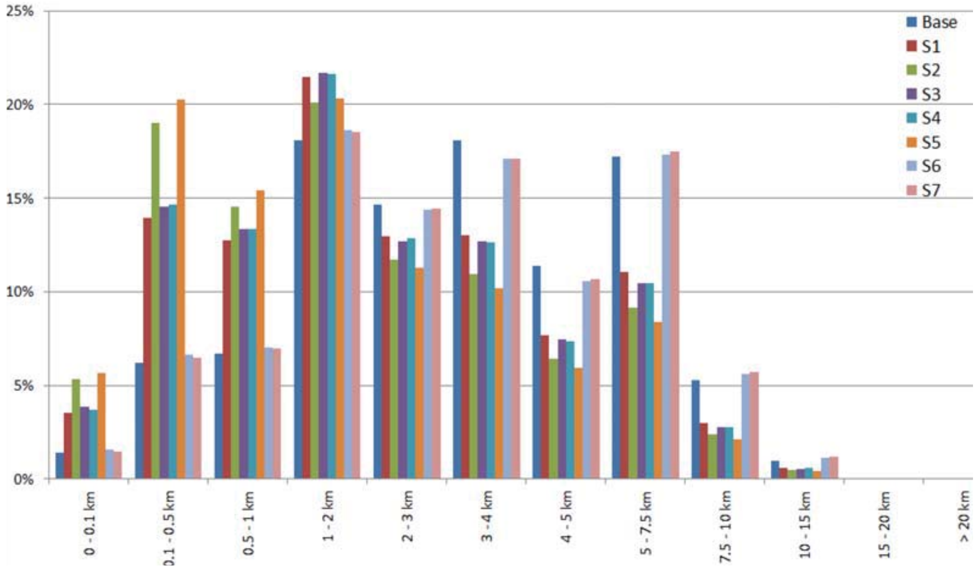


Fig. 5 Travel duration distributions

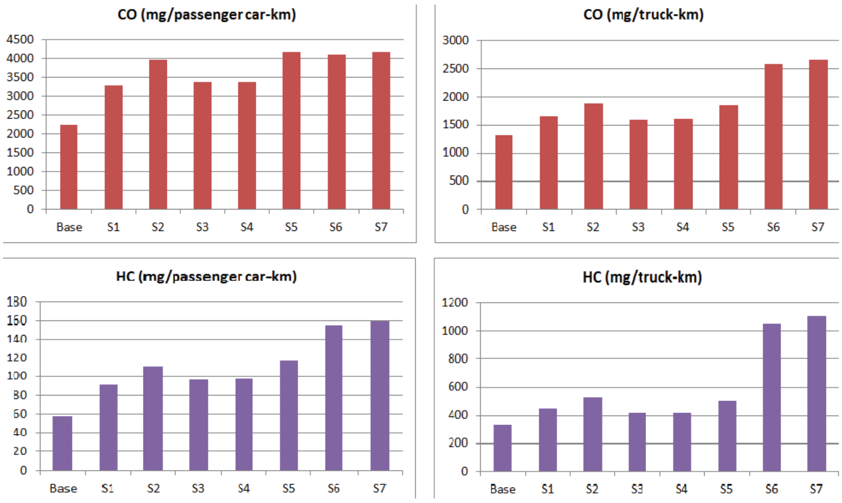
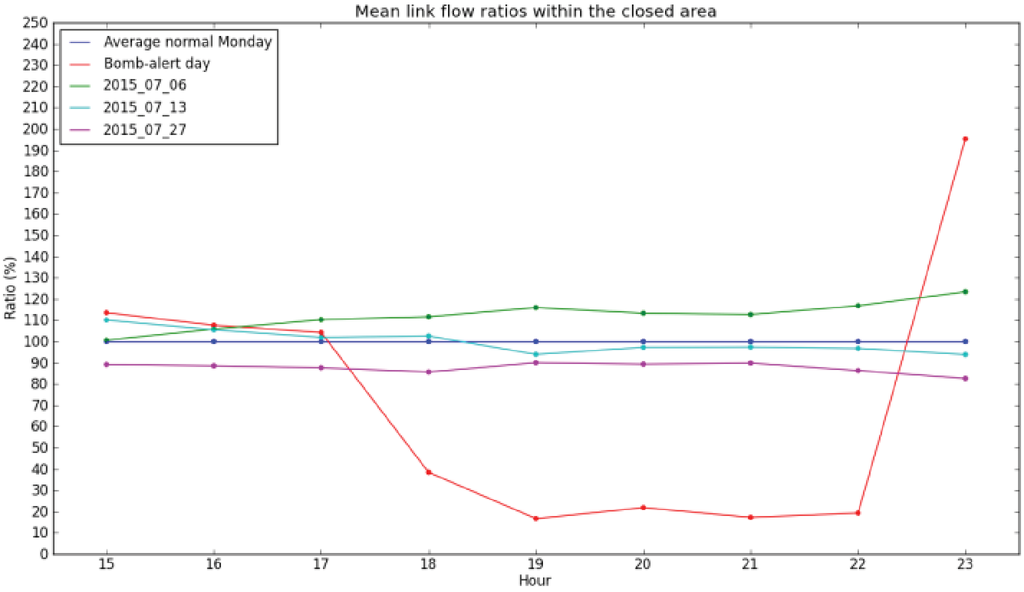


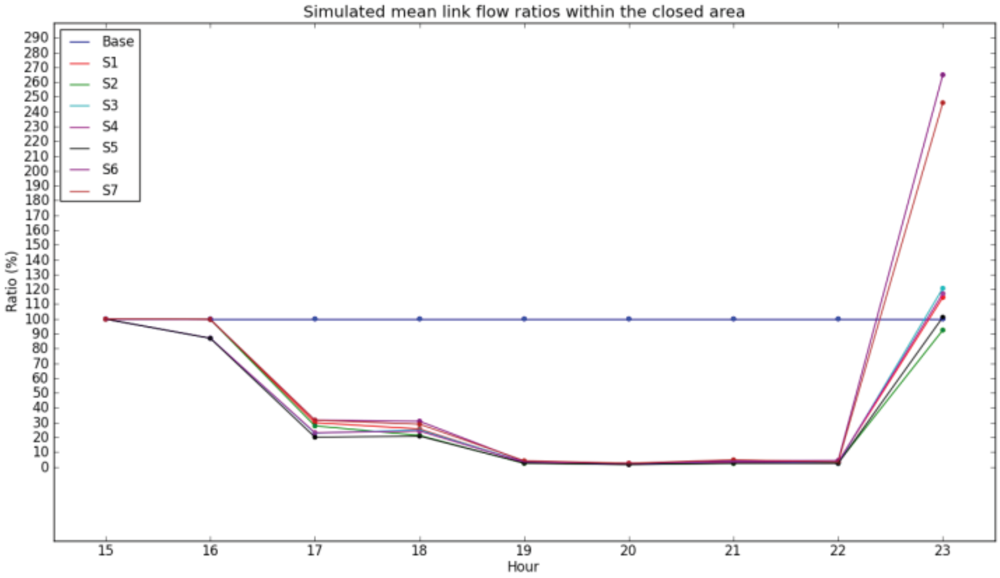
Fig. 6 Simulated CO and HC emission productions

3) Comparison of Mean Traffic Loadings

Fig. 7 shows that SUMO can generally capture the flow ratio pattern in the closed area during the evacuation, especially in scenarios S6 and S7. It is also revealed that two issues cannot be properly be dealt with by SUMO as yet. The first one is the possibility that drivers violate the area closure order and continue their journeys. All vehicles in the simulation are not allowed to move in the closed area until the evacuation period is over. The second one is the adaptation of departure times for the vehicles with the origins in the closed area during the evacuation and the road closure. In reality, the mean traffic flow starts to decrease from 18:00 onwards; although, the evacuation begins at 17:00. People are not eager to leave the area as quickly as possible. However, the traffic flow reduction happens from 17:00 onwards in the simulation, as defined. Therefore, there is a one-hour shift between these two flow ratio patterns. Moreover, there is a clear drop in traffic flow in the second hour of the evacuation period in reality, but not in the simulation. This indicates that people who need to leave the evacuated area still apply their originally planned departure time in the simulation.



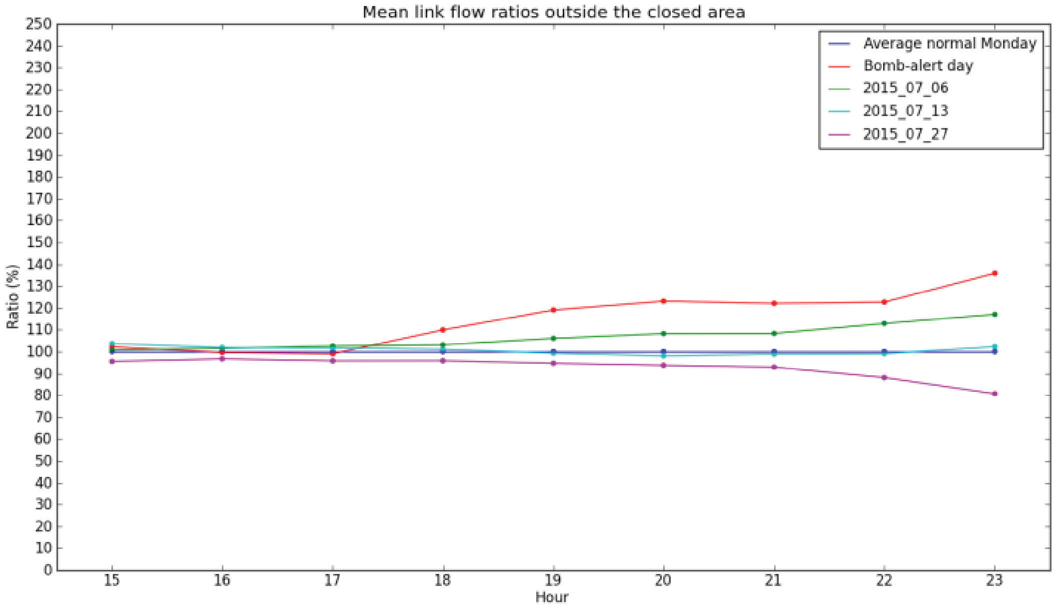
(a) Mean link flow ratios within the closed area



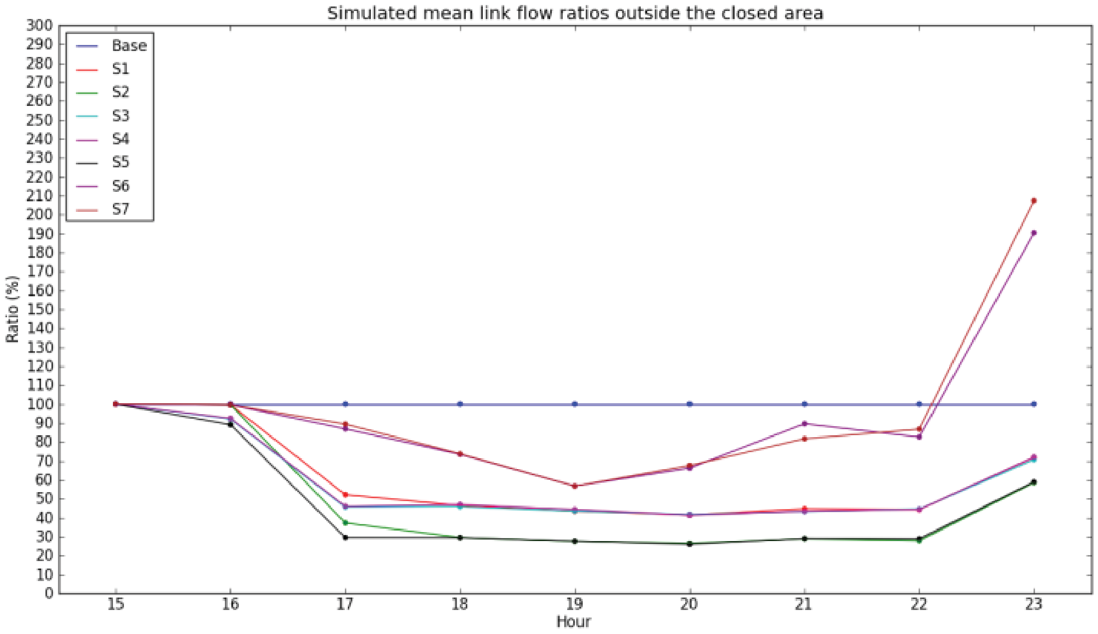
(b) Simulated mean link flow ratios within the closed area

Fig. 7 Comparison of the real and simulated mean traffic flow ratios within the closed area

When observing the real and simulated mean link flow ratios outside the closed area, as shown in Fig. 8, the hourly mean flows are mostly lower than those in the normal case, while the situation is converse in the reality. It is mostly because the traffic congestion is more serious in the simulation than in reality, so that vehicles need to wait longer until they can travel again. It explains the higher traffic flow during 23:00 and 24:00 in S6 and S7. Moreover, most of the scenarios have fewer vehicles than the base scenario. It is mainly due to the applied trip cancellation probabilities and the absent adaptation of the departure times for vehicles that need to leave the closed area in the simulation. Thus, some trips are withdrawn when the respective trip cancellations are decided or the corresponding vehicles cannot leave the area in the given evacuation period. A flatter flow pattern during the evacuation period is also caused by the absent adaptation of the departure times.



(a) Mean link flow ratios outside the closed area



(b) Simulated mean link flow ratios outside the closed area

Fig. 8 Comparison of the real and simulated mean traffic flow ratios outside the closed area

B. With Navigation Effect

The above-proposed seven scenarios are further investigated given the different navigation deployment rates and rerouting intervals. The results in Table V show that the average travel times and travel distances tend to be less when using navigation devices in scenarios S1 to S5 when a trip cancellation is possible. Although the improvement is marginal, it can still be seen that the higher the navigation deployment rate is, the less the average travel time and distance are. The result also shows that the rerouting adaptation with an interval of 300 seconds generally leads to longer average travel time and distance than that with an interval of 600 seconds. More frequent rerouting adaptations may result in more rerouting behaviors which can result in longer travel time and distance. A few of scenarios have more travel time and distance with the interval of 600 seconds than that with the interval of 300 seconds. This maybe mainly due to the considered factors in the respective scenarios; for example, S4 and S5 consider that the vehicles with unreachable destinations have 50% possibility to go to a newly assigned destination, while all such vehicles cancel their trips in the other scenarios. Thus, a more frequent rerouting interval (300 seconds) helps the vehicles to adapt their routes and save more travel time and distance when the navigation deployment rate is high (75%).

TABLE V
AVERAGE TRAVEL DURATIONS AND LENGTHS WITH DIFFERENT NAVIGATION DEPLOYMENTS AND REROUTING INTERVALS

Deployment rate		0%	25%		75%	
Updating interval(s)		-	300	600	300	600
S1	avg. travel time[a]	7.21	7.00	7.03	6.88	6.85
	avg. travel length[b]	4.26	4.22	4.23	4.21	4.19
S2	avg. travel time[a]	7.98	7.88	7.81	7.55	7.53
	avg. travel length[b]	5.01	5.01	4.99	4.96	4.93
S3	avg. travel time[a]	7.46	7.31	7.31	7.06	6.99
	avg. travel length[b]	4.29	4.26	4.26	4.23	4.20
S4	avg. travel time[a]	7.30	7.20	7.18	6.86	6.94
	avg. travel length[b]	4.22	4.20	4.19	4.16	4.14
S5	avg. travel time[a]	8.11	8.07	7.96	7.71	7.75
	avg. travel length[b]	5.09	5.10	5.04	5.02	5.00
S6	avg. travel time[a]	32.33	21.44	22.38	12.24	12.69
	avg. travel length[b]	4.26	4.35	4.35	4.29	4.30
S7	avg. travel time[a]	33.99	22.78	25.39	13.07	13.07
	avg. travel length[b]	4.21	4.32	4.34	4.31	4.26

[a]Unit: minutes/vehicle, [b]Unit: km/vehicle

When there is no trip cancellation for avoiding the expected traffic jams, the influence of the navigation deployment rate on travel time is significant. The average travel times with 25% and 75% navigation deployment rates are around 1.5 and 2.5 times less than those without navigation assistance, respectively. A frequent updating interval (300 seconds) seems to have more time saving than an updating interval with 600 seconds in this case.

VII. CONCLUSION AND FUTURE WORK

As mentioned in the beginning, human behaviors during evacuations are quite complex. Such complex behaviors make the evacuation modeling work challenging. In this paper, the analysis situation is simplified to a certain degree and some assumptions are made for analyzing possible traffic impacts and the current dynamic routing model during evacuation situation. The results show that the implemented dynamic rerouting model in SUMO can simulate the proposed scenarios with or without navigation deployment properly. However, some function needs are discovered and should be further improved and met. Currently, the departure times of the simulated vehicles within the evacuation area are the original planned departure times. It does not correspond to the evacuation situation, where most people want to leave the evacuation area as soon as possible and all people should leave the area within the given evacuation period. Therefore, the simulated flow pattern in the evacuation area is flatter than that in reality. The related function needs to be developed according to different evacuation cases. In addition, a certain number of shelters and the corresponding routes to them are sometimes given during evacuations, especially during serious disasters, such as nuclear disasters. In this case, the combination of the rerouting function and a given route set is necessary for evacuation simulation.

Last but not least is the routing issue. The route choice modeling can basically be divided into the pre-trip route choice modeling, the en-route route choice modeling and the hybrid route choice modeling which is based on the combination of pre-trips and en-route journey decisions. The pre-trip route choice modeling is to determine routes based on the current or expected route utilities, i.e. travel time in this study. The principle to determine such routes is nowadays often based on the Wardrop's user equilibrium. In our example, these routes are already given. In the en-route model, drivers can make a new route choice according to the available traffic information when they approach a decision-making point, for example an intersection and ramps. In general, the hybrid route choice model takes the unfamiliarity of the traffic information into consideration. Drivers choose their routes according to their departure times. They can then adjust their routes according to the available information. Currently, the routing concept of the evacuation in the dynamic rerouting model in SUMO is similar to the hybrid route choice model. However, some sophisticated factors, such as the unfamiliarity and the reliability of road situations and road classes, drivers' time perceptions as well as departure time choosing are not taken into consideration yet. Thus, there is still room for improvement for more sophisticated route choice modeling during evacuation.

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