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Research paper

Various scenarios prediction of Contraflow operation under heterogeneous traffic condition by using VISSIM microscopic simulation

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Abstract

Prior studies showed that most evacuation contraflow designs have never been implemented. As a result, the effectiveness of these contraflow designs remains unknown. In this paper, VISSIM simulation has been used to achieve the possibility for predicting various scenarios at Kajang-Cheras highway contralane by using dynamic assignment model in order to establish best contraflow alternative path design operation. Method of Effectiveness (MOE) for dynamic assignment model (travel time, queue length, vehicles speed, delay time, fuel consumption, and CO emission) parameters has been analyzed first to assess the performance level of Contraflow operation. Seven alternative paths for the same contralane have been considered to achieve less travel time and queue length hence the reduction of fuel consumption and CO emissions that related to long queue length. Connector's number 2 and 5 indicate the best alternative paths with the presence of the original connector (number 1) since contralane user realize that there are multi connectors to contralane ahead. Contraflow lane problems remain challenging for optimizing the best evacuation design system since the heterogeneous characteristics and no lane discipline domain on this highway at peak-hour. However, Contraflow freeway evacuation plan has been shown to be a successful remedy method to rapidly and efficiently move large numbers of vehicles during emergency situations.

Keywords: *Contraflow operation; heterogeneous traffic; no lane discipline; VISSIM; microscopic simulation*

1. Introduction

Simulation of traffic as a tool for investigating traffic systems has increased in popularity over the last decades. A large portion of this rise in popularity can be tracked back to the rapid development in the personal computer area. Fast personal computers have made it possible to develop advanced traffic micro-simulation software packages [1-2]. Efficient modeling of vehicular traffic remains a largely debated issue especially in context of Indian heterogeneous driving conditions. VISSIM is microscopic traffic simulation software that is gaining increasing recognition [3-4]. Traffic in developing countries such as India, Taiwan, and Vietnam is heterogeneous in nature. Heterogeneous traffic is characterized by a wide mix of vehicles having diverse static and dynamic characteristics. The mix consists of both motorized and non-motorized vehicles whose composition varies. Another feature of this traffic is the absence of lane marking and lane discipline. The lane widths are also not constant. Analytical modeling of such traffic is in nascent stage. Micro-simulation is favored to study and model heterogeneous traffic [5]. Microscopic simulations are widely used in transportation operations and management analysis because "simulation is safer, less expensive and faster that field implementation and testing" [5-6].

The highest fuel consumption on urban arterials is associated with driving in congested traffic, characterized by higher speed fluctuations and frequent stops at intersections. However, low traffic and continuous progression along streets do not guarantee the lowest fuel consumption and emissions. Excessive speeding, which may occur on roads with low traffic, may cause increased emissions for several pollutants. The best flow of traffic on arterial streets, in terms of fuel consumption and emissions, is the one with the fewest stops, shortest delays, and moderate speeds maintained throughout the commute [7]. However, congested traffic was simulated by macroscopic and analytical tools, and individual driving behavior was not considered.

Similarly, the relationship between traffic activity, fuel consumption, and vehicular emissions, which was applied to all vehicles, was a simplistic and linear relationship [8].

Contraflow operation on roadways is not a new concept. Reverse lane operation has been used to effectively accommodate routine unbalanced flow for decades. Contraflow operation is common on bridges where one or more outbound lanes are used for inbound commuters during the morning rush hour and one or more inbound lanes are used for outbound traffic during the evening peak period [9-11]. There are several different contraflow lane reversal configurations. For instance, assume a four-lane roadway where there are two inbound lanes and two outbound lanes as shown in Figure 1. Figure 1(a) illustrates the roadway under normal operation. Figure 1(b) shows all inbound lanes reversed to outbound lanes resulting in four outbound lanes for evacuees to utilize. Figure 1(c) shows one inbound lane reversed to an outbound lane. Therefore, there are three outbound lanes that can be utilized by evacuees, and the inbound lane will be maintained for northbound traffic. Typically, under voluntary evacuation, emergency service vehicles and people who want to move against the evacuating

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traffic use the single inbound lane. This type of reverse lane increases the potential of accidents. However, under mandatory evacuation, the single inbound lane is used only by emergency service vehicles. Figure 1(d) shows one inbound lane reversed with the shoulder used as additional outbound lane capacity for evacuees. The most common lane reversal configuration is when all inbound lanes are reversed to the outbound direction, since it is the most one increases the capacity [3,12-13].

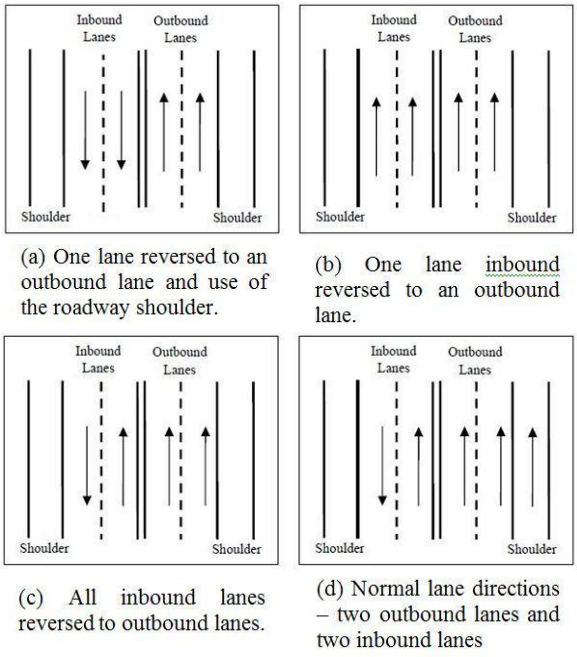


Fig. 1: Various types of contraflow lane roadway configurations

2. Research Methods

VISSIM 9 simulation model has been selected to predict the possibilities of multi-contraflow routs by using dynamic assignment approach for the local traffic conditions of Cheras-Kajang Highway contraflow segments which held in morning working days between (6:30am–8:30am) and evening working days (4:30pm-7:30pm). The methodology process that employed in this study commences with the adaptation of VISSIM model for the traffic data collection and road design of the selected site. Then, static and dynamic routs assignments have been applied to run the simulation. Calibration attempts will be done until best validation result will be reached. Finally, achieving various scenarios prediction results for the selected site. Figure 2 represents the flow chart for research methodology.

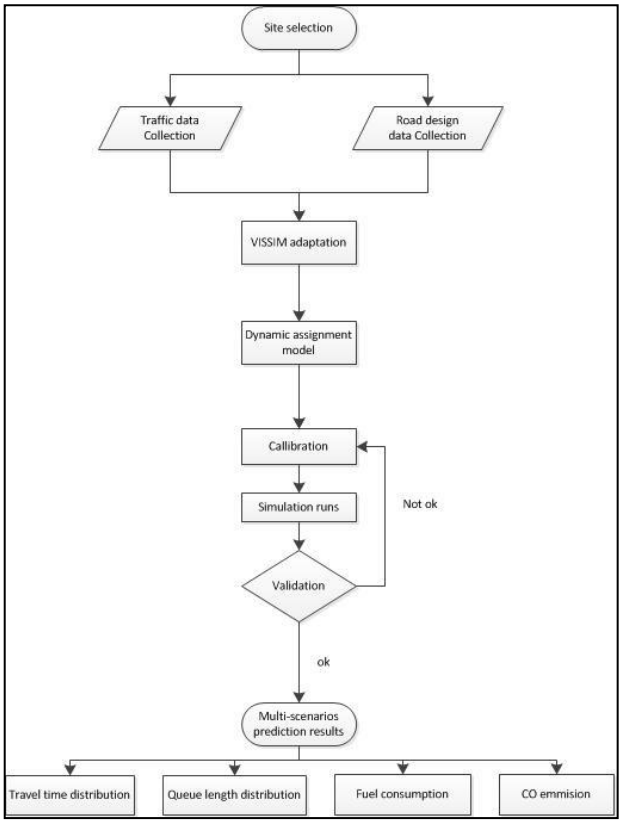


Fig. 2: Flow chart for research methodology

2.1. Site Selection

An expressway segment in Cheras-Kajang highway was chosen for the test site. The site presented in Figure 3, is 6.5 km long contralane which starts at 3°04'32.0"N 101°45'23.9"E and ends at 3°06'54.2"N 101°43'34.0"E in morning rush-hours. The contraflow operation works vice versa in evening rush-hours. There are 4 on-ramps mainstream and 5 off-ramps mainstream beside the contraflow segment. The site was also chosen because of the congested traffic in rush-hours in spite of the efficiency of contraflow operation. Traffic and geometric data have been collected from the field with the help of The Malaysian Institute of Road Safety Research (MIROS) has been used as an input data for the dynamic assignment model.

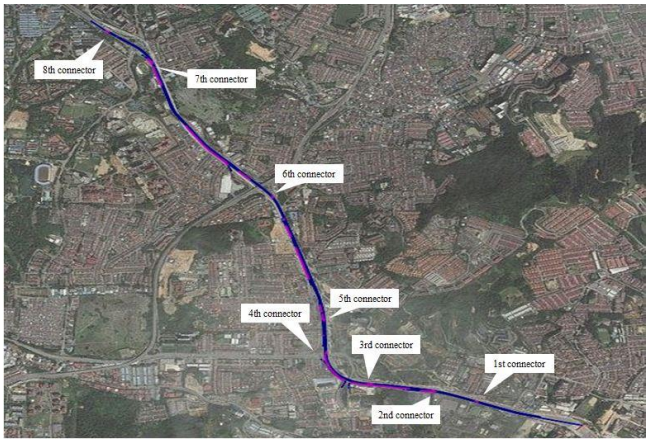


Fig. 3: 6.5 km stretch of Cheras-Kajang highway contralane segment and its paths as simulated in VISSIM

2.2. VISSIM 9 Adaptation

The simulation model used in this research was VISSIM (9). VISSIM is a microscopic, time step, and behavior-based simulation model. The model was developed at the University of Karlsruhe, Germany.

Essential to the accuracy of a traffic simulation model is the quality of the actual modeling of vehicles or the methodology of moving vehicles through the network. VISSIM uses the dynamic assignment model by using the traffic assignment as given traffic demand distribution among various paths in the network, 200 to 400 metres is the distance between each predicted connectors. Traffic assignment is one of the basic tasks in the transport planning process. It is essentially a path selection model of the transport users, for example drivers [14]. The basic concept of this model is by determining a set of possible paths. These alternatives paths must be assessed appropriately. A representation follows on how the drivers decide on the basis of this assessment. These paths selection decision model is a special case of the general problem of decision based on discrete alternatives (discrete choice). Figure 4 shows a sketch of possible paths to the selected network.

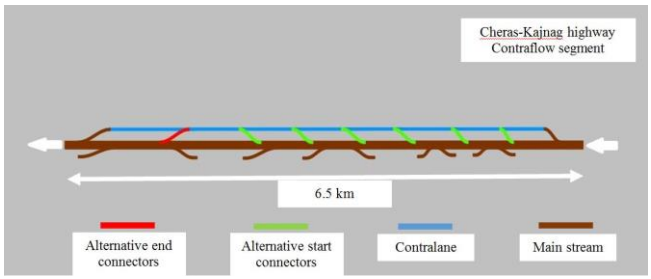


Fig. 4: Possible paths sketch for Cheras-Kajang highway contraflow segment

2.3. Dynamic Assignment

The dynamic assignment procedure in VISSIM is based on the idea of iterated simulation (ten iterations in current research). That means a modeled network is simulated not only once but repetitively and the drivers choose their routes through the network based on the travel cost they have experienced during the preceding simulations. Formally speaking the process aims at computing dynamic stochastic user equilibrium.

Travel demand for dynamic assignment is specified by an origin–destination matrix. To define travel demand using a origin–destination matrix, the area to be simulated is divided in sub-areas called zones and the matrix contains the number of trips that are made from all zones to all zones for a given time interval. To model the points where the vehicles actually appears or leaves the road network, a network element parking lot is used. A parking lot belongs to a certain zone, i.e., trips originating from this zone or ending in this zone can start or end at this parking lot. A zone can have more than one parking lot. The total originating traffic of a zone is distributed to its parking lots according to relative flows. One parking lot can belong to one zone only.

During a simulation, travel times are measured for each zone in the abstract assignment network. All vehicles that leave the zone report the time they have spent on the edge. All travel times during one evaluation interval are averaged and thus form the resulting travel time for that zone. Travel times per edge measured during a time interval for each iteration are exponentially smoothed before they are used in the route choice decision:

$$T_a^{n,k} = (1-\alpha).T_a^{n-1,k} + \alpha.TO_a^{n,k} \quad (1)$$

Where:

k = index of the evaluation interval within the simulation period

n = index of the assignment iteration

a = index of the edge

$TO_a^{n,k}$ = measured travel time on edge a for period k in iteration n

$T_a^{n,k}$ = expected travel time on edge a for period k in iteration n

α = smoothing factor

Since in the first iteration no travel time information from preceding simulation runs is available, the cost is evaluated by replacing the travel time with the distance. Thus for the initial route search also link/connector costs are taken into account. For every subsequent iteration the edges in the network that have not been travelled by any vehicle have a default travel time of only 0.1 s, so that it attracts the route search to build routes including unused edges. This may lead to useless routes in the route collection. A route is considered useless if it is an obvious detour, and an obvious detour is defined as a route that can be generated out of another known route by replacing a sequence of links by a much longer sequence (in terms of distance). How much longer the replacing link sequence must be to qualify as a detour can be defined by the user.

2.4. Calibration and Validation

In the 15 years of VISSIM's existence lot of calibration efforts have been undertaken to adjust the parameters of the behaviour models to the observed driving behaviour in different countries in the world. Since microscopic trajectory data is difficult to get, most of these efforts used macroscopic data provided by standard cross-sectional measurement, typically being volume and speed information in short time intervals. Table 1 presents the traffic data collection for Cheras-Kajang highway contraflow segment for 15 minutes time interval for the whole morning rush-hours (7:00-9:00AM). In this study calibration was based on time profiles of speed-density relationship on a scatter plot for field-simulation pairs (Figure 5). This diagram is very useful for validation because it contains information about a broad range of traffic situations.

Time Interval	Outer lane (veh/15min/ln)				Middle lane (veh/15min/ln)				Inner lane (veh/15min/ln)				Contra lane (veh/15min/ln)			
	MC*	LV*	HV*	Total	MC*	LV*	HV*	Total	MC*	LV*	HV*	Total	MC*	LV*	HV*	Total
7:00 - 7:15	70	80	36	186	23	236	48	307	10	266	5	281	3	88	4	95
7:15 - 7:30	92	121	26	239	50	259	31	340	28	290	4	322	0	180	3	183
7:30 - 7:45	100	125	29	254	76	296	44	416	62	326	9	397	4	230	16	250
7:45 - 8:00	175	138	17	330	137	294	24	455	93	323	6	422	2	310	9	321
8:00 - 8:15	157	178	25	360	134	344	24	502	102	356	9	467	7	372	15	394
8:15 - 8:30	135	136	28	299	145	288	30	463	133	330	8	471	5	393	9	407
8:30 - 8:45	124	185	15	324	111	316	24	451	142	374	7	523	6	396	5	407
8:45 - 9:00	96	172	29	297	138	301	36	475	120	368	7	495	4	367	2	373

*****MC=Motorcycle, LV=Light vehicle, HV=Heavy vehicle

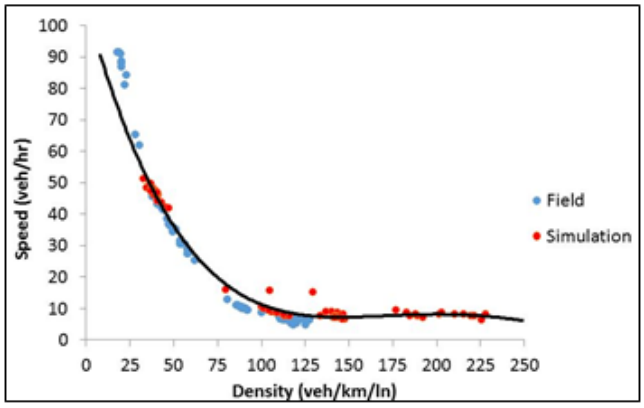


Fig. 5: Speed–density relationship based on calibration results for Cheras-Kajang highway Contraflow segment

The validation study generated parameter sets that reproduced the speed- density diagram very well. An interesting aspect in this work is that the field data provided for some parameter results that were very close to the default parameters in VISSIM for validation. For some other parameters the procedure suggested values different from the defaults provided at the time of the study. The study was therefore extended to look at microscopic trajectory data which were available for the same freeway section from MIROS. As a result, some of the parameters for the driving mode following in VISSIM model could be adjusted to better reflect Malaysian driving style on freeways. Validation on a microscopic level allows evaluating parameters of single-vehicle movements such as time travel, fuel consumption, CO emission from origin to destination.

3. Findings

Ten random seeded runs were made for each of the possible path sets and evaluated based on four criteria. The first evaluation criterion was distribution of contralane travel times produced by VISSIM. The second criterion was queue length upon the entrance of each connector. The third criterion was fuel consumption at each connector. The last criterion was CO emission of connectors' area from contralane users. Based on these criteria the best alternative path set was selected.

3.1. Travel time distribution

Cheras-Kajang highway contralane travel times were collected from 10 random seeded runs. Contralane travel times for each of the eight connectors are presented in Table 2. The best travel time was 526 seconds with an average delay of 46 seconds belongs to the second and fifth connectors. While the worst travel time was 751 seconds with an average delay of 272 seconds belongs the first connector (current connector). The most inconvenient alternative path was the fourth connector with 600 seconds travel and an average delay of 120 seconds. The rest of the travel times' paths were varies between (526-600) seconds. Figure 6 represents the variation of the travel time for all alternative connectors.

Table 1: Travel times for all alternative paths of Cheras-kajang highway Contralane segment

Path number	Travel time (sec.)	Delay (sec.)	Connector
1	752	272	1st connection
2	526	46	2nd Connector
3	581	101	3rd Connector
4	600	120	4th Connector
5	526	46	5th Connector
6	591	111	6th Connector
7	589	109	7th Connector

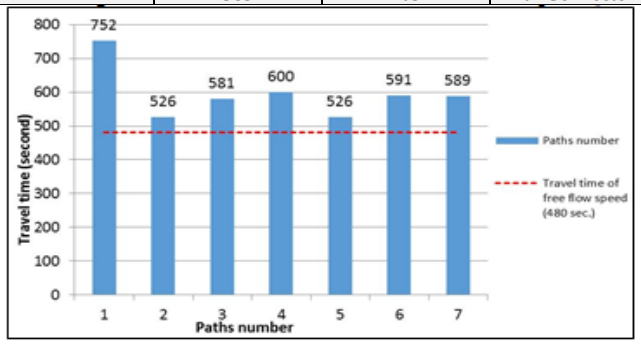
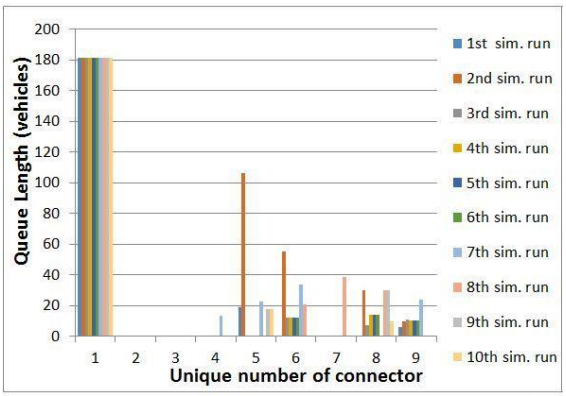


Fig. 6: variation of travel times for all alternative paths

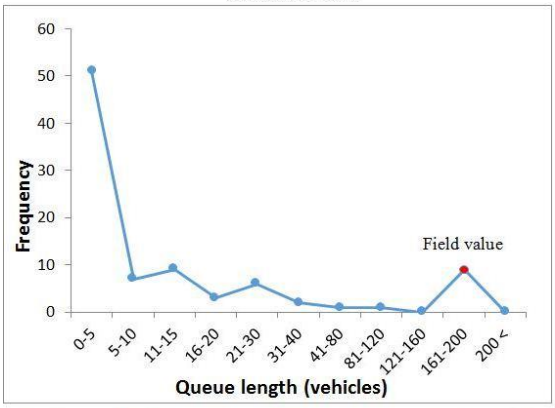
3.2. Queue length distribution

It is noted that the maximum queue length data were found at the first connector (current connector) since most of the contralane users tend to use the first connector as a first cited connector. The maximum queue length in the first connector with the other connectors was compared with the distribution of various runs in VISSIM. The first maximum queue length was about the same value for all simulated distribution as indicated in Figure 7a. Figure 7b represents queue length distribution according to field value. Table 3 presents all the values for queue length, fuel consumption, and emissions of CO for all predicted connectors.

Simulation run	Connector	Queue Length (veh.)	Fuel cons. (litre)	Emissions of CO (grams)	Simulation run	Connector	Queue Length (veh.)	Fuel cons. (litre)	Emissions of CO (grams)
1	1st	181	387	7144	5	9th	10	10	174
1	5th	19	15	272	6	1st	181	336	6200
1	9th	6	8	157	6	6th	12	32	589
2	1st	181	312	5761	6	8th	14	12	225
2	5th	106	48	888	6	9th	10	9	174
2	6th	55	31	571	7	1st	181	336	5284
2	8th	30	12	222	7	4th	13	9	150
2	9th	10	10	181	7	5th	23	17	591
3	1st	182	326	6011	7	6th	34	32	560
3	6th	12	37	674	7	9th	23	9	155
3	8th	7	12	225	8	1st	181	336	6604
3	9th	11	9	173	8	6th	20	32	494
4	1st	181	387	6200	8	7th	39	13	239
4	6th	12	28	589	8	8th	30	12	220
4	8th	14	12	225	9	1st	182	286	5433
4	9th	10	8	174	9	5th	18	32	251
5	1st	181	312	6200	9	8th	30	12	200
5	6th	12	31	589	10	1st	181	358	5273
5	7th	0	13	236	10	5th	18	33	245
5	8th	14	12	225	10	8th	10	12	203

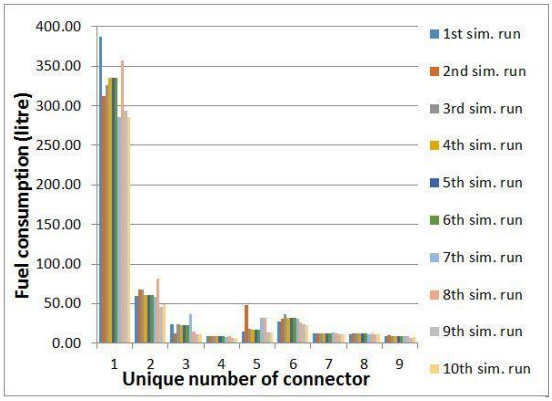


a) Predicted queue length values for all connectors for 10 simulation runs

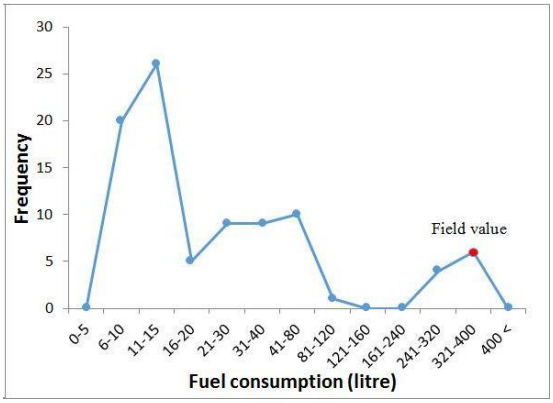


b) Queue length prediction distribution according to field value

Fig. 7: Queue length prediction of all connectors for 10 simulation runs



a) Predicted fuel consumption values for all connectors for 10 simulation runs



b) Fuel consumption prediction distribution according to field value

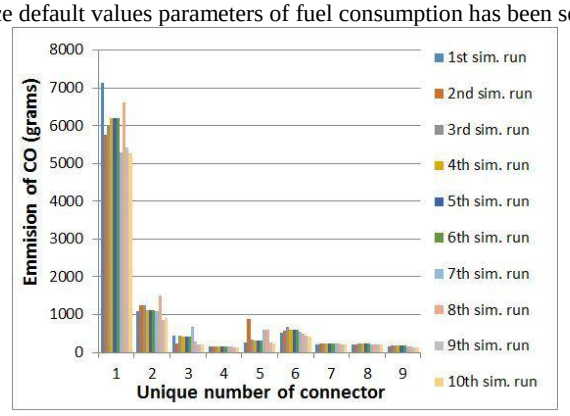
Fig. 8: Fuel consumption prediction of all connectors for 10 simulation runs

3.3. Fuel consumption distribution

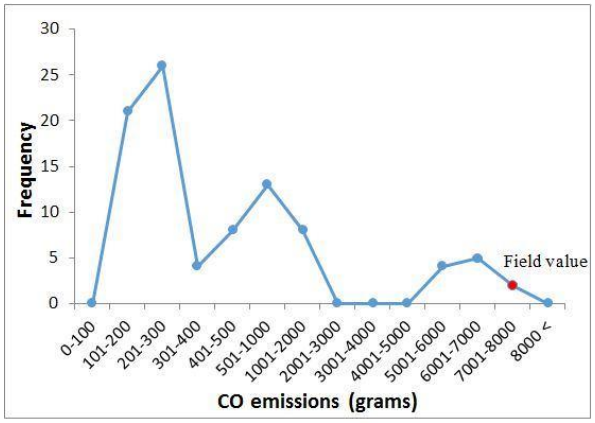
Optimization of VISSIM estimated fuel consumption model was applied to demonstrate the average fuel consumption over 10 simulation runs for all connectors. The 10 VISSIM runs were recorded and averaged. Average values from these runs are presented in Table 3 for all connectors. Figure 8a illustrates the simulation run results with respect to the reduction in fuel consumption comparing the first scenario which represent the current connector in field. Figure 8b represents the fuel consumption distribution according to field value. The first thing that catches one's eye when looking at the graph is that, at 4, 7, 8, and 9 connectors the evaluated values of fuel savings is significantly lower than the first current connector. Note that we do not claim these values to be the "true" saving ratio to be expected from a real-world deployment of alternative connectors. In fact, the graph may rather serve as an orientation point, since in reality; a multitude of influencing factors may shift the absolute values upward or downward. For example, we used a rather basic path-adaption algorithm model not considering the exact scheduling of on-ramps and off-ramps traffic volumes discharge.

3.4. CO emissions distribution

Carbon dioxide (CO_2) and monoxide (CO), mono-nitrogen oxide (NO_x) and particulate matter are among the emission types with the highest impact on the environment. Since CO_2 emissions can be calculated from fuel consumption using a linear function, we limit our evaluation to fuel consumption and CO. Figures 9a shows that the CO emissions of road users with standard engine type can be reduced by up to 80% if the model adaption algorithm is applied. Thus, for CO emissions, the most important factor is to avoid stopping at queue. Figure 9b represents the predicted CO emissions distribution based on its fuel consumption filed value since default values parameters of fuel consumption has been set.



a) Predicted CO emissions values for all connectors for 10 simulation runs



b) CO emissions prediction distribution according to field value

Fig. 9: CO emissions prediction of all connectors for 10 simulation runs

4. Conclusion

This paper proposed a procedure for scenarios prediction of Contraflow operation at large-size network using dynamic assignment model. Calibration and validation of this procedure appears to be effective for VISSIM dynamic assignment model for such large-size network. Two important issues were encountered during implementation of the calibration and validation procedures. The first issue dealt with statistical testing when claiming the calibrated model was equal to the field data. The second issue was the importance of validation based on time profiles of speed and distance of field-simulation pairs.

Dynamic assignment model uses the method of effectiveness (MOE) to determine pre-trip dynamic equilibrium path choices. The method was successfully applied to the network and the study was successfully described the integration of VISSIM dynamic assignment model to optimize contraflow operation in such a way to achieve minimal value of travel time, queue length, fuel consumption, and CO emissions.

The paths results based on the network indicate that the VISSIM dynamic assignment simulation model was able to replicate field travel times and come with best alternative paths along with the presence of current connector (1st connector). All paths' travel time results showed that the field travel time lies within the distributions of travel times, beside to best travel time of connectors 2, 4 and 7. In addition, maximum field queue length was shown in VISSIM dynamic assignment model as one of the predicted paths along with minimum queue length of in case of using multiple alternative paths.

Fuel consumption and CO emissions that obtained from VISSIM dynamic assignment model were investigated as result parameters as a final decision to select most adequate alternative path since fuel consumption and CO emissions have directly proportional relationship between them. High values of fuel consumption and CO emissions at first connector indicate that most of the user uses this connector as first site salvation for any future congestion knowing that there are no alternative paths lies ahead. At the tenth simulation run of dynamic assignment model, contralane users start to decrease at first connectors since there are multi alternative connectors along the contralane due to convergence results at end of the simulations. Resulting as connectors 4 and 7 is best alternative paths since these connectors have the lowest value of fuel consumption and CO emissions.

Finally, the study shows that connectors 2, 4, and 7 represent the best solution for alternative paths with the presence of current connectors due to the diverting decision of contralane users tend to use them as second opinion for using the contralane.

Furthermore, it is more desirable to consider many different calibration parameters such as parameters related to the dynamic origin–destination demand and multiple MOEs such as density and type of vehicles to understand inherent variability associated with the simulation models. Also, future research should address additional advanced algorithm that yield positive effects on fuel consumption. Furthermore, an optimized user vehicle type model could further improve fuel efficiency.

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