Simulating the Impact of Increased Truck Traffic through Tunnel Crossing Mobile River

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ABSTRACT

This paper presents the development of a simulation model to evaluate the impact of increased 18-wheel truck traffic on the I-10 tunnel crossing the Mobile River in downtown Mobile, Alabama. The increased truck traffic is resulting from overall globalization of international trade and from truck traffic resulting from the expansion of the container terminal at the Port of Mobile. A number of alternatives were evaluated to reduce passenger traffic while increasing truck traffic, including alternative passenger traffic routes, carpooling and passenger car ferries. Included in this paper are a description of the simulation model, the experimental design, the simulation results and lessons learned.

1. INTRODUCTION

The interstate system in the U.S. is experiencing rapid growth in truck traffic. One reason for this increase is the globalization of international trade. The growth in commuter and truck traffic is significantly increasing the congestion at the I-10 tunnel crossing the Mobile River in Mobile, AL. In addition to the overall effects of growing international trade, area-specific growth of container shipments is occurring at the Mobile Container Terminal at the Port of Mobile, AL. The majority of containers at the recently expanded Port of Mobile are arriving and departing on trucks.

Figure 1 is a map of the Wallace tunnel on I-10 that crosses the Mobile River in downtown Mobile, AL. The Mobile Container Terminal is approximately two miles south of the tunnel and adjacent to I-10. Eastbound truck traffic exiting the tunnel continues on the Jubilee Parkway (I-10) across Mobile Bay. The Jubilee Parkway is a 7.5 mile girder bridge. Depending on the destination, westbound truck traffic exiting the tunnel will stay on I-10 towards Mississippi, take I-10 to I-65 North, or exit at

Figure 1: I-10 through Downtown Mobile, AL

Water Street and travel south to the Mobile Container Terminal or north to I-65 via I-165.

The increase in commuter and truck traffic is significantly increasing the congestion through the Mobile tunnel. A number of alternatives have been suggested to reduce this congestion. Some alternatives that have been proposed are 1) rerouting passenger traffic, 2) encouraging carpooling and 3) deploying passenger car ferries or transit (bus or rail). This paper presents the application of simulation to initiate the evaluation of these alternatives.

2. SIMULATION MODEL

Figure 2 gives the conceptual framework for the tunnel simulation model. Since traffic moves freely in the off-peak direction, the model only simulates the traffic moving in one direction in the tunnel. The simulation model was written in ProcessModel (1999).

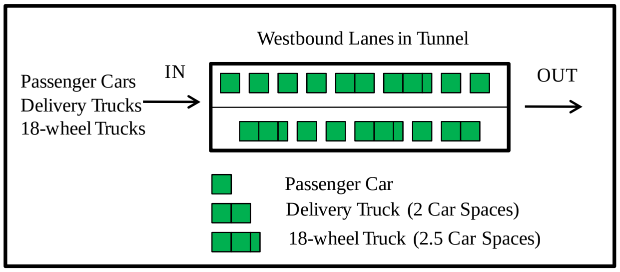

Figure 2: Conceptual Framework for Tunnel Simulation Model

3. VERIFICATION AND VALIDATION

Model verification can be defined as determining if the model is correctly represented in the simulation code. Verification was accomplished by eliminating all variation in the model and only using constants for all arrival times and service times. The times through the system could then be readily compared with the input data.

Model validation is determining if the model is an accurate representation of the real world system (Harris et al. 2008). ProcessModel has a "Label" block that displays data generated by the global variables during the simulation (ProcessModel, 1999). By slowing the simulation down it is possible to observe these values as the entities move through the simulation. A group of transportation experts were placed in front of the computer to observe the model operation. The model only simulated the peak hour traffic in one direction through the tunnel. A total of eleven percent of the daily traffic volume, or 6,560 vehicles, occurred during the peak hour. Fifty-five percent of the peak hour traffic, or 3,608 vehicles, moved in one direction. The simulation model was run for one hour to reach steady state and then for another eight hours. The average hourly traffic volume was 3,610 vehicles and compares to the actual volume of 3,608 vehicles.

4. EXPERIMENTAL DESIGN

Table 1 defines the experiment. Run1 was the baseline run to simulate existing traffic volumes during the peak hour. The second set of runs, Runs2&3, increased the directional traffic split from 55% to 60% and 65% while maintaining the 11% of the total daily traffic. The third set of runs, Runs4&5, increased truck traffic 5% and 10% while keeping other traffic volumes constant. The fourth set of runs, Runs6&7, decreased passenger car traffic by 5% and increased truck traffic by 5% and 10% respectively. Runs8&9 decreased passenger car traffic by 10% and increased truck traffic by 15% and 20%.

Table 1: Experimental design

Run	Description
Run1 (Baseline)	Existing traffic volumes
Run2	Increase traffic volume to 60%
Run3	Increase traffic volume to 65%
Run4	Increase truck traffic 5%
Run5	Increase truck traffic 10%
Run6	Decrease car traffic 5% and increase truck traffic 5%
Run7	Decrease car traffic 5% and increase truck traffic 10%
Run8	Decrease car traffic 10% and increase truck traffic 15%
Run9	Decrease car traffic 10% and increase truck traffic 20%

5. BASELINE RUN

The input data for the Baseline Run1 consisted of:

- 1.2 miles tunnel length from US 90/98 exit 27, through the tunnel to Water Street exit 26B. The actual tunnel length is approximately one-half mile. However, once a vehicle passes one of the above exits, the vehicles are committed to proceed through the tunnel. Therefore, for modeling purposes the length of the tunnel is 1.2 miles.
- Four lanes of traffic in tunnel, two lanes in each direction.
- Assumed speed of 55 mph maximum speed though the tunnel.
- 59,630 daily volume of vehicles through tunnel.
- 11% of daily volume occurs during peak hour.
- 55%/45% directional split for peak hour traffic.
- Daily percentage of truck traffic is 15% of total traffic volume. During peak hour, the percentage of truck traffic is 11%.
- 10% of delivery truck traffic during peak hour.
- 79% of passenger traffic during peak hour.
- Highway Capacity Manual lists the maximum density for a basic freeway section to be 45 passenger cars per

mile per lane, which translates to 117-feet per passenger car per mile.
- Vehicle time in tunnel follows triangular distribution with parameters of 1.243, 1.309, and 1.374 minutes (based on 55 mph).

It should be noted that the model was run based on the peak hourly traffic and consequently models the worse case scenario. Traffic is less during the non-peak hours and congestion would also be less. The sources of the input data are the Alabama Department of Transportation and the South Alabama Regional Planning Commission.

The traffic volume to capacity ratio for the tunnel is defined as the number of vehicles in the tunnel divided by the tunnel capacity for vehicles. The volume to capacity ratio is a standard measure used to quantify congestion. A volume to capacity ratio of more than 90% indicates a deficient condition, or congestion, on that segment of highway according to the Alabama Department of Transportation specifications (UAH 2005).

The capacity of vehicles in the tunnel is defined as the number of car spaces, or car slots, in the tunnel. A car space is assumed to be 117 feet. Then a total of

<u>1.2 miles (length of tunnel) x 2 lanes per tunnel</u>
117 ft per car slot

= 108 car slots

The size and operating characteristics of trucks cause them to require more space than passenger cars. Since all vehicles must travel on up/down grades when using the tunnel, the assumption was made to treat one delivery truck space as equal to 2 passenger cars and one 18-wheel truck space as equal to 2.5 passenger cars (which is consistent with the *Highway Capacity Manual* for rolling terrain). The ProcessModel has a global variable named Capacity that is incremented as vehicle spaces are in use (that is as vehicles enter the tunnel) and decremented as vehicles exit the tunnel.

6. SIMULATION RESULTS BASELINE RUN1

The Baseline run had a two-hour warm-up and ran for eight hours. Table 2 gives the results of the Baseline Run1. A total of 77 vehicles were in the tunnel at the end of the simulation and occupied 97 car slots. As a result 89% of the car slots were occupied, or the traffic volume to capacity ratio was 89%. Most transportation planning organizations consider a volume to capacity ratio greater that 90% as congestion. Since the tunnel volume to capacity ratio was 89%, there were no time delays and no queue buildups of vehicles waiting to enter the tunnel. Consequently, there could be a small increase in tunnel traffic volume before experiencing delays.

Table 2: Baseline Run1 simulation results

Output	Cars	Delivery Trucks	18-Wheel Trucks	Total
Vehicles in tunnel at end of simulation	61	8	8	77
Slots in use at end of simulation	61	16	20	97
Volume to capacity ratio				89%
Average delay entering tunnel (min)	0	0	0	
Average queue entering tunnel	0	0	0	
Hourly traffic	2,857	359	394	3,610

7. INCREASE IN DIRECTIONAL TRAFFIC SPLIT

The Baseline Run1 indicated a volume to capacity ratio of 89%. Therefore, a small percentage increase in traffic is possible before reaching the congestion level of 90%. The input data was changed from a 55% directional traffic split to 60% and 65%, respectively.

Table 3 gives the simulation results for Runs2&3. The simulation model had a two-hour warm-up and ran for eight hours. The volume to capacity ratio for Run2 was 99% indicating congestion. The volume to capacity ratio for Run3 was 100%. Both runs had large buildups of traffic waiting to enter the tunnel. The ProcessModel for Run3 was only run for four hours because of the queue buildups. A volume to capacity ratio of less than 100% should result in no traffic buildup waiting to enter the tunnel. However, for Runs2&3 the system can be considered unstable because of the 100% volume to capacity ratio for Run3 and the delays beginning to occur for Run2. The longer the simulation for Runs2&3 the greater these traffic buildups will become.

Table 3: Simulation results for Runs2&3

Output	Run1	Run2	Run3
Directional traffic split	55%	60%	65%
Vehicles in tunnel at end of simulation:			
Passenger cars	61	67	69
Delivery trucks	8	8	8
18 wheel trucks	8	10	9
Slots in use at end of simulation	97	107	108
Volume to capacity ratio	89%	99%	100%
Average delay before entering tunnel (min):			
Passenger cars	0	2	17
Delivery trucks	0	2	17
18-wheel trucks	0	2	17
Queue length before entering tunnel at end of simulation:			
Passenger cars	0	295	1,455
Delivery trucks	0	37	185
18-wheel trucks	0	40	205
Average hourly traffic:			
Passenger cars	2,857	3,158	3,169
Delivery trucks	359	392	404
18-wheel trucks	394	431	445
Hourly traffic	3,610	3,943	4,018

8. INCREASE IN TRUCK TRAFFIC

The input data for Runs4&5 was modified to include an increase in truck traffic by 5% and 10% over the Baseline Run1, respectively. The simulation run had a two-hour warm-up and ran for eight hours. Table 4 gives the results for Run4&5. The volume to capacity ratio was 93% with a 5% increase in truck traffic and 94% with a 10% increase in truck traffic. These ratios suggest that both a 5% and a 10% increase in truck traffic result in congestion.

Table 4: Simulation results for Runs4&5

Output	Run1	Run4	Run5
Directional traffic split	55%	55%	55%
Increase in 18-wheel traffic	0%	5%	10%
Vehicles in tunnel at end of simulation:			
Passenger cars	61	63	64
Delivery trucks	8	8	8
18 wheel trucks	8	9	9
Slots in use at end of simulation	97	101	102
Volume to capacity ratio	89%	93%	94%
Average delays before entering tunnel (min)	0	0	0
Queue length entering tunnel at end of simulation	0	0	0
Average hourly traffic:			
Passenger cars	2,857	2,857	2,856
Delivery trucks	359	359	359
18-wheel trucks	394	413	434
Hourly traffic	3,610	3,629	3,649

9. DECREASE IN PASSENGER CAR TRAFFIC AND INCREASE IN TRUCK TRAFFIC

The input data for Runs6&7 was modified to include a 5% reduction in passenger car traffic and a continual increase in truck traffic of 5% and 10% respectively. The input data for Runs8&9 was modified to include a 10% reduction in passenger car traffic and a continued increase in truck traffic to 15% and 20% respectively. Table 5 gives the simulation results for Runs6 through 9. The volume to capacity ratio for Run6 was 89% and increased to 91% for Run7. The volume to capacity ratio for both Run8 and Run9 was 89%.

Table 5: Simulation results for Runs6 Through 9

Output	Run6	Run7	Run8	Run9
Directional traffic split	55%	55%	55%	55%
Decrease in passenger car traffic	-5%	-5%	-10%	-10%
Increase in 18-wheel traffic	+5%	+10%	+15%	+20%
Vehicles in tunnel at end of simulation for:				
Passenger cars	60	59	56	57
Delivery trucks	7	8	7	7
18 wheel trucks	9	9	11	10
Slots in use at end of simulation	97	99	97	96
Volume to capacity ratio	89%	91%	89%	89%
Average delay entering tunnel (min)	0	0	0	0
Queue lengths entering tunnel at end of simulation for all vehicle types	0	0	0	0
Average hourly traffic:				
Passenger cars	2,727	2,727	2,608	2,609
Delivery trucks	359	359	359	359
18-wheel trucks	413	434	454	472
Hourly traffic	3,499	3,520	3,421	3,440

10. CONCLUSIONS

Figure 3 is a plot of the volume to capacity ratios for the simulation runs. In summary the following conclusions are made for peak hour traffic through the I-10 tunnel:

- The current traffic through the I-10 tunnel during the peak hour is close to congestion with a volume to capacity ratio of 89% (Run1).
- An increase in the directional traffic split from 55% to 60% (Run2) resulted in a volume to capacity ratio of 99% that is above the 90% congestion.
- An increase in the directional traffic split from 55% to 65% (Run3) resulted in a volume to capacity ratio of 100% that is above the 90% congestion. Also, a large number of vehicles were waiting to enter the tunnel. Runs2-3 can be considered unstable where the arrival rate exceeds service rate. Consequently, the queues and delay times will continue to increase.
- A small increase of 5% in truck traffic (Run4) resulted in a volume to capacity ratio of 93%, resulting in congestion.
- A 5% increase in truck traffic with a 5% decrease in passenger car traffic (Run6) is possible with a volume to capacity ratio of 89%. However, a 10% increase in truck traffic (Run7) resulted in a volume to capacity ratio of 91%.
- A 15% increase in truck traffic with a 10% decrease in passenger car traffic (Run8) resulted in a volume to capacity ratio of 89%. A further increase in truck traffic to 20% with a 10% decrease in passenger car traffic (Run9) also resulted in a volume to capacity ratio of 89%.

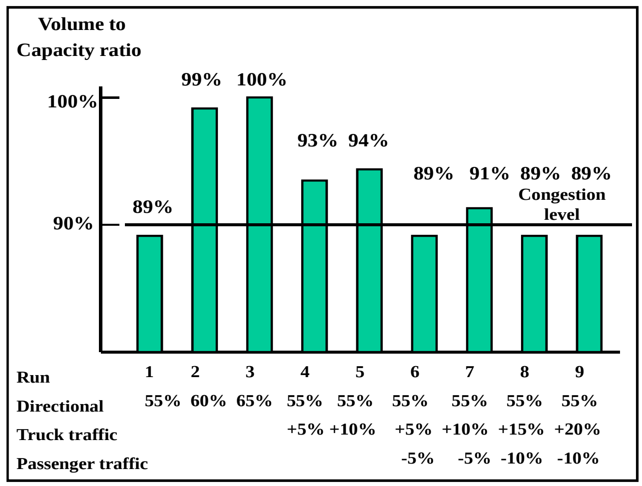

Figure 3: Volume to capacity ratios for simulation runs

Once the Baseline Run1 had been made and the volume to capacity ratio determined, it is possible to compute the increase in truck traffic given a reduction in car traffic. For example, Run9 had a 10% decrease in car traffic, or 285 cars. A total of 285 cars/2.5 slots per truck or 114 trucks, can occupy these slots. Therefore, a total of 508 trucks (394 from baseline Run1 plus 114) is possible before the volume to capacity ratio exceeds 90%. In summary, the results for Run9 are:

Decrease in passenger car traffic per hour:
2,857 (Run1) to 2,608 (-10%)
Increase in truck traffic:
394 (Run1) to 508 (+29%)
Slots in use at end of simulation:
98

Volume to capacity ratio:
90%
Average delays and queues:
0
Hourly traffic through tunnel
Passenger cars 2,609
Delivery trucks 359
18-wheel trucks 508

11. ERROR ANALYSIS

There is always a danger in using the absolute numbers from the simulation. For example, the volume to capacity ratios of 89, 90 and 91 percent may all represent congestion in the tunnel. Variability in the simulation can easily result in these differences. Therefore, it could be concluded that all these runs (See Figure 3) represent congestion.

Several runs were made with longer run times such as forty hours. These runs gave slightly different results especially the volume to capacity ratios. These differences may be due to the input variability in the times in the tunnel for different vehicle types.

12. ACKNOWLEDGEMENTS

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