RC25384 (MRL1305-001) May 3, 2013
Computer Science

IBM Research Report

Millgrove Evacuation Study

Anton Beloglazov, Juerg von Kaenel, Jan Richter, Kent Steer, Ziyuan Wang*

IBM Research Division
Level 5
204 Lygon Street
Carlton, VIC 3053
Australia

*In alphabetical order

Abstract

In this research report we present a recent study undertaken by IBM Research Australia into the dynamics of an evacuation of residents from the Victorian country town of Millgrove. The primary objective was to explore and understand the difference, in terms of traffic conditions, between the establishment of a single fire-safe refuge, or the establishment of two such refuges.

The study utilised a set of evacuation planning tools that are currently under development by IBM Research Australia that should be considered a *research prototype level*.

NOTE: readers should carefully study the assumptions and simplifications that have been made, and described herein, to fully understand to what level the findings may be applicable. IBM makes no warranties as to the applicability or usability of the results in this research study.

Introduction

The township of Millgrove is located 61 km east of Melbourne (Australia) and is home to around 2700 people. It lies on the edge of the Yarra Ranges National Park, which creates an idyllic setting, but also presents a significant bushfire risk. Local authorities are planning to establish either one or two refuges within the township where locals can seek refuge in the event of a fire. Two candidate sites have been chosen: (1) a school on Cavanagh Road, and (2) a soon-to-be disused fire station on the southern side of the Warburton Highway (see Figure 1).

IBM Research Australia has used these plans to test our evacuation simulation prototype by carrying out a study of the traffic conditions induced by an evacuation under the two refuge options. Points of concern include the single bridge across the river that the majority of residents will need to use, and two intersections on the Warburton Highway where evacuees must negotiate oncoming traffic before reaching the designated refuges. IBM Research's evacuation planning tools provide detailed insights into the location and extent of congestion under a variety of scenarios and assumptions, which may enable planning authorities to make more informed decisions.

In particular, the impact of the following three factors has been studied:

1. The number of fire refuges: one refuge at the school on Cavanagh Road, or two refuges with an extra site at the fire station on the southern side of the Warburton Highway.
2. The percentage of evacuee vehicles leaving to refuge destinations: 40%, 60%, or 80%.
3. The volume of highway background traffic: 100, 500, or 1000 cars per hour, much of which may be caused by evacuees from neighbouring towns trying to leave the area.

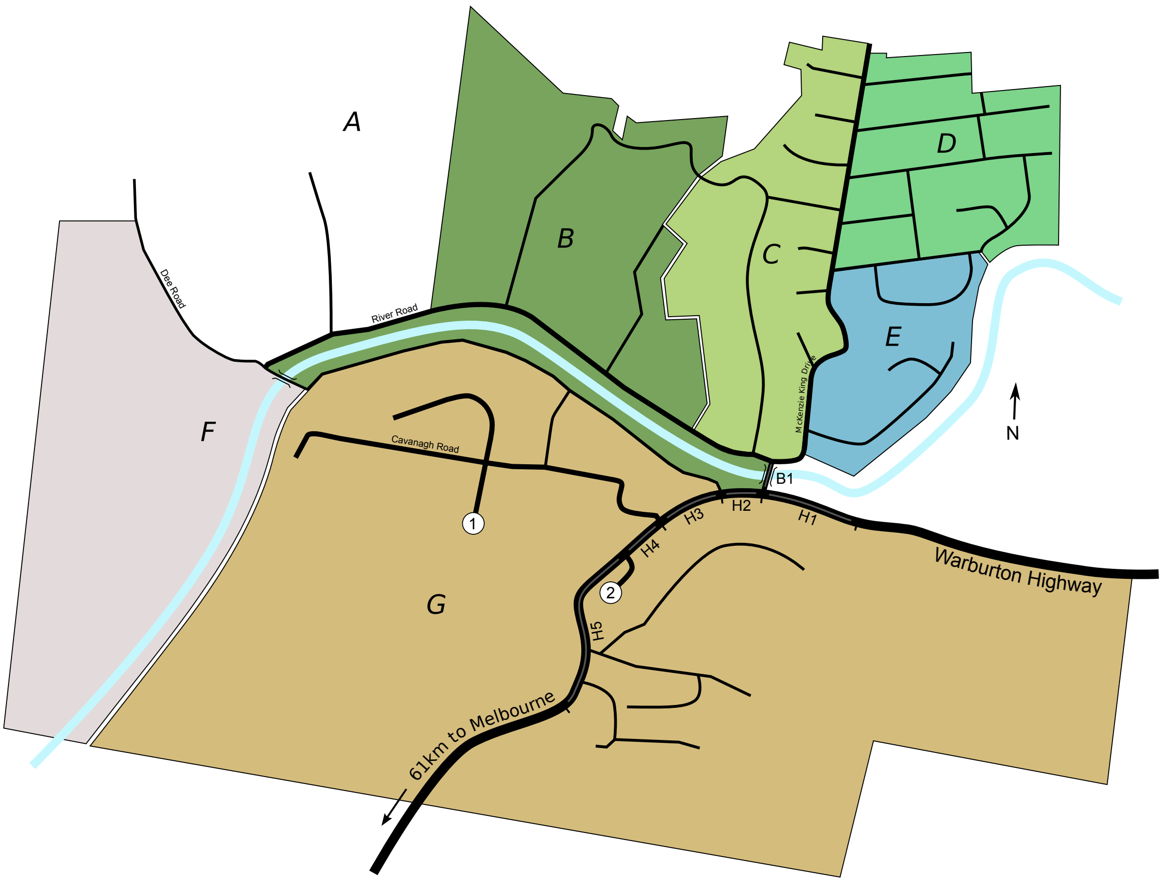


Figure 1: Map of the Millgrove area showing: regions A through G; road segments B1 and H1 through H5; and, two refuges sites under consideration, labelled nodes 1 and 2.

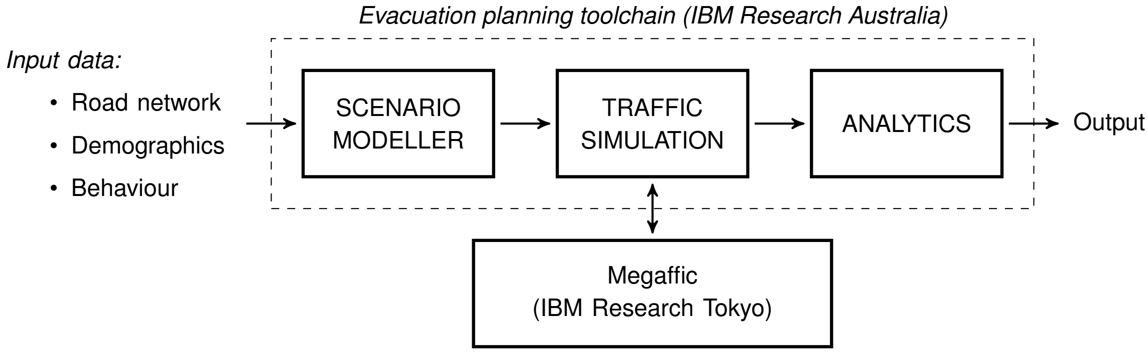


Figure 2: The evacuation modelling workflow. Boxes represent functional components. The Scenario modeller, Traffic simulation, and Analytics components compose an evacuation modelling toolchain developed at IBM Research Australia. This toolchain utilises *Megaffic*, an agent-based traffic simulator developed at IBM Research Tokyo.

Figure 2 is a high level schematic of the evacuation planning workflow. We use Megaffic[1] as our traffic simulation component in this study. Megaffic is an agent-based simulator developed by IBM Research Tokyo. It is capable of representing millions of vehicles and their interactions in large-scale traffic networks, and is well suited to major road infrastructure planning. As we demonstrate here, it can also be used to simulate traffic under evacuation conditions by carefully constructing an appropriate input scenario.

The analytics component performs post-processing on the simulation results to produce views of the data that support evacuation planning.

[1]Osogami et al., "IBM Mega Traffic Simulator": http://domino.research.ibm.com/library/cyberdig.nsf/papers

Experiment design

Data

The models developed during this study are based on information obtained from public data sources and input from subject matter experts. The following public data sets have been used:

- The road network model used in this study is based on data obtained from the OpenStreetMap (OSM) project[2]. The project creates and distributes free and open geographic data, licensed under the Open Data Commons Open Database License (ODbL)[3]. Since maps provided by the project are a work-in-progress, and anyone is allowed to edit the data, OpenStreetMap is not a complete or accurate map of the world. This study utilises the OpenStreetMap road network data current for April 2013.
- Demographic data were obtained from the Australian Bureau of Statistics (ABS)[4]. In particular, the data are a subset of the data collected during the Census of Population and Housing conducted by the ABS on 9 August 2011, which was Australia's sixteenth national Census[5]. This study uses the data on population size and household counts per Statistical Area Level 1 (SA1); SA1s are the smallest areas for which these types of Census data are released. SA1s have been designed to contain an average population of approximately 400 people. There are about 55,000 SA1s covering Australia. The provided data sets are of the highest quality available on the demographics of Australia. Prior to being released, the data pass through a confidentiality process, which results in small introduced errors; however, the information value of the data set as a whole is not affected.

The input from subject matter experts (SMEs) defined the evacuation area and destinations, as well as the road segments of interest displayed in Figure 1. SMEs also provided guidance on the distribution of the number of vehicles utilised by each household type, shown in Table 1. This information, in conjunction with the ABS data, enabled the calculation of the number of vehicles originating from each SA1 listed in Table 2.

Table 1: Distribution of vehicles per household type

	Singles	Families without children	Families with children
0 vehicles	0%	0%	0%
1 vehicle	100%	90%	50%
2 vehicles	0%	10%	50%
3 vehicles	0%	0%	0%

Table 2: Number of vehicles per SA1

SA1	Vehicle number
A	49
B	137
C	254
D	271
E	311
F	200
G	189

[2] OpenStreetMap. http://openstreetmap.org/
[3] OpenStreetMap: Copyright and License. http://openstreetmap.org/copyright
[4] Australian Bureau of Statistics. http://abs.gov.au/
[5] Australian Census of Population and Housing. http://abs.gov.au/websitedbs/censushome.nsf/home/census

Scenario modelling

The modelling approach undertaken in this study was to design a base scenario and determine a set of variables, whose value combinations would define a number of scenarios. In the base scenario, the evacuation starts at 10:10 am. We allow a 10 minute buffer at the beginning of each simulation to reach steady traffic conditions on the Warburton Highway prior to the evacuation (i.e., the simulation itself begins at 10:00 am). Vehicles from each origin area travel to one of the available destinations: fire refuges, or towards Melbourne. When entering the highway, vehicles merge with the background traffic formed by vehicles travelling towards the Melbourne from other suburbs, and vehicles travelling in the opposite direction.

A number of scenarios have been derived from the base scenario by varying three major variables, as listed in Table 3. The first variable directly follows from the aim of the study, i.e., the number of refuges serving as destinations for the evacuees. One option is to construct a single fire refuge based at a school on Cavanagh Road with the capacity of 500 people. The other option is to establish two refuges: a school on Cavanagh Road and another refuge at a fire station on the southern side of the Warburton Highway.

Table 3: Scenario variables and their values

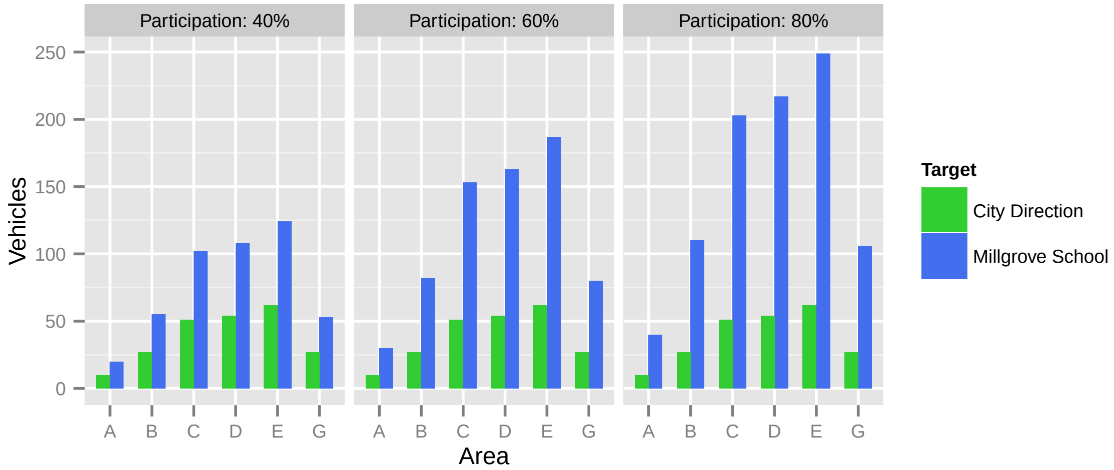
Variable	Set of values
Number of fire refuges	1 refuge, 2 refuges
Refuge participation rate	40%, 60%, 80%
Volume of the highway traffic (cars per hour)	100, 500, 1000

Another variable in defining the scenarios is the percentage of vehicles from the evacuation area that leave to one of the refuge destinations, which is referred to as the refuge participation rate. Three participation rates have been selected to construct scenarios: 40%, 60%, and 80%. The fraction of evacuee vehicles heading towards the city is fixed at 20% for all the scenarios. The scenarios with the 80% refuge participation rate can be considered the worst cases as they assume 100% of people will leave the evacuation area.

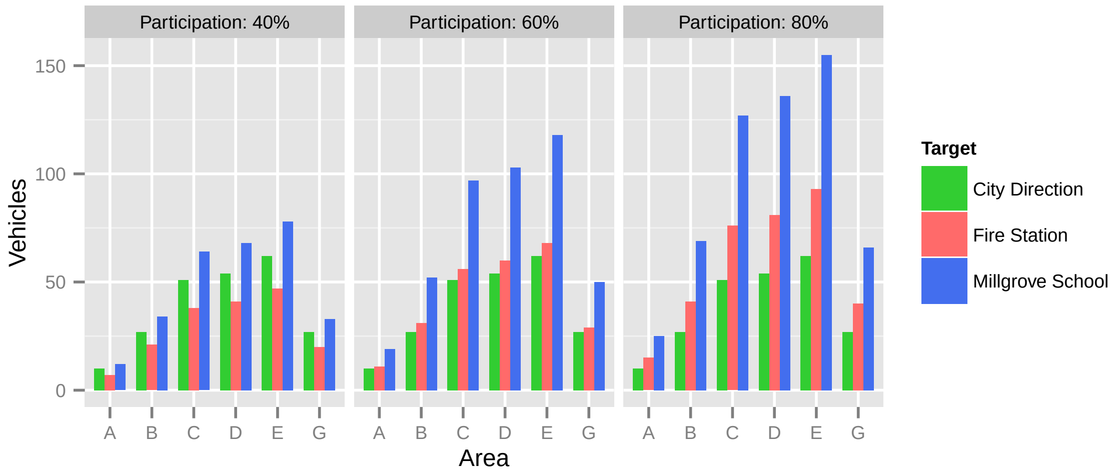
The third variable investigated is the volume of background traffic on the highway, which has been set to 100, 500, and 1000 vehicles per hour. The arrival times of the background traffic vehicles are calculated based on time intervals between vehicle arrivals sampled from an exponential distribution with the specified rate parameter.

All the combinations of the described variable values have been used to construct simulation scenarios giving in a total of 18 scenarios. Using the modelling tools, the input for each scenario has been converted into a trip design for the traffic simulator. A trip design is an input data format required by Megaffic to initiate traffic simulation. The input contains a list of tuples of origin and destination road network nodes, departure time, and the number of vehicles following the trip. According to the received trip design, Megaffic calculates a route for each vehicle based on a given driver or route selection model. In this study, we use the shortest path route selection criterion. Figure 3 shows the vehicle numbers generated based on the trip design per area and destination for the one and two refuge scenarios. In order to provide similar conditions, the total number of vehicles travelling to refuge destinations has been set equal for each participation rate for one and two refuge scenarios. This allowed us to isolate the effect of the addition of a second refuge on the southern side of the Warburton highway.

The output generated by Megaffic contains statistical information for each road segment, such as the average speed or the number of passed cars in a certain time interval. We use the average speed for 10 minute time intervals.



(a) One refuge



(b) Two refuges

Figure 3: Vehicle numbers for both scenarios per area and destination, for each of the three participation levels studied (40%, 60% and 80%).

Assumptions and simplifications

The scenarios presented are not necessarily representative of all possible scenarios and care should be taken when attempting to generalise from any findings. Furthermore, the following assumptions need to be taken into account when interpreting the results:

- Evacuee departure times (also called mobilisation times) follow a Rayleigh distribution with a mode of 30 minutes. This distribution has been found to closely match data provided by subject matter experts (see Tweedie et al.[6]). The Rayleigh cumulative distribution function with a mode of σ can be expressed as:

$$F(t) = 1 - \exp(-t^2/2\sigma^2).$$

- The version of the traffic simulator used in this study incorporates a simplified vehicle interaction model. Specifically, merging of two streams of traffic into one is based on equal priority and vehicles moving along crossed paths are assumed to have no interaction. To mimic the influence of priority, merging and egress factors, we modify the speed limit on certain segments: the bridge immediately before the highway; and segments connecting the highway and outgoing roads.
- To simulate the car parking behaviour, the speed limits on the road segments immediately preceding the refuge destinations have been reduced to 20 km/h.
- Vehicle numbers are derived from residential data. This will tend to over-estimate the number of people in the area, particularly during the day when many people may be away from their homes.
- Route selection is static; drivers do not change their route even when encountering significant delays.

[6]Tweedie, Stephen W., et al. "A methodology for estimating emergency evacuation times," *The Social Science Journal*, Volume 23, Issue 2, Summer 1986, 189-204.

Results

The figures presented in this section have been designed to show the difference between the one and two refuge options under a variety of scenarios. As such, within each figure we always show both options (among other variables) and indicate the one refuge option with a solid line, and the two refuge option with a dashed line. In general, the difference can be seen by comparing two lines of the same colour.

Each figure corresponds to one direction of one road segment. We have focussed on six segments in total (Table 4): five from the Melbourne direction of the Warburton Highway as it passes through Millgrove (labelled H1 through H5 in Figure 1), and one for the bridge connecting properties north of the river to the Warburton Highway (labelled B1 in Figure 1). For each segment we show the direction that will be most significantly affected by a large volume of traffic moving from residences to the refuges. For the Warburton Highway this also shows the traffic moving from Warburton towards Melbourne.

Table 4: Road segment groups and labels

Road segment group	Labels
Melbourne direction of the Warburton Highway	H1, H2, H3, H4 and H5
Bridge from the north Millgrove area to the Warburton Highway	B1

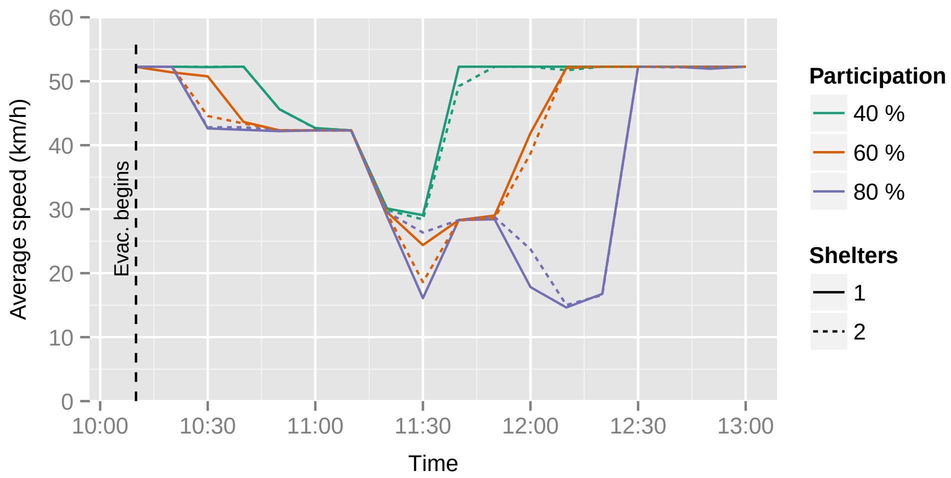
Figures 4-7 all show the average speed of vehicles travelling over the aforementioned segments. These averages are calculated for every 10 minute interval of time, and thus represent a discrete time series. For example, a data point at time 10:30 am represents the average speed of all vehicles travelling along the given segment between 10:20 am and 10:30 am. If no vehicle passes a segment during that interval of time, then no value is plotted (e.g., Figure 5c after 12:10 pm.) These averages are presented with respect to time so that we can see how the average speed of a segment changes over the period of simulation. The figures are broken into those which show variation in participation rate (Figures 4 and 5) and those which show variation in highway traffic volume (Figures 6 and 7).

It is interesting to see that the use of the second refuge (the fire station) does not significantly change the traffic conditions on the Warburton highway when the departure times of all vehicles are distributed. On the highway segments H1 and H2 (Figures 4a, 4b, 6a, and 6b) before and after the intersection with bridge B1 the average speed for the two scenarios (one and two refuges) is almost identical across different highway traffic and participation rates. Although the average speed on road segments H3 and H4 (Figures 4c, 5a, 6c, and 7a) reduces in some cases for two refuges, the difference is only significant for a 60% participation rate and highway traffic with 500 cars/h. On the other hand, Segment H5 (Figures 5b and 7b) shows no difference. Figures 5c and 7c demonstrate that bridge B1 acts as a bottleneck since it is the only direct connecting road to the residential area across the river. The speed drops below 10 km/h for a longer period of time where most cars leave to the refuges. As expected, the duration of the congestion depends primarily on the participation rate (Figure 5c) whereas the congestion on the bridge eases only if traffic on the highway is very low (100 cars/h, Figure 7c).

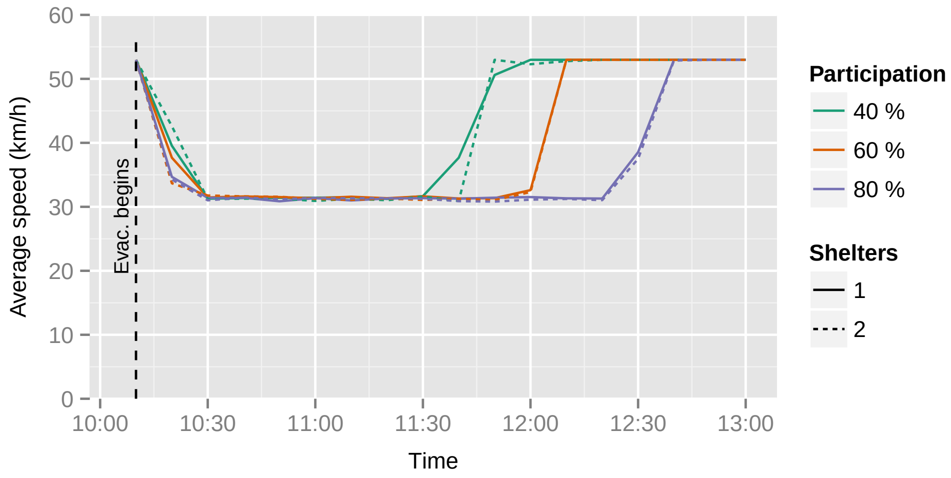
In general, the participation rate of vehicles leaving significantly affects the traffic conditions on and near the bridge B1, especially segments H1 and H2. As shown in Figures 4a and 4b, lower rates reduce the average speed to a shorter period of time. The other segments—H3, H4 and H5—are not significantly affected. Similarly, highway traffic rates mostly affect segments H1 and H2 (Figures 6a and 6b) with a pronounced effect on segment H1 due to the merging traffic from the bridge. Increasing traffic rates lowers the average speed on H1, whereas on H2 lower rates result in an earlier return to a higher average speed.

Tables 5 and 6 show an overview of the minimum and maximum average speed on the studied road segments and variables over all 10 minute time intervals during the simulation. Table 7 provides an overview of the duration the average speed was below a certain threshold on the road segments. We can see that the minimum and maximum speeds on the segments around the bridge are most affected, especially by the rate of highway traffic. Due to the bridge being the only road where traffic flows into the highway it has the lowest maximum speed throughout the simulation. Also, the values in the tables are similar for both refuge scenarios in most cases.

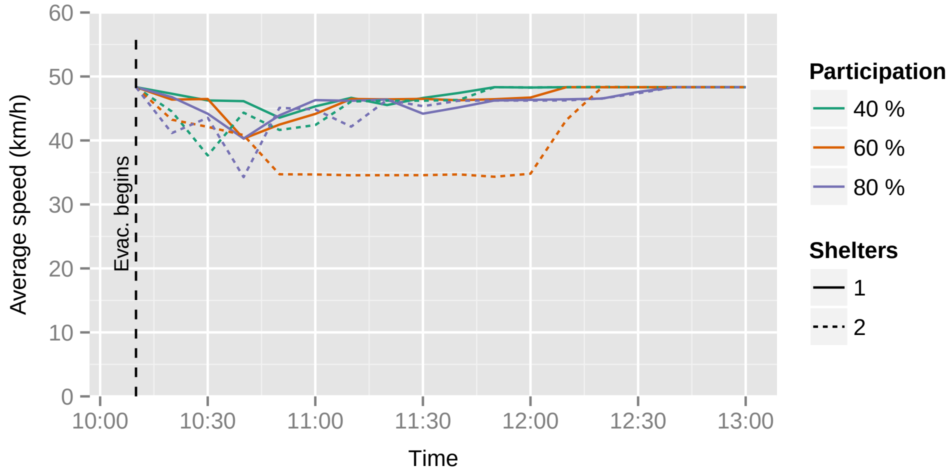
It should be noted that the similarity of the one and two refuge cases were observed when the departure behaviour of all vehicles is distributed over time (in this study we used the Rayleigh distribution with a mode of 30 minutes). Such departure distributions typically represent the evacuation behaviour more realistically. The difference in average speed for one and two refuges may increase, however, when departure times of vehicles are less distributed, or, in the extreme case, are simultaneous. This scenario is presented in the appendix.



(a) Segment H1

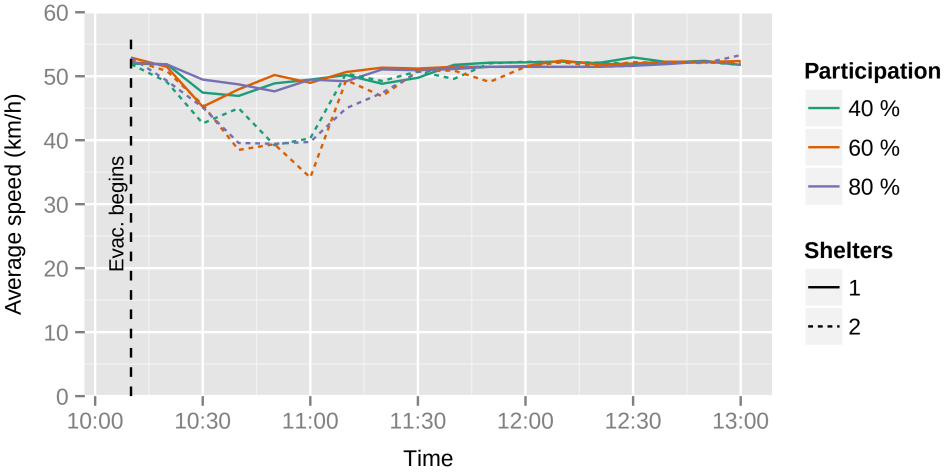


(b) Segment H2

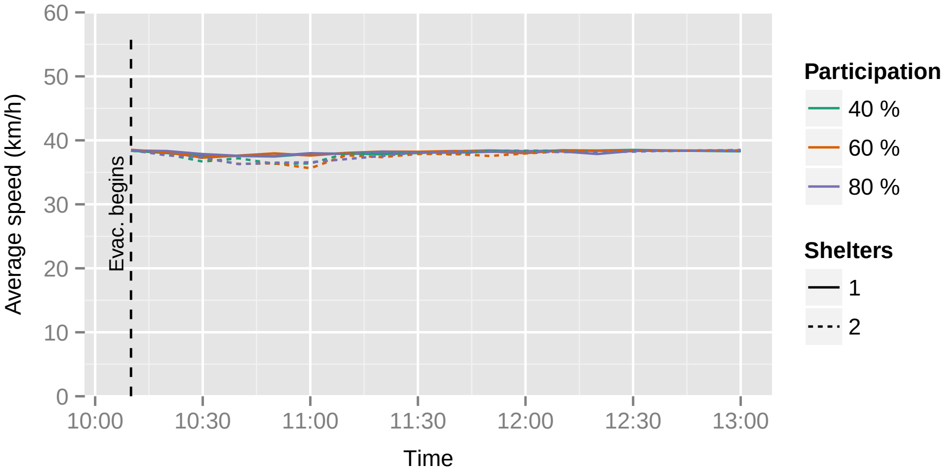


(c) Segment H3

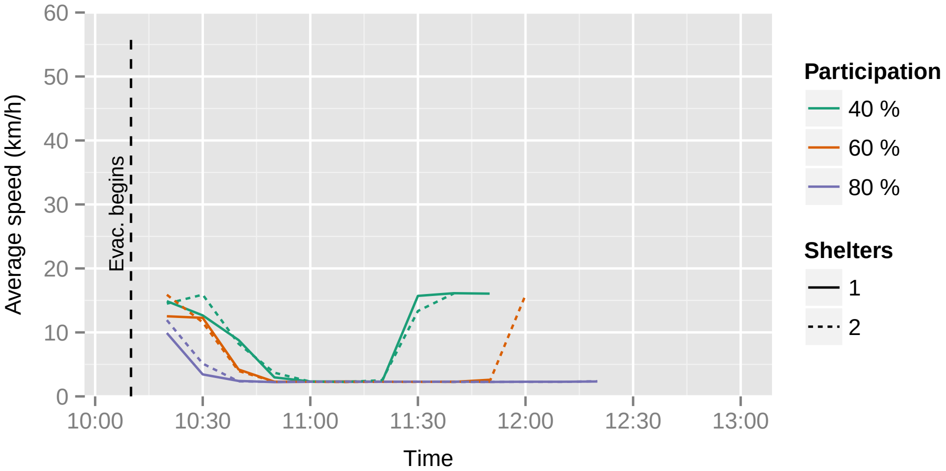
Figure 4: The effect of participation rate (highway rate is fixed at 500 cars per hour, distributed departure times)



(a) Segment H4

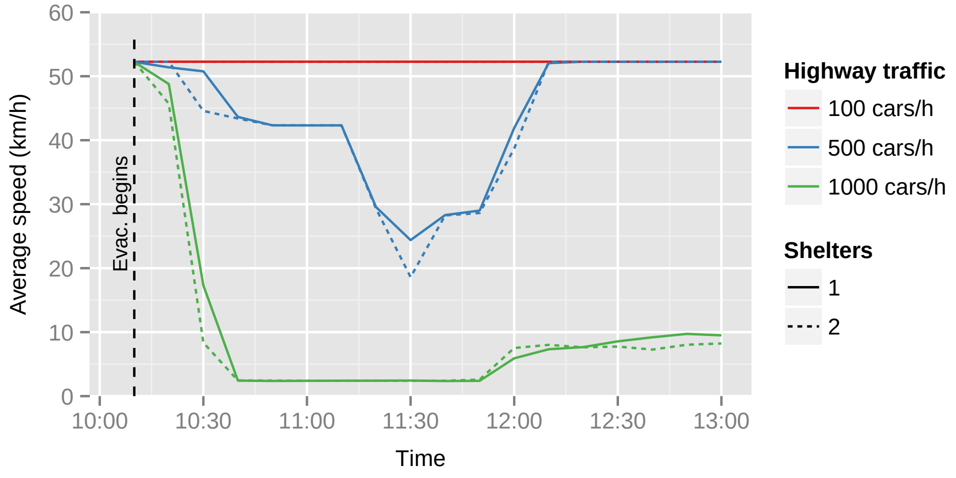


(b) Segment H5

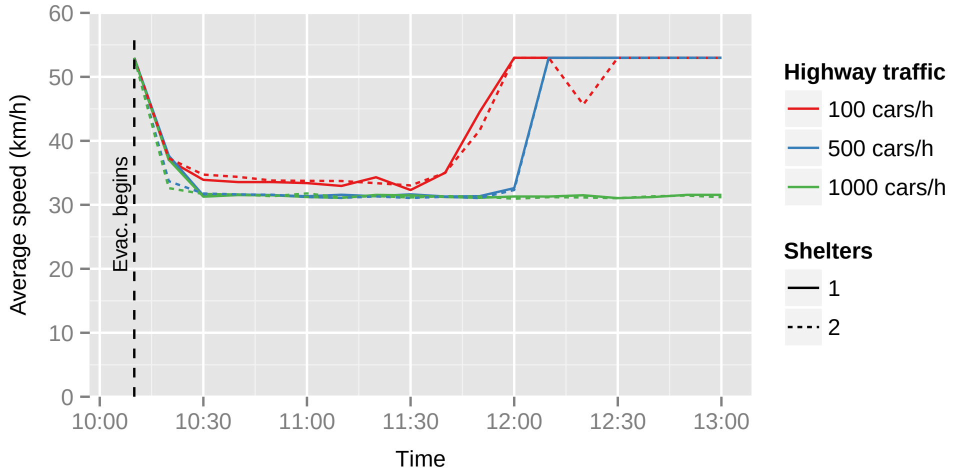


(c) Segment B1

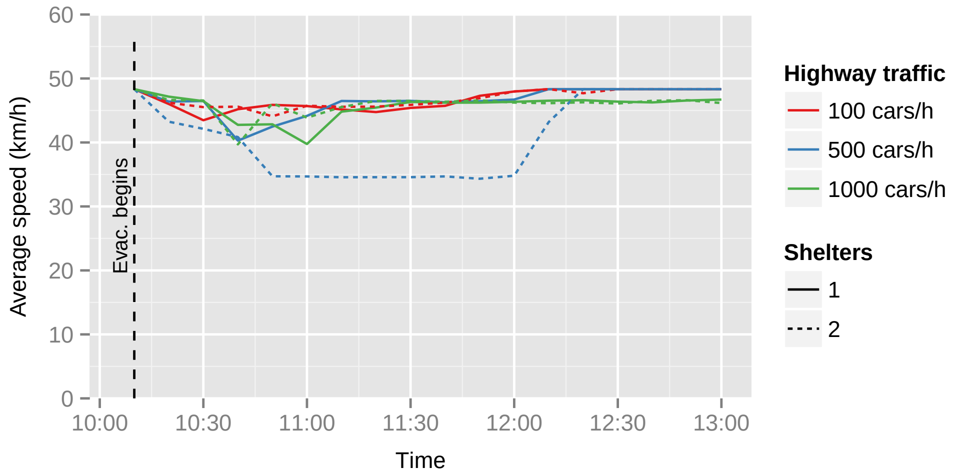
Figure 5: The effect of participation rate (highway rate is fixed at 500 cars per hour, distributed departure times)



(a) Segment H1

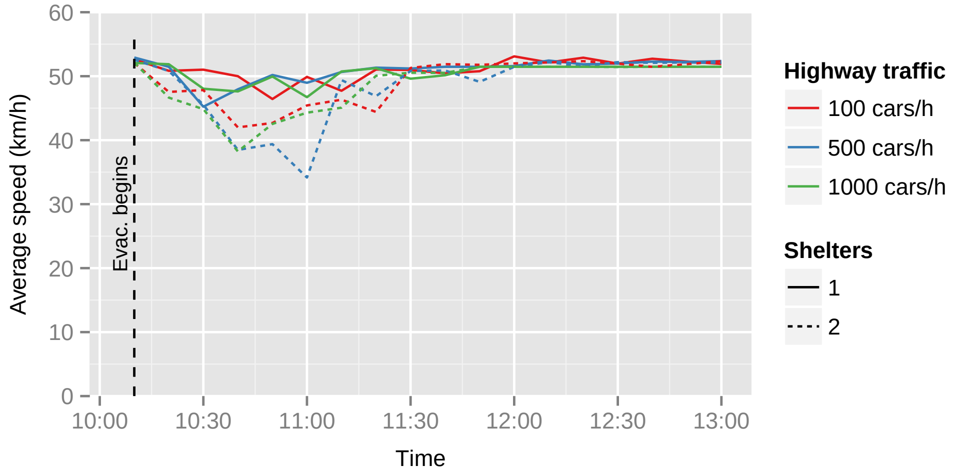


(b) Segment H2

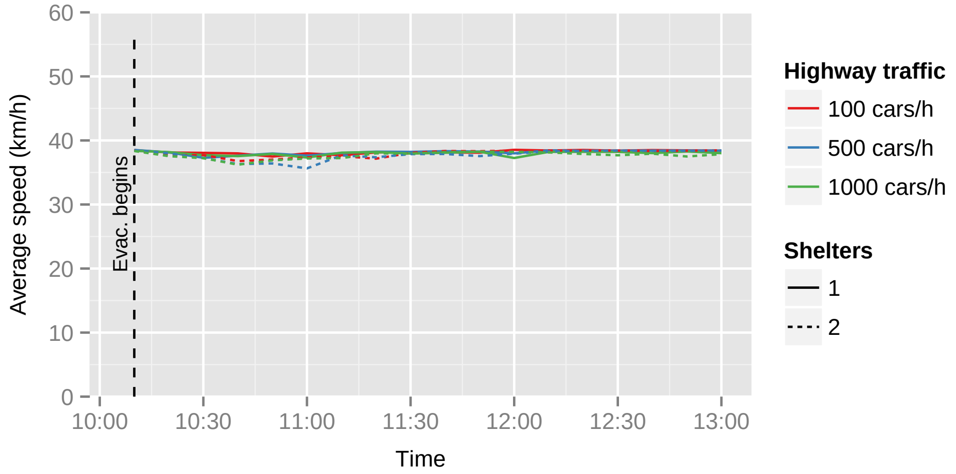


(c) Segment H3

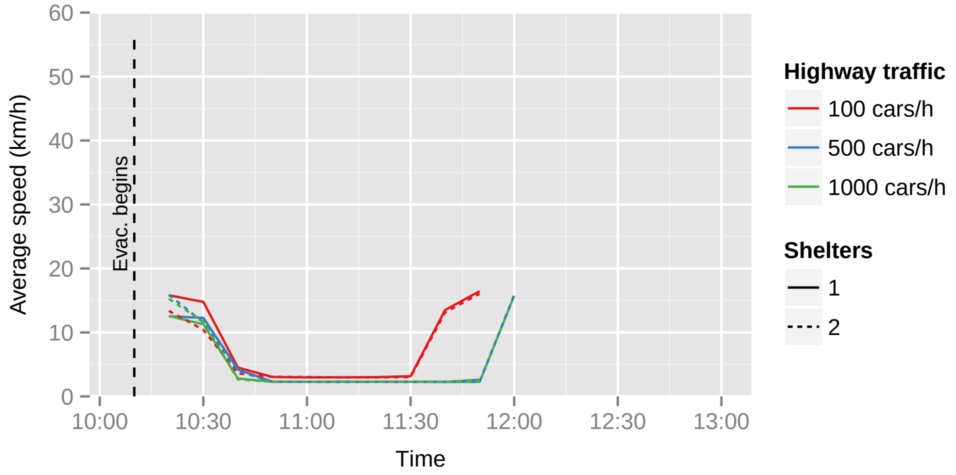
Figure 6: The effect of highway rate (participation rate is fixed at 60%, distributed departure times)



(a) Segment H4



(b) Segment H5



(c) Segment B1

Figure 7: The effect of highway rate (participation rate is fixed at 60%, distributed departure times)

Table 5: Minimum average speed in km/h (1 refuge / 2 refuges)

Hwy traffic (cars/h)	Part. rate (%)	H1	H2	H3	H4	H5	B1
100	40	52.3 / 52.3	33.3 / 33.0	44.9 / 44.8	45.2 / 42.3	37.3 / 36.9	0.0 / 0.0
	60	52.3 / 52.3	32.3 / 33.0	43.5 / 44.1	46.4 / 42.0	37.5 / 36.8	0.0 / 0.0
	80	52.3 / 52.3	33.1 / 29.8	44.6 / 44.4	44.9 / 41.3	37.2 / 36.7	0.0 / 0.0
500	40	29.1 / 28.4	31.2 / 30.9	43.6 / 37.7	46.9 / 39.2	37.5 / 36.3	0.0 / 0.0
	60	24.4 / 18.6	31.3 / 31.1	40.3 / 34.3	45.2 / 34.2	37.3 / 35.6	0.0 / 0.0
	80	14.6 / 15.0	30.9 / 30.8	40.3 / 34.3	47.6 / 39.4	37.6 / 36.3	0.0 / 0.0
1000	40	2.4 / 2.4	30.1 / 30.8	41.4 / 34.7	45.8 / 43.4	37.3 / 36.8	0.0 / 0.0
	60	2.4 / 2.4	31.1 / 30.9	39.8 / 39.7	46.7 / 38.2	37.3 / 36.2	0.0 / 0.0
	80	2.4 / 2.4	30.5 / 30.9	41.9 / 30.1	45.6 / 42.0	37.4 / 36.2	0.0 / 0.0

Table 6: Maximum average speed in km/h (1 refuge / 2 refuges)

Hwy traffic (cars/h)	Part. rate (%)	H1	H2	H3	H4	H5	B1
100	40	52.3 / 52.3	53.0 / 53.0	48.3 / 48.3	52.3 / 53.2	38.4 / 38.5	16.2 / 16.7
	60	52.3 / 52.3	53.0 / 53.0	48.3 / 48.3	53.1 / 52.4	38.5 / 38.5	16.4 / 16.3
	80	52.3 / 52.3	53.0 / 53.0	48.3 / 48.3	53.5 / 53.2	38.6 / 38.5	16.1 / 16.0
500	40	52.3 / 52.3	53.0 / 53.0	48.3 / 48.4	52.9 / 52.2	38.5 / 38.4	16.1 / 16.1
	60	52.3 / 52.3	53.0 / 53.0	48.3 / 48.3	52.9 / 52.6	38.5 / 38.4	12.5 / 15.9
	80	52.3 / 52.3	53.0 / 53.0	48.3 / 48.3	52.3 / 53.3	38.4 / 38.5	9.9 / 11.9
1000	40	52.3 / 51.9	51.9 / 52.9	48.2 / 48.3	52.1 / 52.0	38.4 / 38.3	16.1 / 16.3
	60	52.2 / 52.3	52.9 / 53.0	48.3 / 48.3	52.1 / 52.1	38.4 / 38.4	15.7 / 16.0
	80	52.3 / 51.8	53.0 / 53.0	48.3 / 48.4	52.0 / 52.2	38.4 / 38.4	12.2 / 13.8

Table 7: Duration of decreased speed period in minutes (1 refuge / 2 refuges)

Speed below	Highway traffic (cars/h	Part. rate (%)	H1	H2	H3	H4	H5	B1
< 50 km/h	100	40	0 / 0	120 / 110	180 / 180	60 / 50	180 / 180	180 / 180
		60	0 / 0	100 / 110	180 / 180	30 / 70	180 / 180	180 / 180
		80	0 / 0	130 / 110	180 / 180	20 / 60	180 / 180	180 / 180
	500	40	50 / 60	90 / 90	180 / 180	60 / 70	180 / 180	180 / 180
		60	90 / 100	110 / 110	180 / 180	30 / 70	180 / 180	180 / 180
		80	120 / 120	140 / 140	180 / 180	50 / 70	180 / 180	180 / 180
	1000	40	170 / 170	170 / 170	180 / 180	50 / 70	180 / 180	180 / 180
		60	170 / 170	170 / 170	180 / 180	50 / 60	180 / 180	180 / 180
		80	170 / 170	170 / 170	180 / 180	40 / 160	180 / 180	180 / 180
< 30 km/h	100	40	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
		60	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
		80	0 / 0	0 / 10	0 / 0	0 / 0	0 / 0	180 / 180
	500	40	10 / 20	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
		60	40 / 40	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
		80	70 / 70	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
	1000	40	160 / 160	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
		60	160 / 160	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
		80	160 / 160	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
< 20 km/h	100	40	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
		60	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
		80	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
	500	40	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
		60	0 / 10	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
		80	40 / 20	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
	1000	40	150 / 160	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
		60	160 / 160	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
		80	160 / 160	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180

Summary

Figure 8 summarises the difference between the one and two refuge options in terms of the average speed over the whole simulation. Positive values indicate the one refuge option produced, on average, better traffic flow.

Based on the results presented here, we make the following observations:

- There is not a major difference between traffic conditions between the one and two refuge options in most situations.
- The bottleneck at the bridge reduces the influence of departure behaviour.

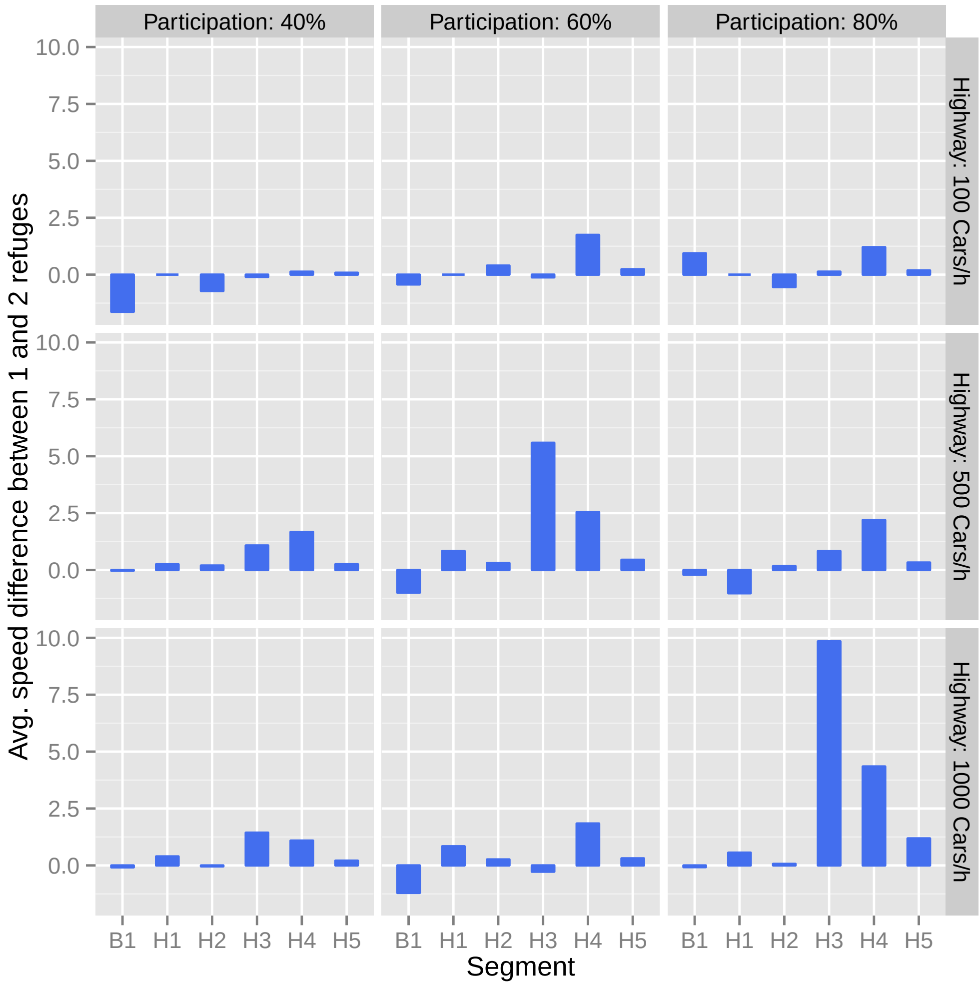


Figure 8: The average speed difference between one and two refuges for each of the variables being studied. Positive values indicate that the average speed for the one refuge option was greater than for the two refuge option.

Appendix

The remaining pages present the results for the scenarios in which all vehicles depart their homes at the same time. In this set of scenarios the difference between the one or two refuges is more pronounced for higher participation and highway traffic rates on the highway segments *after* the bridge, especially H2 and H3 (Figures 11b, 11c, 9b, and 9c). The observed average speed was lower in most of these cases for the two refuge scenario. Similar to the previous case with distributed departures the bridge B1 acts as a bottleneck causing prolonged congestion times. As a result, the average speed on bridge B1 is very low for a longer time period than in the previous case, and recovers only once the area above the river is cleared (Figures 10c and 12c).

As in the scenario with distributed departures the highway segments H1 to H3 are most affected during the evacuation, and the strongest change in average speed could be observed at different rates of highway traffic. As most of the traffic caused by the simultaneous evacuation flows into the highway, at least on segment H2, the participation rate also strongly influences the highway traffic conditions, but to a lesser degree than the traffic on the highway itself. The minimum and maximum average speed in Tables 8 and 9 as well as the duration for various speed thresholds in Table 10) further demonstrates this finding.

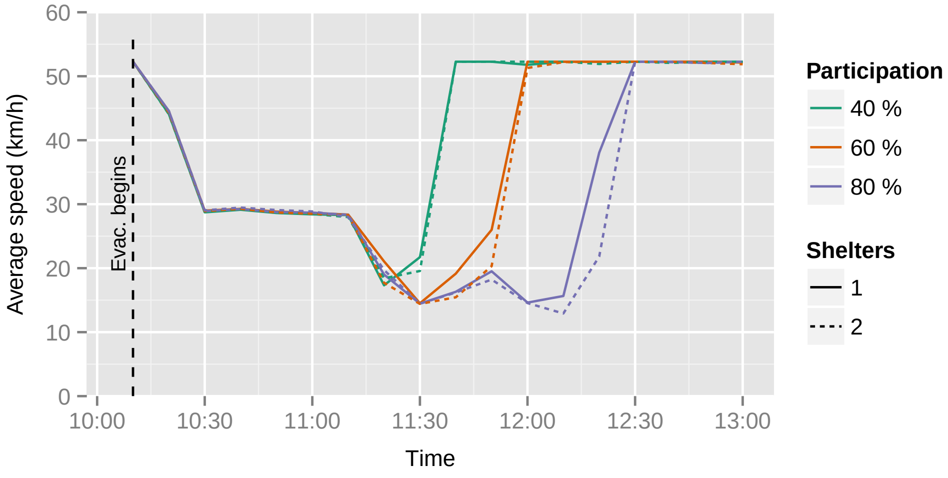
It should be noted that although there is a significant difference between the two refuge scenarios for larger highway traffic and participation rates (Figure 13) the simultaneous departure of all vehicles is very unrealistic. This is even more so for a higher participation rate. Lower participation and highway traffic rates as well as distributed departure behaviour show no significant difference in traffic conditions for one or two refuges.

Table 8: Minimum average speed in km/h (1 refuge / 2 refuges) for simultaneous departure

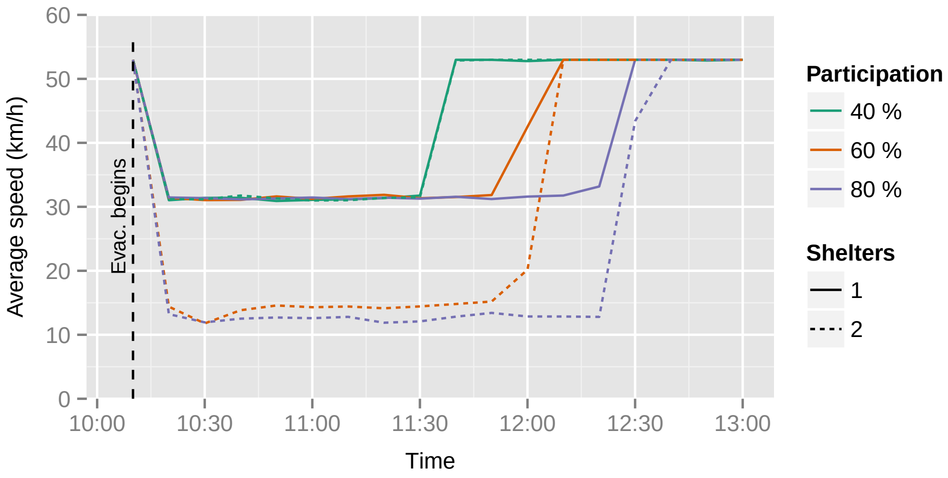
Hwy traffic (cars/h)	Part. rate (%)	H1	H2	H3	H4	H5	B1
100	40	52.3 / 52.3	33.1 / 31.7	45.5 / 44.1	36.4 / 27.9	36.1 / 34.8	0.0 / 0.0
	60	52.3 / 52.3	32.6 / 32.7	43.1 / 37.3	37.1 / 26.5	36.2 / 34.6	0.0 / 0.0
	80	52.3 / 52.3	32.7 / 32.8	43.6 / 34.5	40.0 / 25.4	36.5 / 34.4	0.0 / 0.0
500	40	17.3 / 18.4	30.9 / 31.0	34.5 / 34.6	34.7 / 25.1	35.7 / 34.3	0.0 / 0.0
	60	14.5 / 14.4	31.1 / 11.8	26.8 / 29.2	35.4 / 25.1	35.6 / 34.4	0.0 / 0.0
	80	14.4 / 12.9	31.2 / 11.9	43.0 / 28.7	33.7 / 24.9	35.7 / 34.3	0.0 / 0.0
1000	40	2.4 / 2.4	31.0 / 29.0	34.4 / 28.4	29.0 / 25.2	34.9 / 34.4	0.0 / 0.0
	60	2.4 / 2.4	27.6 / 12.2	35.1 / 28.8	30.2 / 25.0	34.9 / 34.3	0.0 / 0.0
	80	2.4 / 2.3	30.4 / 11.9	33.7 / 21.3	30.0 / 25.0	35.1 / 34.4	0.0 / 0.0

Table 9: Maximum average speed in km/h (1 refuge / 2 refuges) for simultaneous departure

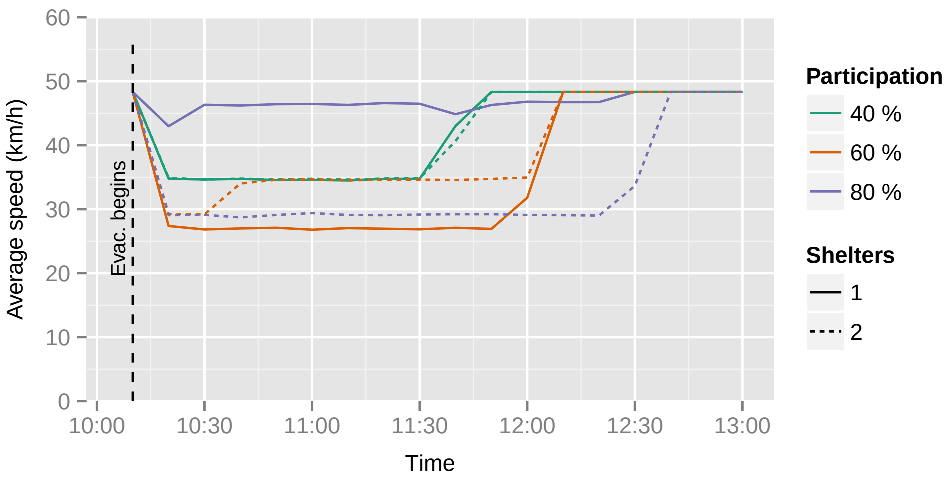
Hwy traffic (cars/h)	Part. rate (%)	H1	H2	H3	H4	H5	B1
100	40	52.3 / 52.3	53.0 / 53.0	48.3 / 48.3	53.2 / 52.9	38.5 / 38.5	4.2 / 4.3
	60	52.3 / 52.3	53.0 / 53.0	48.3 / 48.3	53.2 / 52.4	38.5 / 38.5	4.4 / 4.2
	80	52.3 / 52.3	53.0 / 53.0	48.3 / 48.3	53.2 / 52.9	38.5 / 38.5	4.3 / 4.4
500	40	52.3 / 52.3	53.0 / 53.0	48.3 / 48.3	52.7 / 52.7	38.5 / 38.5	4.1 / 4.1
	60	52.3 / 52.3	53.0 / 53.0	48.3 / 48.4	52.5 / 52.3	38.5 / 38.4	4.1 / 4.0
	80	52.3 / 52.3	53.0 / 53.0	48.3 / 48.4	52.7 / 53.3	38.5 / 38.5	4.2 / 4.2
1000	40	52.3 / 52.3	53.0 / 53.0	48.3 / 48.3	52.2 / 52.0	38.4 / 38.4	3.6 / 3.7
	60	52.3 / 52.2	53.0 / 53.0	48.3 / 48.4	52.2 / 52.8	38.4 / 38.5	3.7 / 3.7
	80	52.3 / 51.8	53.0 / 53.0	48.3 / 48.3	52.5 / 51.9	38.4 / 38.4	3.8 / 3.7



(a) Segment H1

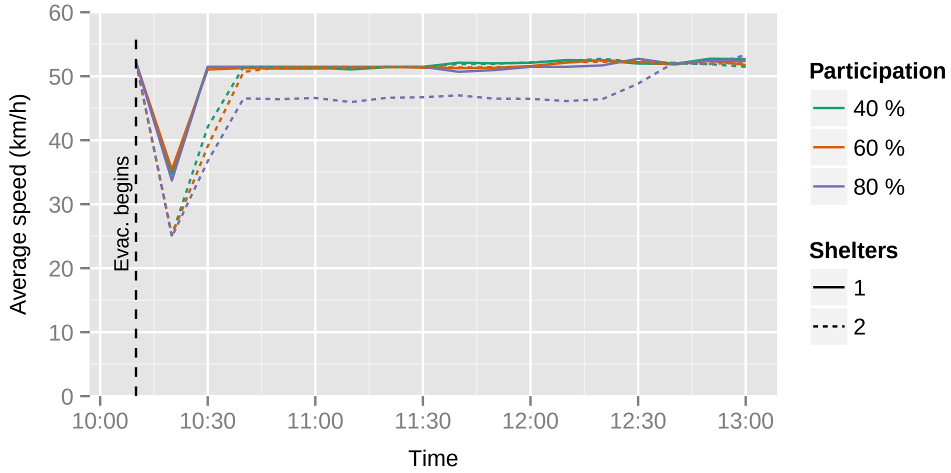


(b) Segment H2

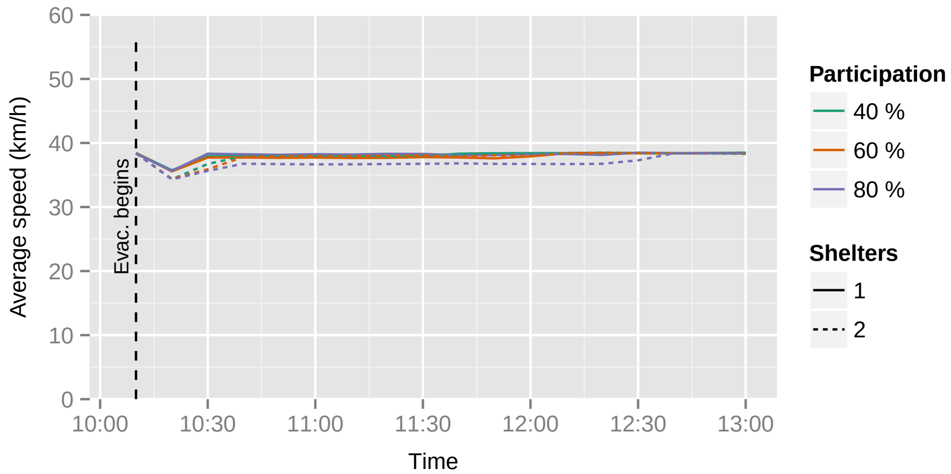


(c) Segment H3

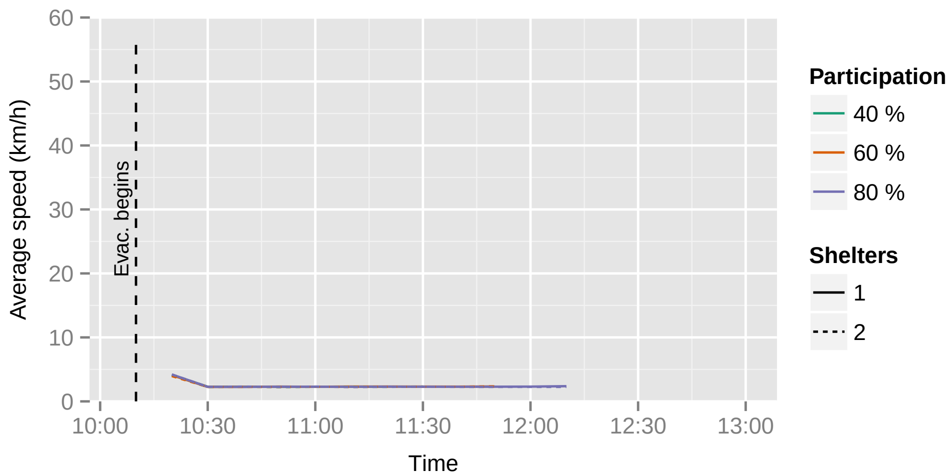
Figure 9: The effect of participation rate (highway rate is fixed at 500 cars per hour)



(a) Segment H4

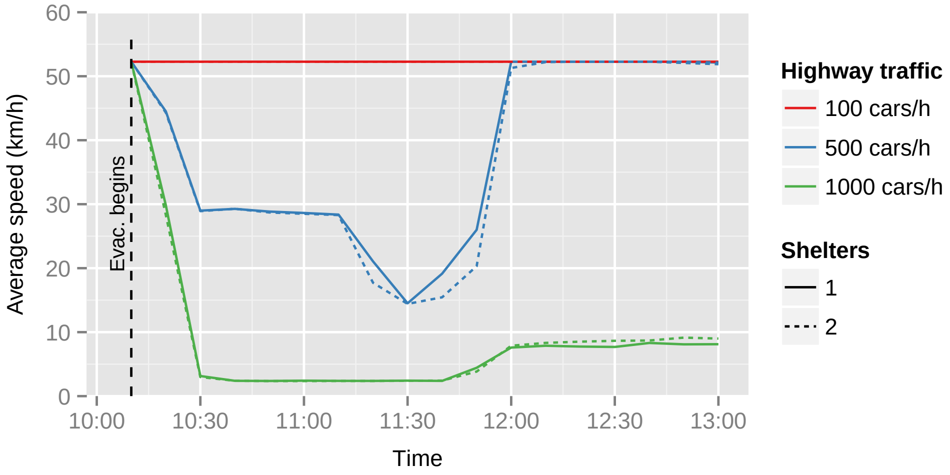


(b) Segment H5

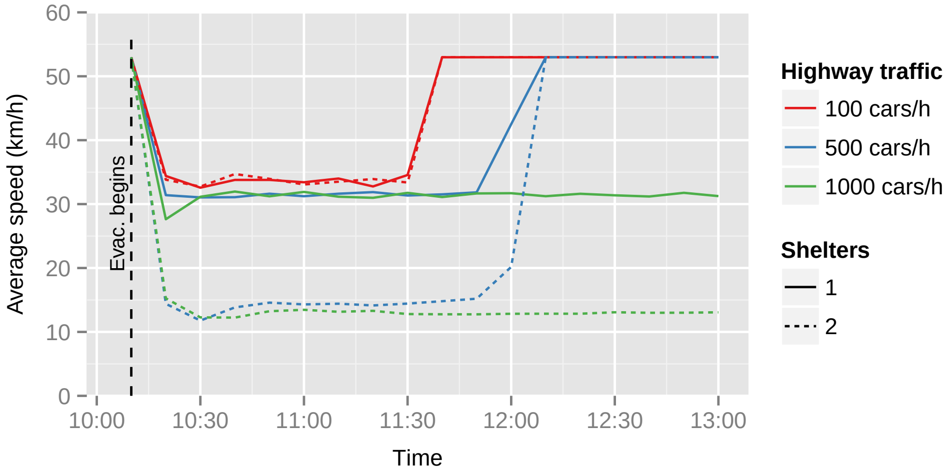


(c) Segment B1

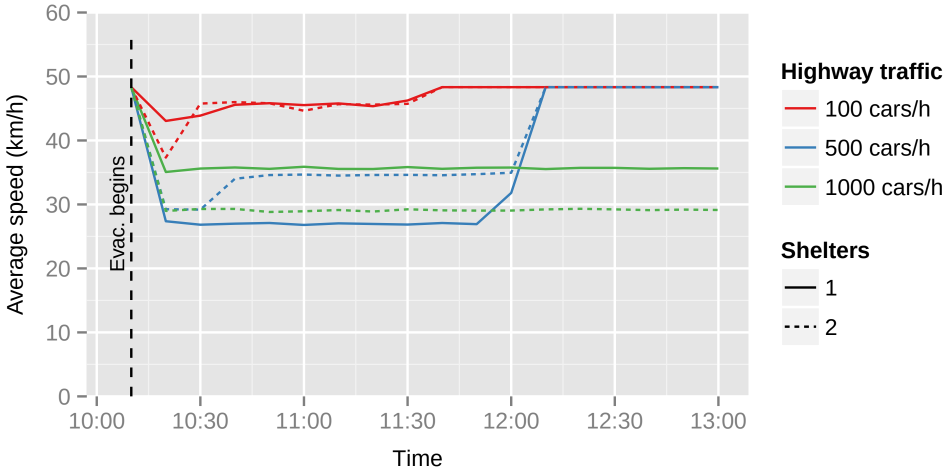
Figure 10: The effect of participation rate (highway rate is fixed at 500 cars per hour)



(a) Segment H1

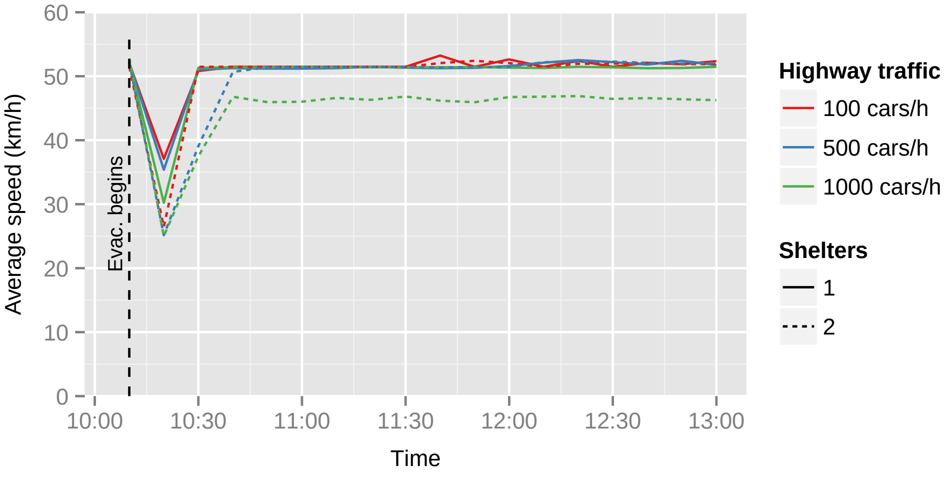


(b) Segment H2

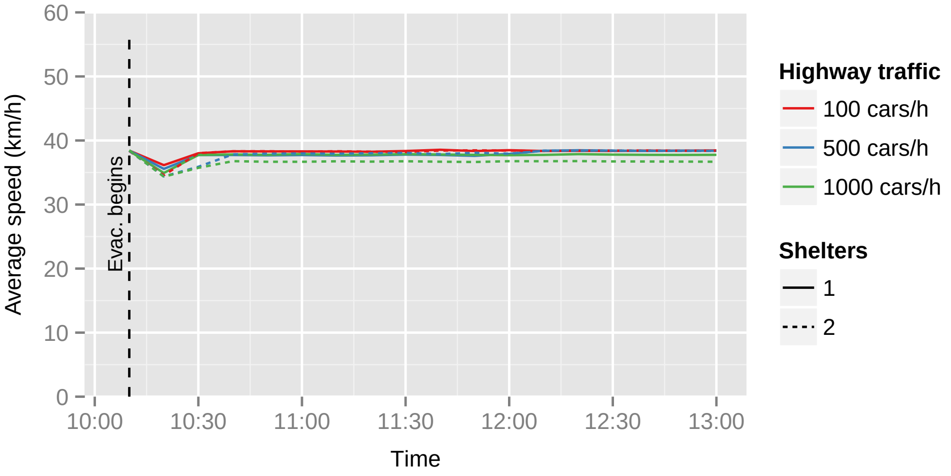


(c) Segment H3

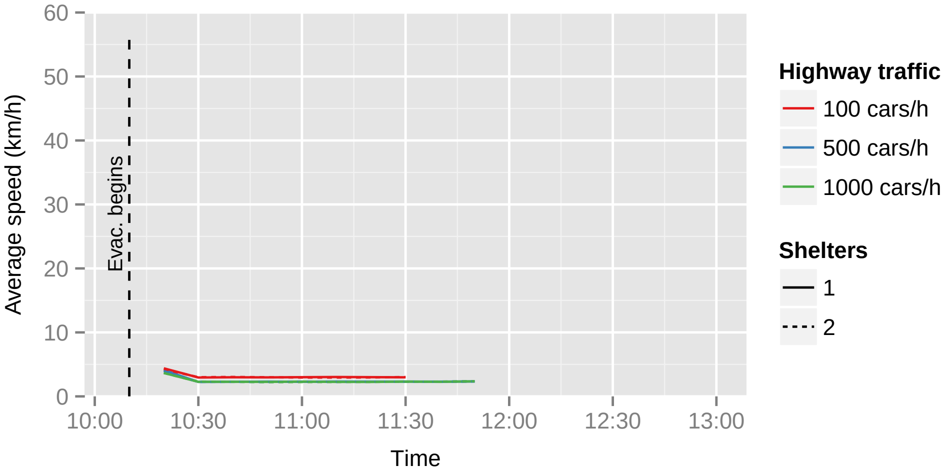
Figure 11: The effect of highway rate (participation rate is fixed at 60%)



(a) Segment H4



(b) Segment H5



(c) Segment B1

Figure 12: The effect of highway rate (participation rate is fixed at 60%)

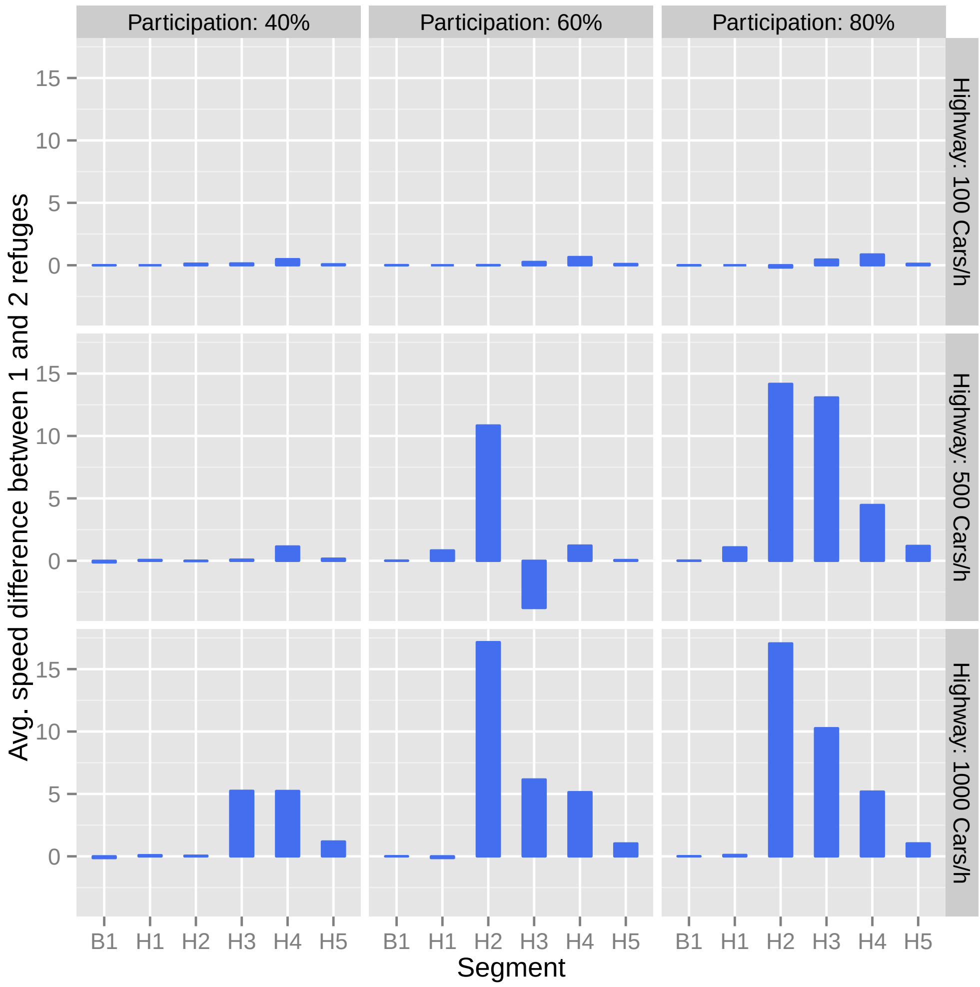


Figure 13: Average speed difference between one and two refuges for each of the studied variables in the case of simultaneous departure times of vehicles (Positive values indicate that the average speed for the one refuge option was greater than for the two refuge option).

Table 10: Duration of decreased speed period in minutes (1 refuge / 2 refuges) for simultaneous departure

Speed below	Highway traffic (cars/h	Part. rate (%)	H1	H2	H3	H4	H5	B1
< 50 km/h	100	40	0 / 0	60 / 60	180 / 180	10 / 10	180 / 180	180 / 180
		60	0 / 0	80 / 80	180 / 180	10 / 10	180 / 180	180 / 180
		80	0 / 0	100 / 100	180 / 180	10 / 10	180 / 180	180 / 180
	500	40	80 / 80	80 / 80	180 / 180	10 / 20	180 / 180	180 / 180
		60	100 / 100	110 / 110	180 / 180	10 / 20	180 / 180	180 / 180
		80	130 / 130	130 / 140	180 / 180	10 / 140	180 / 180	180 / 180
	1000	40	170 / 170	170 / 170	180 / 180	10 / 170	180 / 180	180 / 180
		60	170 / 170	170 / 170	180 / 180	10 / 170	180 / 180	180 / 180
		80	170 / 170	170 / 170	180 / 180	10 / 170	180 / 180	180 / 180
< 30 km/h	100	40	0 / 0	0 / 0	0 / 0	0 / 10	0 / 0	180 / 180
		60	0 / 0	0 / 0	0 / 0	0 / 10	0 / 0	180 / 180
		80	0 / 0	0 / 0	0 / 0	0 / 10	0 / 0	180 / 180
	500	40	70 / 70	0 / 0	0 / 0	0 / 10	0 / 0	180 / 180
		60	90 / 90	0 / 110	100 / 20	0 / 10	0 / 0	180 / 180
		80	110 / 120	0 / 130	0 / 130	0 / 10	0 / 0	180 / 180
	1000	40	160 / 170	0 / 10	0 / 170	10 / 10	0 / 0	180 / 180
		60	170 / 170	10 / 170	0 / 170	0 / 10	0 / 0	180 / 180
		80	170 / 170	0 / 170	0 / 170	10 / 10	0 / 0	180 / 180
< 20 km/h	100	40	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
		60	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
		80	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
	500	40	10 / 20	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
		60	20 / 30	0 / 100	0 / 0	0 / 0	0 / 0	180 / 180
		80	60 / 60	0 / 130	0 / 0	0 / 0	0 / 0	180 / 180
	1000	40	160 / 160	0 / 0	0 / 0	0 / 0	0 / 0	180 / 180
		60	160 / 160	0 / 170	0 / 0	0 / 0	0 / 0	180 / 180
		80	160 / 160	0 / 170	0 / 0	0 / 0	0 / 0	180 / 180