Microscopic Model of Road Capacity for Highway Systems in Port Based Metropolitan Areas

Final Report

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Abstract

In this report, we present our approach to use microscopic modeling to assess highway traffic mobility during lane blockage situation. A test microscopic model using ARENA software is developed. In this model, we specifically aim to simulate the impact of container trucks on highway traffic capacity and risk of accident during lane blockage.

The test model simulates a 3000 feet distance on a two lane highway, while the passing lane is blocked at 2500 feet distance from the beginning. Merging sign and taper zone was used to guide traffic on the passing lane to merge to driving lane. We adjust the cargo truck traffic ratio to assess the effect of cargo trucks on the road mobility. The road mobility is assessed using the throughput ratio (total number of vehicles exited the system/ total number of vehicles entered the system). The risk of collision is assessed using the number of un-successful merging attempts at the taper end.

Traffic throughput and risk of collision is simulated as a function of traffic density, cargo truck percentage as well as number of merging signs placed onsite. We found that: 1) Increasing traffic density significantly reduces the road throughput, while increases the risk of collision moderately too; 2) Increasing cargo truck percentage reduces road throughput, while increases the risk of collision; 3) Increasing number of merging signs increases the traffic throughput and reduces the risk of collision up to a threshold. Under the traffic condition we studied, this threshold is two merging signs.

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Introduction

Although Los Angeles County should be proud of its well-developed, conveniently accessible highway systems, due to increasing volume of automobiles on road, the traffic situation still becomes worse and worse each year. According to RAND California statistic database [1], most of the highway sections in Los Angeles County have already reached their maximum capacity, which is measured by RVC (Ratio of Volume to Capacity Factor). RVC equals 1.0 means this highway section is already serving in its full load. Table 1 gives the RVC of selected highway sections near Port of Long Beach. Highway I-605, I-710 and I-405 are three major highways passing close-by Port of Long Beach. All of their sections have been already fully saturated years ago.

On the other hand, Port of Long Beach, the nation's largest and most important sea-port, accommodates almost one-half of the nation's port-related cargo container distributions. All those containers need to pass through the Los Angeles metropolitan area to reach interior areas through either truck or railroad transportation (Alameda Corridor). According to statistics provided by Port of Long Beach and Alameda Corridor [5], the daily container traffic at port of Long Beach is nearly 20,000 for year of 2006, and this number is projected to be doubled or tripled in the next decade. The container movement paradigm has several requirements. The first is to accommodate projected port growth so that economic base of the Southern California region, and the entire country, can continue to grow. The second is to optimize the existing highway infrastructure which currently cannot well handle its load before alternatives come into implementation.

Hwy	Grade	Terrain	Category	1999	2000
405 -- FWY 710	Flat	Flat	Ratio of Volume to Capacity.	1.00	1.00
605 -- ORA CO L	Flat	Flat	Ratio of Volume to Capacity.	1.00	1.00
710 -- FWY 91	Flat	Flat	Ratio of Volume to Capacity.	1.00	1.00

Table 1. RVC of selected highway sections near Port of Long Beach. [1]

The Alameda rail corridor (the appropriative railroad connects port of Long Beach to LA downtown railroad transportation center)-developed to help accommodate the unprecedented growth of container traffic going to and from the Port - has not significantly reduced the impact of freight movement on the Los Angeles community. The daily throughput of Alameda Corridor is only 9,600 containers. That leaves more than half of the containers waiting to be moved out of the port by truck transportation. In addition to that, a number of terminals at the port must relocate containers to the terminal of the Alameda corridor, four miles from the port, before they could be shipped out by train. This additional container truck traffic not only causes significant congestion inside the port terminals as well as the surrounding community, but also brings up more concerns on safety issues and speedups the aging of roads.

Recently, CCDoTT (Center for the Commercial Deployment of Transportation Technologies) at California State University Long Beach developed the idea of ECCO (Electric Cargo Conveyor) [2] to help improve Port of Long Beach's daily throughput by

Maglev freight which can move large numbers of containers quickly and efficiently from port terminals to transcontinental trains, tarns-shippers, and Inland Empire warehouses with markedly reduced pollution as well as reduced traffic congestion. The suggested strategy is to build an appropriative Maglev freight way from Port of Long Beach to a less condensed inland port. Therefore, some containers could avoid merging into regular traffics across the population condensed LA base. This strategy has been partially implemented inside the port terminals and generated positive impacts [3]. But larger scale implementation in entire LA basin area needs further justification in terms of effectiveness and cost.

Despite of these new ideas, the conventional highway transportation will still be the primary media for the container distribution for years in the near future due to several reasons, such as insufficient infrastructures other than highway and union protection of truck drivers. Therefore efficient utilization of the current limited highway resources continues to be in urgent need. The congestion and risk for collision becomes more severe when a road construction or temporary lane closure cannot be avoided. To ensure safety, lane closure signs need to be placed way ahead of the actual blockage location and lane closure taper need to be placed as well. Obviously, the longer the notifying distance, the longer time the drivers get to react, thus the lower the risk of collision. However, lane closure taper zone virtually lengthens the blocking zone, which makes the highway resources stingier. This clearly indicates a trade-off between highway capacity and risk of collision. On a highway section that constantly consumes large amount of cargo truck traffics, more factors need to be considered in order to build a precise simulation model, such as vehicle class (length), percentage of vehicles in each class, following distance for each class, specific merging distance for each class, deceleration rate for each class, to name a few. In this project, we aim to study the highway throughput and the risk of collision during merging as a function of traffic density, percentage of heavy cargo trucks during a lane blockage situation. Moreover, this study also aim to determine the optimal number of merging signs to be placed in order to reduce the risk of collision without heavy delay penalty.

Overview of Construction Zone Control

The lane closure due to construction or accidents often cause capacity bottleneck of the freeway. During lane closure, traffic needs to be redirected and forced to merge into open lanes. There are several merging strategies that are either implemented or under study now. These strategies follow either an early merge concept or a late merge concept. An early merge concept encourages drivers to merge ahead of the work zone. The advantage of this concept is reduced safety concern as all drivers are provided sufficient time to plan merging action. On another hand, the early merging virtually reduces the road capacity because the road section ahead of the work zone is not effectively used. Therefore, the throughput is sacrificed. The late merge concept encourages drivers to use both the open and closed lane until the beginning of work zone. This concept clearly takes full advantage of road resources, but the tradeoff is risk of collision since the drivers are not provided very much time to plan for merging.

The traditional strategy uses advanced warning signs (i.e. merging signs) placed ahead of the work zone together with blockage tapers. This is still the most frequently used method due to its easy implementation. This strategy follows a static early merging concept, which encourages drivers to merge to the open lane way ahead of the working zone. Obviously, how far ahead the working zone we should place the merging sign affect the overall throughput as well as the risk of collision.

A dynamic early merging strategy a merging notice is posted at a variable distance ahead of the work zone based on the traffic density. The strategy seems to overcome the shortcoming of the traditional early merge. However, simulation study conducted by Tarko et al indicates that the travel time through the work zone is actually longer. Plus, the implementation of this strategy is more complicated and cost significantly more than the traditional one.

The static late merging strategy place “USE BOTH LANES TO MERGE POINT” sign on both side of the roadway. Near the beginning of taper zone, “MERGY HERE” signs are placed. The intention of this strategy is to efficiently use both open and closed lanes. McCoy et al. showed that the capacity of the late merge strategy is significantly higher than the conventional merge. However, the concerns here are about the risk of collision in heavy traffic environment. Beacher et al. evaluated the late merge strategy under 3-to-1, 2-to-1 and 3-to-2 situations. They claim that the late merge strategy should be considered for 2-to-1 and 3-to-2 situations only when the heavy truck percentage is higher than 20%. While the implementation of late merge strategy to 3-to-1 situation needs more evidence from field study. They also showed concerns by claiming more field studies are needed for all situations before wide implementation.

Due to the concerns regarding static late merge strategies, many studies are devoted to dynamic late merge strategies. Wei et al. suggested a Dynamic Merge Metering Traffic System (DMM-Tracs), in which a meter is installed at the work zone location, whose actions are controlled by the traffic density, detected a certain distance ahead of the work zone. If the traffic volume from upstream exceeds a threshold, the meter is triggered to instruct the vehicles in the advance areas of the work zone. They found the DMM-tracs strategy reduces delay for heavy traffic density. Kang et al. suggested a strategy that combines the early merge and late merge concept. Under light traffic, an early merge concept is implemented, while under heavy traffic, a late merge concept the recommended. They also suggested an algorithm to determine the optimal threshold dynamically considering the moderate flow rate, optimal merging capacity and the maximum flow rate. Their simulation shows the advantage of this dynamic strategy on throughput becomes significant only when the traffic density increases above 40 vehicles/min.

Despite the performance advantages of dynamic merging strategies, they all require more complicated hardware implementation, which may not be always possible for lane blockage due to traffic incidents. The most frequently used merging strategy is still the traditional method mentioned above. There are still things we can do to improve the throughput under the traditional method, such as adjusting the location and number of merging signs. Also, the effect of heavy truck to the construction area is also of interest and is studied in this work.

Methodology

❖ Data Collection

Collecting real world traffic data, such as incoming traffic flows, class of vehicles and percentage, speed of movement, traveling time in construction zone, is necessary to build a model that produce reliable results. Data collection is usually time and money consuming. Therefore, limited by the scope of this project, we could not afford to collect real world data ourselves. Due to the scope of this project, we suggest a test microscopic model that is capable to be expanded to analyze mobility and risk problems as a function of vehicles types and construction zone layout provided the traffic data. We will build the test model based on an estimated data from the Caltrans live camera videos on highways.

Based on our observations through Caltrans live video, the following estimated data is used in our initial set-up.

Table 2 Vehicle Statistics for Initial Set-up

	Heavy Traffic		Light Traffic	
	Driving Lane	Passing Lane	Driving Lane	Passing Lane
Mean Vehicle Arrival Interval (Exponential Distribution)	1 second	2 second	4 seconds	5 seconds
Cargo Truck percentage	40%	8%	40%	8%

❖ Model Overview

We considered a scenario of a two lane one way highway section where one of two lanes is blocked. The highway section under consideration has a container truck flow merges with urban vehicles. A real world prototype of this situation is the I-710 south bound from I-91 ramp all the way to the Port of Long Beach. Due to the funding and time limitation, only a two-lane one way test model is developed in this project. However, this model could be expanded into multi-lane system as a second phase project.

- **Arena software introduction**

Arena simulation software (by Rockwell Automation) will be used to build this traffic model. This software is designed to model queues. The program uses Entities to represent dynamic players in system, such as people, parts or cars. Entities enter the system for some kind of service, but there are only limited resources to provide this service. The service will be provided on a first come first serve base, the later comers will form a queue waiting for the resources to be available. After the entities received the service, they leave the system.

Arena provides statistical analysis tools to assist user analyzing the simulation results, such as queuing time, length of queue, waiting time in system etc. It also provides a nice animation option, which makes it possible to visualize the system's operation.

- **Road Configuration and Driver Behavior**

Figure 1 shows the configuration of the road section to be modeled. The model begins 500 ft before the first "Merge" sign and stop approximately 500 feet after the blocked zone. We assume the passing lane is blocked, while all traffic need to merge to driving lane. Three "Merge" signs and 1 taper zone are place one the passing lane, which are used to direct the traffic. The distance between the "Merge" signs are 500 ft and the taper zone is 500 ft long. We assume vehicles do not change lanes before the first merging sign. After the first "Merge" sign, vehicles on the blocked lane start to look for opportunities to merge onto the passing lane. The acceptable merging condition depends on the vehicle type, speed of vehicle on blocked lane and speed of traffic on the passing lane. Once the merging conditions are satisfied, the vehicle will be placed on the passing lane and removed from blocked lane.

Chances are not all drivers can successfully merge after they see a "Merge" sign; some of them have to wait for an opportunity to come up. At the beginning of taper zone, if the merging condition is still not satisfied, the vehicle has to stop until there is opportunity for it to merge. In ARENA software, this module can be realized by assigning each point of interest (each merging sign, beginning of taper, end of taper) with a "station".

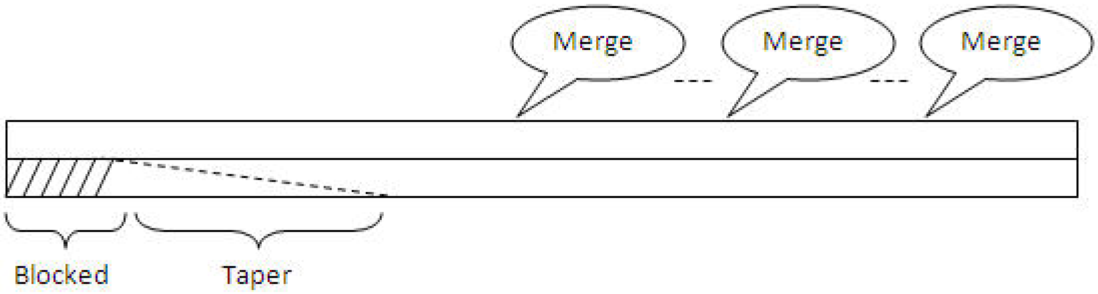

Figure 13 Road configuration of two lane one way highway section with lane closure in ARENA module.

- **Model Vehicles**

Major components of this ARENA module are “Entities”, representing different types of vehicles. They will be paired with “Transporters” that travels on the links between intersections. In this proposed module, we will consider two types of vehicles:

- Cars or light trucks (length < =20 ft)
- Cargo trucks or very heavy vehicles (length=65ft)

Entities are generated by Create module in ARENA based on the distribution of each type of vehicles in the entire traffic. Once generated, entities are assigned to different types of Transporters. Two types of transporter are used in this project, CT (Car Transporter) and TT (Truck Transporter). Attributes of transporters, such as speed and length, are assigned based on the vehicle type (cars, trucks or cargo trucks). The needed merging distance will be determined based on vehicle type and its relative speed to the passing lane traffic. Each entity-transporter pair represents one vehicle traveling on the highway.

This model allows user to adjust input variables, such as inter-arrival time, speed distribution, vehicle type distribution, to simulate for different situations. .

- **Model Car Following and Merging using Network Links**

In Arena software, there are two ways to move a transport. One is using free-path transporter, the other is through guided transporter. Free-path transporter moves from point 1 to point 2 at a specified speed, but the exact path is not defined. Therefore, the time it takes for free path transporter to reach a destination only depends on the distance between two destinations and the speed of the vehicle. However, the vehicles on highway is bounded by the road, therefore, they are not really moving freely. Therefore, we chose guided transporter to model the highway vehicles.

In order to guide the transporter, we need to specify the paths that are allowed for the transporter to take. These paths (named “network links” in ARENA) could be linked as desired based on real world scenario. Usually the linked paths build a network (name "network" in ARENA. One could define more than one network, which specifically designed for each type of transporter. However, in our scenario, the highway is considered public and any vehicle can choose any path it wants. Therefore, one network is necessary for our problem.

In ARENA, network links are links that connects "intersections", which are defined specifically for each event that needs to be considered in the problem. We defined the following intersections in this project:

Table 3 Definition of Intersections

Intersection Number	**Description of Intersection**
Intersection-1 (I-1)	Starting point of Passing Lane
Intersection-2 (I-2)	First "Merge" sign on Passing Lane
Intersection-3 (I-3)	Second "Merge" sign on Passing Lane
Intersection-4 (I-4)	Third "Merge" sign on Passing Lane
Intersection-5 (I-5)	Starting point of taper zone on Passing Lane
Intersection-6 (I-6)	End of taper zone on Passing Lane
Intersection-7 (I-7)	Starting point of Driving Lane
Intersection-8 (I-8)	Corresponding location of 1st "Merge" sign on Driving Lane
Intersection-9 (I-9)	Corresponding location of 2nd "Merge" sign on Driving Lane
Intersection-10 (I-10)	Corresponding location of 3rd "Merge" sign on Driving Lane
Intersection-11 (I-11)	Corresponding location of start of taper zone on Driving Lane
Intersection-12 (I-12)	Corresponding location of end of taper zone on Driving Lane
Intersection-13 (I-13)	Car's virtual destination (500 ft from I-12)
Intersection-13 (I-14)	Truck's virtual destination (500 ft from I-12)

The following network links are defined in this project:

Table 4 Description of Network Links

Network Link Number	**Description of Links**

Network Link-1 (L-1)	Initial position for Truck Transporter
Network Link-2 (L-2)	Initial position for Car Transporter
Network Link-3 (L-3)	Link I-1 to I-2
Network Link-4 (L-4)	Link I-7 to I-8
Network Link-5 (L-5)	Link I-2 to I-3
Network Link-6 (L-6)	Link I-8 to I-9
Network Link-7 (L-7)	Link I-3 to I-4
Network Link-8 (L-8)	Link I-9 to I-10
Network Link-9 (L-9)	Link I-4 to I-5
Network Link-10 (L-10)	Link I-10 to I-11
Network Link-11 (L-11)	Link I-5 to I-6
Network Link-12 (L-12)	Link I-11 to I-12
Network Link-13 (L-13)	Link I-12 to I-13
Network Link-14 (L-14)	Link I-2 to I-8 (merging link)
Network Link-15 (L-15)	Link I-3 to I-9 (merging link)
Network Link-16 (L-16)	Link I-4 to I-10 (merging link)
Network Link-17 (L-17)	Link I-5 to I-11 (merging link)
Network Link-18 (L-18)	Link I-6 to I-12 (merging link)
Network Link-19 (L-19)	Link I-12 to I-14
Network Link-20 (L-20)	Link I-1 to I-2 (start point link)
Network Link-21 (L-21)	Link I-2 to I-1 (start point link)

The following (Figure 2) is a distribution chart of the network containing link 1-21.

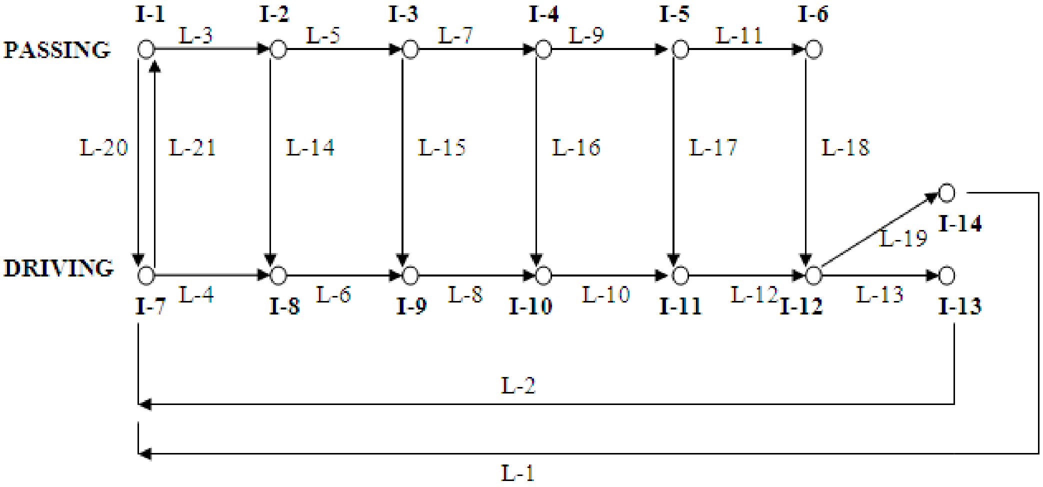

Figure 14 Distribution Plot of Intersections and Network Links

In the following figure (Figure 3), we show a sample model set-up at merging signal #1.

In the Signal_1 sub-model, incoming traffic comes from both driving lane station (Sig1_D) and passing lane station (Sig1_P). We first assess the vehicle type (car or truck) by using "T_C_Sig1_P" module. This is necessary to determine proper merging conditions for the vehicle. The Car Transporter will first check the traffic conditions on both lanes ("D-lane Crowdy?" module). If passing lane has less traffic, the car will choose to stay on passing lane, otherwise, it will seek merging following the merging condition set by "Continue?_Sig1_P" module. This module sets the merging condition considering the vehicle speed. As far as the Truck Transporters, since most of cargo trucks are less aggressive than cars, they will seek merging once they see the merging sign. Therefore, we didn't set any check traffic module for the truck transporters.

Table 5 listed the merging gap data used to determine the necessary merging gap at different vehicle speed. We applied linear regression on the data to determine the merging function in our model (Speed*1.81+75 for cars and Speed *1.81+120 for trucks).

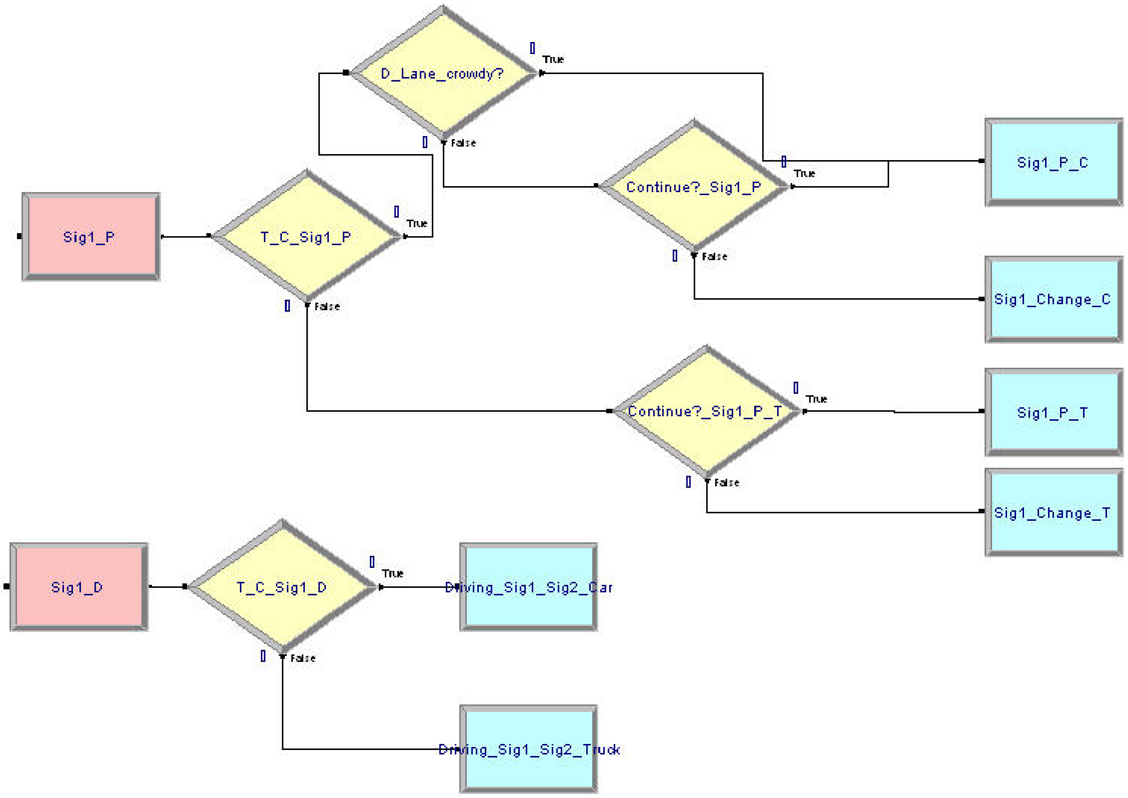

Figure 15 Model for Merging Behavior at Signal_1

Table 5 Merging Gap

Car Speed (ft/sec)	**Merging Gap (ft)**		**Truck Speed (ft/sec)**	**Merging Gap (ft)**
75	215		75	260
55	170		55	215
35	140		35	185
10	95		10	140

The merging modeling for Signal 2, Signal 3 and taper zone are similar to the one listed in Figure 3. The only difference is at Taper zone end, the vehicle will be delayed for a certain time and check merging condition again, as they already reached the end of the passing lane.

Simulation Results

❖ Effect of Arriving Interval

First, we tried to assess the effect of traffic flow on the mobility of the road. The mobility of the road is measured by percentage of vehicle leaving the system and the transfer time in the system. The simulation results are shown in Figure 4 and Figure 5. The simulation time is 1 hour (3600 seconds).

From Figure 4, we can see that, the percentage of vehicles that leaving the system is decreasing as a function of number of vehicles entering the system. The latter is a direct measure of the traffic flow. Intuitively, the more vehicles entering the system, the busier is the traffic.

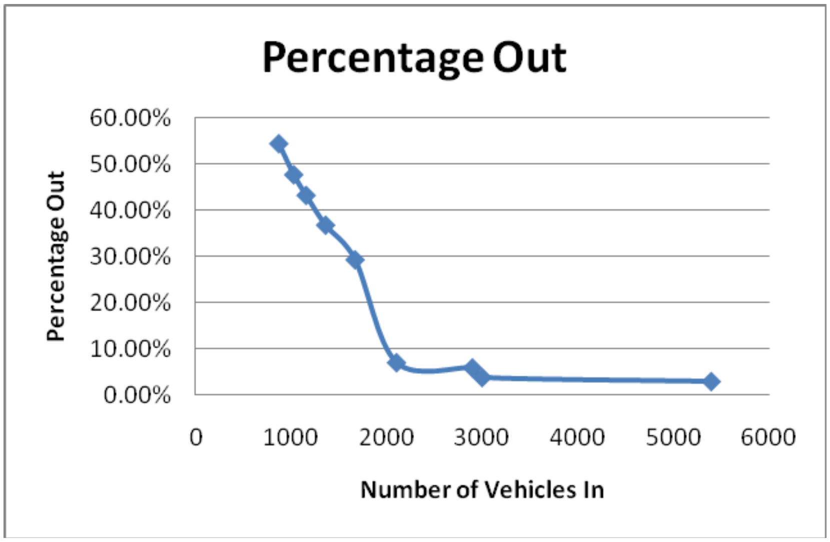

Figure 16 Percentage of vehicles leaving the testing zone as a function of total number of vehicles entering the testing zone.

From Figure 5, we observe that the total transfer time is showing an overall decreasing trend as a function of number of vehicles entering the system. This is kind of contradicts with common sense. Our explanation to this is for less traffic situation, more vehicles wait till the taper to start their merge. Because in the model, the driver will assess which lane has less traffic. For the first few vehicles, the passing lane is less traffic, therefore, they go on on that lane until they hit taper end. At that time, the driving lane is also at a relatively high speed, because the overall traffic is light. Then they need larger merging distance to complete the merge, so they wait longer at the taper end. This enlarged the overall average of transfer time in the system. On the other hand, when the traffic is normal or heavy, more vehicles start their merging earlier. This basically reduced the number of taper end merging (which is hardest location to merge since your speed is way lower than the driving lane), therefore, reduced the average traveltime. This can be seen by looking at the number of cars in taper zone (Figure 6). When the traffic is light, we have more cars gathering in the taper zone waiting to merge. According to our simulation, threshold of light traffic is less than 2000 vehicles on the 3000 feet that is being simulated. We do see the transfer time gradually builts up as the traffic getting more and more severe.

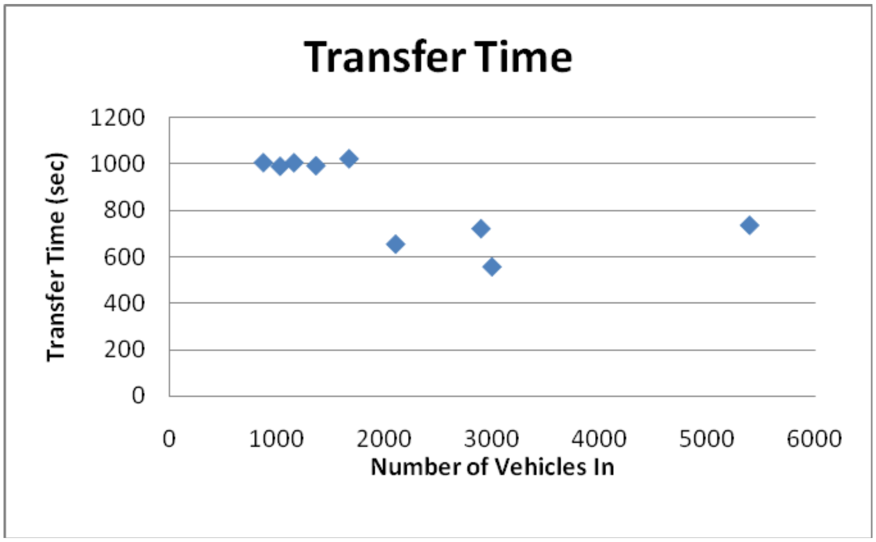

Figure 17 Total transfer time in testing zone as a function of number of vehicles entering the testing zone.

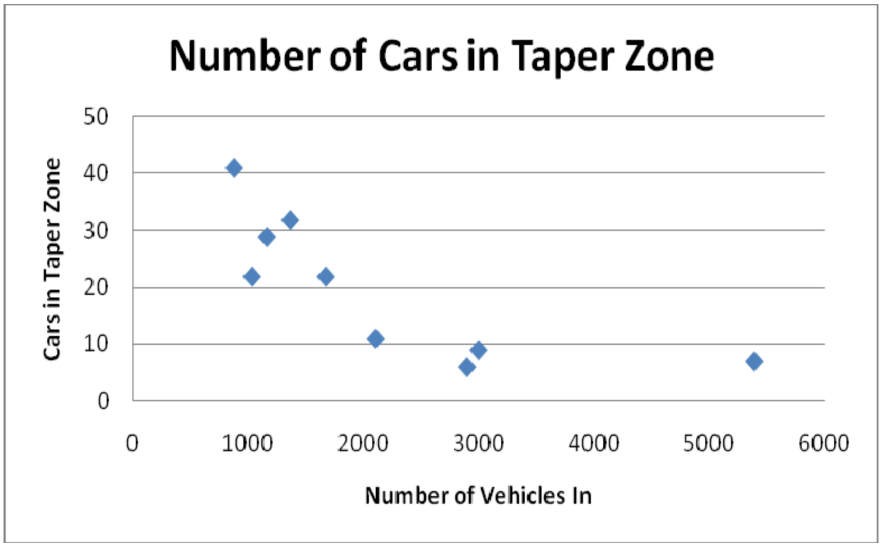

Figure 18 Number of Vehicles in taper zone as a function of number of vehicles entering the testing zone.

We also simulated the number of car’s attempts to merge at the taper end. The results are shown in Figure 7. The attempts of merging at taper end could be account for a risk. This is because the cars at taper ends are desperate in merging and they are likely to conduct a merging when merging condition is not met. This may result in collision. From Figure 7, we can see that this risk of collision is increasing with the traffic flow, that is, heavier traffic results in higher likely-hood of collision.

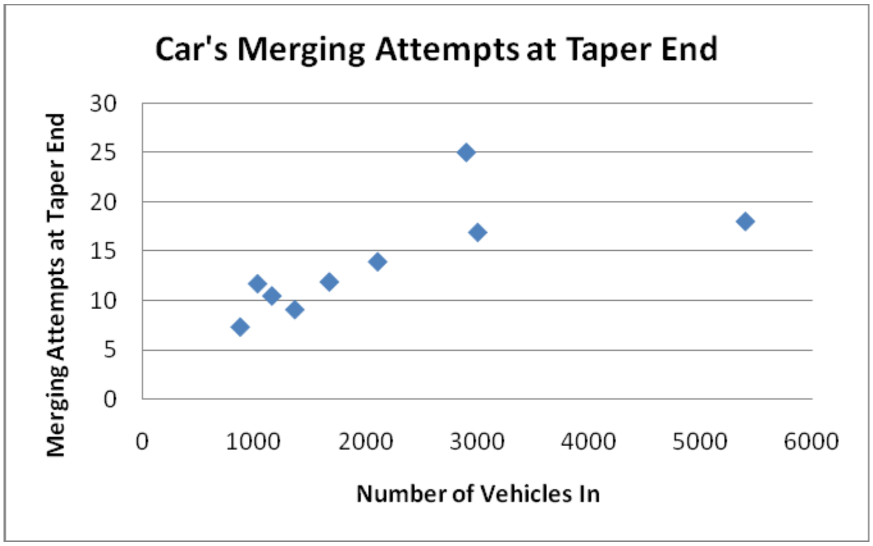

Figure 19 Merging attempts in taper zone (a measure as risk of collision) as a function of number of vehicles entering the testing zone.

- **Effect of Cargo Truck Percentage**

The next question in mind will be whether the cargo truck traffic has an effect on the traffic efficiency as well as the risk of collision. Therefore, we also simulated the mobility of the road as a function of cargo truck percentage. We set the overall traffic at medium light rate, i.e. mean arrival interval to be 4 seconds.

Figure 8 shows the percentage of vehicles leaving the testing zone as a function of percentage change of cargo trucks. The original percentage of cargo truck is 8% at passing lane and 40% at driving lane. We adjusted the percentage from -5% to +7%. We observe that the number of vehicle leaving the testing zone in the 1 hour simulation limit reduces as we increase the cargo truck percentage. This indicates the number of cargo truck on road has a negative impact on road mobility.

Similar trend is observed in travel time result, as shown in Figure 9. The travel time is increasing as number of cargo trucks grows, indicating slower traffic and more traffic congestion.

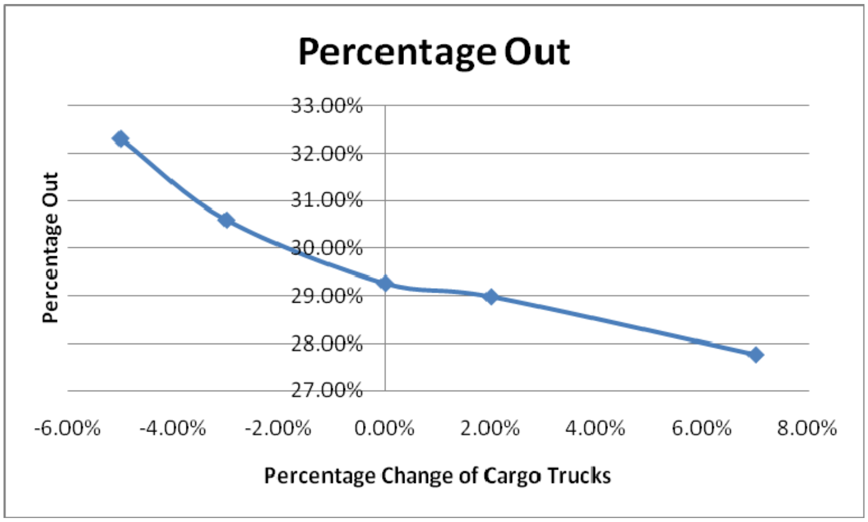

Figure 20 Percentage of Vehicles Leaving the testing zone vs. Cargo Truck Percentage Change

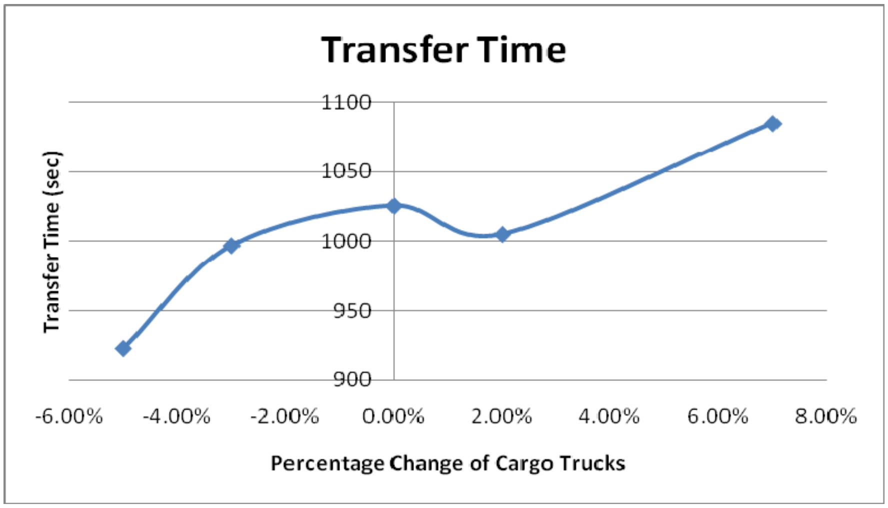

Figure 21 Total Travel Time in Testing Zone vs. Percentage Change of Cargo Truck

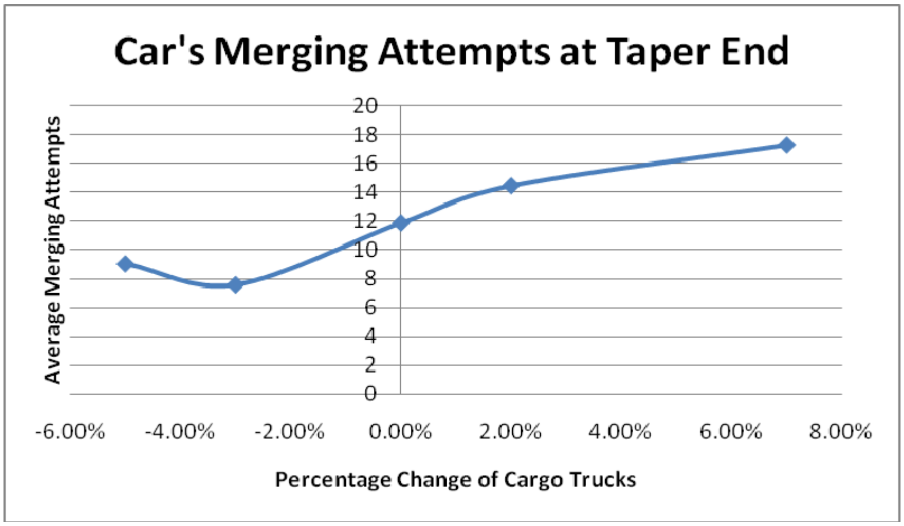

Figure 22 Average Merging Attempts in Taper Zone

The risk of collision is also assessed by simulating number of merging attempt in taper zone (Figure 10). The overall merging attempts at taper end grow with cargo trucks traffic as well. This indicates more cargo trucks on highway results in higher risk of collision during lane blockage.

❖ Effect of Number of Merging Signs

In the initial set-up, we designed 3 merging signs to guide drivers to merge to the driving lane as it is possible. The number of merging signs warns the drivers ahead of time, so that they get more chances to seek for a successful merge. However, the more merging signs we put on the road, the more disturbance we introduces to the traffic. Therefore, it is of interest to study how many merging signs should be applied to the road without wasting the road resources.

In this experiment, we studied the percentage of vehicles exiting the system as a function of merging signs. We set the average interval between incoming vehicles to be 5 seconds, and we reset the percentage of cargo truck to the original setting. (39% for driving lane and 9% for passing lane). As shown in Figure 11, as we increase the number of merging signs, up to a certain point, it does help the vehicle getting out the of system faster. But above that threshold, we do not see significant correlation between number of signs with percentage of vehicle out. This suggests that under the current traffic situation, three merging signs will be a waste; two merging signs will be a more efficient choice.

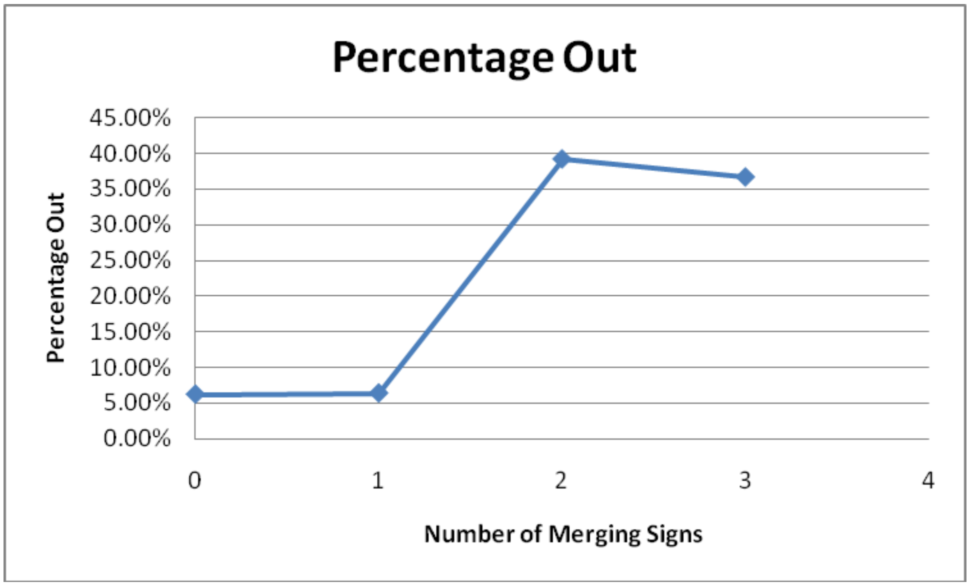

Figure 23 Percentage of vehicle exiting the system as a function of number of merging signs.

Another concern maybe whether reducing the merging signs increase the risk of collision at the taper end. Figure 12 shows our test of merging attempts at taper end as a function of number of merging signs. We can see that increasing merging signs does reduce the risk of collision; however, the difference is not significant as we go above two signs. Therefore, both the throughput and the risk test confirms that under the current traffic condition, two merging signs will be more efficient than 3 signs.

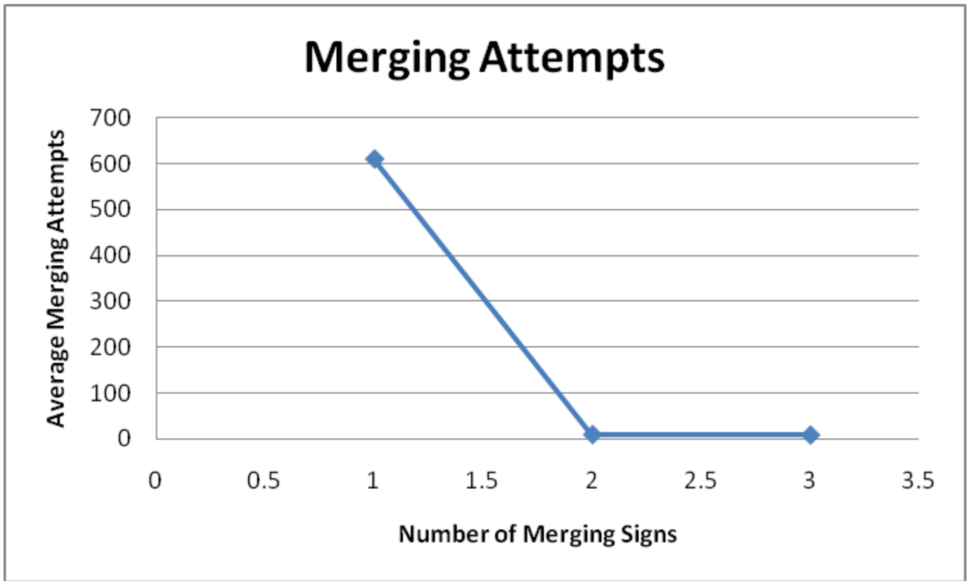

Figure 24 Merging attempts at taper end as a function of number of merging signs

Conclusion

In this project, we built a simulation model using Arena Software to model a two lane highway section under road blockage. Traffic through put and risk of collision is considered as a function of traffic density, cargo truck percentage as well as number of merging signs placed onsite. We found that: 1) Increasing traffic density significantly reduces the road throughput, while increases the risk of collision moderately too; 2) Increasing cargo truck percentage reduces road throughput, while increases the risk of collision; 3) Increasing number of merging signs increases the traffic throughput and reduces the risk of collision up to a threshold. Under the traffic condition we studied, this threshold is two merging signs.

The model built in this project is a test model, therefore, only two lanes are considered. It could be expanded into multi-lanes in a future work. Therefore, more realistic questions can be answered, such as number of lane blockage, length of lane blockage. Also, a real field data collection could help in building more realistic statistical distribution of traffic densities as well as vehicle type percentage.

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