SIMULATION IN INTERNATIONAL SERVICE – ANALYSIS OF WINDSOR-DETROIT TUNNEL TRAFFIC

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ABSTRACT

Discrete-process simulation, at first most heavily used for analyses of manufacturing operations, has steadily expanded its areas of application into provision of health care, service industries, supply and logistics, and transportation facilities. In the application described here, simulation documented quantitatively, and provided suggestions for ameliorating, severe delays at a publicly accessible transportation facility, the tunnel between Windsor, Ontario, Canada; and Detroit, Michigan, United States.

INTRODUCTION

Soon after the general availability of specialized simulation languages and subsequent software package tools (historically first on mainframe computers), simulation analysis was most frequently used to analyze, and improve the efficiency of, manufacturing operations (Law and McComas 1999). Since the ability of discrete-process simulation to provide accurate abstractions of numerous real-world systems is high, simulation analysis subsequently proved its value in the study, design, and enhancement of health care delivery systems (Standridge 1999), service systems and the hospitality industry (e.g., banks, stores, restaurants, hotels, and entertainment parks) (Starks and Whyte 1998), and transportation systems (harbors, railroads, highways, and airlines, for example) (Fishburn, Golkar, and Taaffe 1995). Excellent and specific examples of simulation to design and improve transportation systems appear in (Nanthavanij et al. 1996), (Tolujev, Straußburger, and Schulze 2000), and (García, Gutiérrez, and Moreno 2001). The analysis described here was devoted to quantitative assessment of the delays involved in traveling from Windsor, Ontario, Canada to Detroit, Michigan, United States via the Detroit-Windsor Tunnel.

BACKGROUND CONCERNING THE TUNNEL

The cities of Windsor, Ontario, Canada and Detroit, Michigan, United States are separated by the Detroit River, which joins two of the five Great Lakes (Huron, via much smaller Lake St. Clair) and Erie. The Detroit-Windsor Tunnel runs under the Detroit River, and the nearby Ambassador Bridge spans it. Before these vital international links were built, vehicles crossed the river on ferries. The tunnel, opened in 1930, was privately financed, built, and operated. The tunnel itself is slightly less than two kilometers long (Poremba 2001). Some two dozen buildings, housing tollbooths, customs offices, and immigration offices, represent infrastructure supporting this international tunnel. The tunnel itself accommodates one lane of traffic in each direction.

CURRENT IMPORTANCE OF THE TUNNEL – MOTIVATIONS FOR THE STUDY

The tunnel carries 17% of all vehicular traffic between the province of Ontario (Canada's largest province in an economic-output sense) and the United States. This traffic comprises about 4.4 million vehicles and 8.7 million travelers annually. "Vehicles" in this context includes not only privately owned automobiles, but also omnibuses and large lorries [trucks] hauling industrial and commercial goods for hire.

A significant underlying motivation of this study was the tragic attack upon the United States, via airplanes seized in flight, which occurred on 11 September 2001. Subsequently, the United States government greatly tightened security at border entry points, including the tunnel. Dramatic increases in delays to vehicles traveling from Windsor to Detroit proved very costly to commercial enterprises, especially in view of the recent popularity of lean manufacturing, which is intolerant of high inventories. Successful implementation of lean manufacturing requires frequent and strictly to-schedule delivery of goods, often, in the context of this study, via heavy lorry. Long delays also infuriated the traveling public and alarmed officials of Windsor's municipal government, since fire engines and ambulances were blocked on emergency runs by lines of vehicles on Windsor's thoroughfares awaiting access to the tunnel.

DATA COLLECTION

Significant data collection efforts were required in support of this study, despite the availability of some historical data. Tunnel management shared long-term data specifying weekly counts of vehicles through the tunnel over a year (January and April are the lightest traffic months; August the heaviest) and recent distributions of vehicles per day of the week (traffic volume rises gradually from Monday to Saturday by nearly 30%, then drops back rapidly to the Monday value). Since the client tunnel managers had requested a study of acknowledged limitations in scope to demonstrate feasibility of simulation use and to obtain quantitative results within eight weeks, additional short-term arrival data was collected. These data showed that the increase in traffic flow during "morning rush hour" from 5AM to 9AM was nearly independent of day of the week (Monday through Friday). Therefore, the client managers and the simulation analysts jointly decided to limit the scope of the study to the development of congestion within the tunnel each weekday morning.

Therefore, the simulation team, having obtained special clearance from the tunnel and customs authorities, gathered data on hourly vehicle arrival rates between 5AM and 9AM weekdays, including data on the (non-constant) relative proportions of automobiles, omnibuses, and lorries during those four-hour periods. Data collection also included the times required to pay the toll and the travel speeds of various vehicles through the tunnel (when unimpeded, automobiles travel faster than either omnibuses or lorries) and the average lengths of these three vehicle types. These lengths (about 5 meters for automobiles, 12 meters for omnibuses, and 18 meters for large commercial lorries) were of importance to calculate how many vehicles (automobiles, omnibuses, and lorries interspersed) could fit into the queues on the Windsor side of the tunnel to pay the tunnel toll. Next, the simulation team gathered observational data on customs-passage times for automobiles and omnibuses. These data comprised the following:

a) Distribution of time required to ask an automobile driver routine questions
b) Distribution of time required to search an automobile and its occupants thoroughly (the historical data are proprietary to the United States government, not the Detroit-Windsor Tunnel Corporation)
c) Fraction of automobiles pulled aside for thorough search (deciding to do so is at the discretion of customs officers, who may use random search and/or their intuition based on experience); an average of four automobiles are thus detained hourly
d) Distribution of time required for passengers to exit an omnibus, answer questions and show credentials, and reenter the omnibus.

On the United States side, heavy commercial lorries enter a separate lane for inspection of cargo manifests and possible extensive search. Due to both time constraints on the study and high secrecy attached to those data, quantitative analysis of the queuing performance relative to heavy commercial lorries was excluded from this study.

These empirical data were fitted to closed-form distributions using the BestFit distribution-fitting software tool (Jankauskas and McLafferty 1996); the Pearson V, Pearson VI, and gamma distributions (Law and Kelton 2000) often characterized empirical data well for this model.

CONSTRUCTION, VERIFICATION, AND VALIDATION OF THE MODEL

The model was constructed, using the SIMUL8® software model-building tool (Hauge and Paige 2001), as a series of storages (queues), work centers, and conveyors. Vehicles entering the system are provided three attributes (called "labels" in SIMUL8®) specifying their length, customs queue to use, and whether they are fated for an extensive search at United States customs. A vehicle traveling from Windsor to Detroit first queues for a tollbooth, which may be either automatic (accepting exact change or a previously purchased special token) or manned (hence able to make change). Omnibuses and lorries must pass through a designated tollbooth equipped to weigh them automatically and thence determine the correct toll. Vehicles from all tollbooths then converge upon the tunnel, which is modeled as an accumulating conveyor, inasmuch as no vehicle is permitted to overtake another within the tunnel. This characterization of the tunnel as a conveyor is an example of stepping mentally from reality to a conceptual model to a computer model (Krug 2001), inasmuch as "conveyor" is a primitive construct in SIMUL8® usually used in the simulation of manufacturing processes. At the far end of the tunnel, vehicles fan out to an appropriate customs queue. Lorries must go to queue #1; omnibuses, to queue #2. Automobiles choose the shortest of remaining queues. As a result of increasingly stringent security, vehicles are not allowed to wait within the tunnel (Capeloto and Windsor 2001). Therefore, the model implements logic which, upon sensing a queue for customs extending back to the tunnel exit, blocks vehicles on the Windsor side from entering the tunnel.

Model verification was undertaken primarily via desk checking and close examination of the animation corresponding to the simulation (Banks et al. 2001). Examples of errors thus detected and corrected were:

a) Misrepresentation of a work center's routing-out logic caused vehicles to stay indefinitely in an upstream work center
b) Misrepresentation of a work center's routing-out logic caused lorries and omnibuses to wrongly enter queues reserved for automobiles
c) An incorrectly specified work center cycle time caused maximum time-in-system to be preposterously long.

The most fundamental validation undertaken by the simulation team was to enter the tunnel from the Windsor side during each of the hourly intervals (5AM to 6AM, 6AM to 7AM, 7AM to 8AM, and 8AM to 9AM) and note the time taken to clear customs on the Detroit side. The actual times required, when compared to required times as predicted by the model, did not differ at the $\alpha = 0.05$ level.

Additional validation was done in collaboration with the client tunnel managers; they were shown both model animation and quantitative model predictions. Upon successful completion of this step, the model had attained not only validity, but also face validity, and hence credibility with the client.

RESULTS

Multiple replications of the model were run and compared under two scenarios typical at the time of the study: (1) five tollbooths open in Windsor and five customs booths open in Detroit; (2) five tollbooths open in Windsor and six customs booths open in Detroit. The two most significant performance measures of the tunnel are time-in-system and the percentage of time that access to the tunnel must be prohibited to vehicles wishing to enter it from Windsor to obey the prohibition against vehicles queuing within the tunnel itself. During the first half of the morning period (5AM – 7AM), scenario 1 was adequate. During the second half of the morning period (7AM – 9AM), scenario 2 quickly became dramatically superior to scenario 1, as shown in the following table.

Performance Metric		Scenario One	Scenario Two
Time in System	Mean	281 sec.	498 sec.
	Min	193 sec	195 sec.
	Max	1411 sec.	2502 sec.
% Blockage Time		2.9%	21.1 %

Hence, the closure of just one booth on the Detroit side nearly doubles the average time-in-system and multiplies by more than seven the probability that the tunnel will be closed to entry from the Windsor side at any given moment of time. Tunnel management quickly began to use these results in negotiations with the United States government relative to reassigning, at least temporarily, some military personnel from their regular duties to border patrol and customs duties to prevent severe increases in queuing times (Gray 2001).

LIMITATIONS AND INDICATIONS FOR FURTHER WORK

Due to the short time frame of this study, it concerned itself only with traffic flow on weekday mornings. Extensions of the study to other time periods would, as a practical matter, require automated data collection (e.g., via roadway sensors), inasmuch as traffic flow is too fast and complex for even several analysts observing simultaneously to monitor manually.

Also, automobiles, omnibuses, and lorries all have a fixed length in this model; a more detailed model would rely on probability distributions, based on extensive observations, to characterize vehicle lengths. Similarly, vehicle speed is either zero (when a vehicle is in queue) or 40 kph.

Since travel in the opposite direction (Detroit → Windsor) is not currently troublesome or delay-prone, due largely to high levels of customs staffing provided by the Canadian government, it was not modeled at all; that is, the tunnel was modeled as unidirectional.

CONCLUSION

This study proved itself an excellent example of using discrete-process simulation to model a publicly accessible transportation facility. The tunnel managers, now that they have become acquainted with the availability of and power of simulation analysis, are much more likely to extend its use in the future as changing conditions warrant. Also of high importance, the industrial engineering students who contributed to this project obtained valuable insight into the challenges of an *entire* simulation project (particularly data collection and analysis), versus the overly narrow view of "simulation as model building." (Black and Chick 1996). Furthermore, the results of this study were a significantly contributing factor to the United States government's decision to add 97 customs officers to Michigan's border crossings vis-à-vis Canada (Angel 2000).

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