Computer simulation: Modeling school system traffic flow with high population growth

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ABSTRACT

Medina Middle School will be increasing its student population by 100 students in the next two years, adding stress to the current carpool system that is already showing signs of overpopulation. Using advanced computer technology, software was used to accurately recreated the traffic system with the intention of increasing efficiency, reducing congestion, and providing alternative growth options in preparation for future increases in traffic flow. The results indicated that the current system will not be able to withstand the estimated increase in flow without delaying traffic significantly, blocking important city roads, decreasing child safety, and contributing to the concerning pollution problem. Therefore, one can conclude that to maintain high standards of safety, efficient traffic flow, clear roads, reduced fuel consumption and fewer carbon emissions, the school needs to create an additional pick-up area to evenly distribute the volume of traffic flow.

Keywords: computer simulation, traffic congestion, population growth, efficiency, safety

INTRODUCTION

Have you ever experienced the frustration of waiting in a long line to pick up school children? The typical process is stressful for the parents who must wait and for the frantically busy teachers and helpers, who must identify/verify the parents/guardians before allowing them to collect their children.

As regional populations rapidly increase, traffic systems are one of the first and most visible systems that are negatively impacted. In the most extreme cases, accidents and loss of life occur. More often, congestion and waiting create frustration, delays and reduced productivity. Additionally, congestion increases fuel consumption, carbon emissions, and pollution.

Medina, Tennessee is one of the fastest growing cities in west Tennessee (http://www.cityofmedinatn.org/). It is a bedroom community of Jackson with ten new housing subdivisions, a new middle school, and a high school that graduated its first class in 2012. During peak times when students are arriving to school, long lines are possible, including traffic congestion extending outside of the school property onto public roads. Emergency vehicle access could be severely restricted during these times.

Many different solutions exist. Most are expensive. However, which option is best is often unclear. Often, solving one bottleneck only shifts the bottleneck to another location, resulting in a new problem. Bottleneck shifting is a frequent occurrence when solutions are implemented directly on the real system without first evaluating a prototype or simulation. A proven solution to system (re)design is computer simulation. Computer simulation has been successfully used many times in the last 25 years; however, barriers still exist for its widespread use, especially in rural areas.

The primary benefit of this research project is a better understanding of traffic issues; however, potential tangible benefits include improved flow, increased safety, less waiting, less fuel consumption and fewer carbon emissions.

LITERATURE REVIEW

Using Simulation to Model Traffic Congestion

Computer simulation is a well-defined methodology of operations research and many excellent explanatory texts explain this methodology [13, 16]. The methodology is particularly useful in evaluating interdependencies among random effects that may cause a serious degradation in performance even though the average performance characteristics of the system appear to be acceptable [18]. Additionally, simulation models are intuitive to understand, which is an important reason for their longtime and continuing application to complex systems. As such, simulation has been used to study many types of systems, such as manufacturing and supply chain systems [1, 2, 5, 6].

Computer simulation is a tool that can be used to model alternative ways to alleviate traffic congestion. The use of computer simulation modeling was a success in 2001 when The National Capital Planning Commission (NCPC) formed an Interagency Security Task Force to examine ways to alleviate traffic congestion [7]. Tiger et al.(2010) used similar technology to model the impact of radio frequency identification (RFID) tags on school system pickups [19].

The Impact on Waiting in Traffic on Safety and the Environment

Ebbesen and Haney [8] performed an extensive field study and found that the probability of turning into traffic was directly related to the temporal distance of oncoming cars. Additionally, it was found that being forced to wait in line before turning substantially increased a driver's risk taking.

The toxins in car exhaust have the greatest impact on young people, old people, and people with respiratory problems, such as asthma, emphysema, and bronchitis. Children with respiratory problems are particularly at risk. According to the Center for Disease Control, the percentage of children with asthma jumped to 9% in 2005 from 3.6% in 1980 [14]. Although confounding variables make it difficult to ascribe exact causes for the increase, it is clear that the toxins in vehicle exhaust increase the number and level of asthma attacks and respiratory problems in children [17].

Automobile Fuel Consumption and Carbon Emissions While Idling

The United States consumes about one-fourth of the world's yearly oil production and produces about one-fourth of all carbon dioxide emissions [20]. One gallon of gasoline produces 19.564 pounds of CO_2, according to the Energy Information Administration [15].

Many school districts, primarily in metropolitan areas, now ask drivers to turn off vehicles while waiting to pick up children from school [3]. Several states and many municipalities have legal or voluntary restrictions against idling, most frequently for heavy-duty or diesel vehicles [9, 12]. Vehicle tailpipe emissions relate directly to gasoline combustion [4]. Running a vehicle at idle speed uses less gas than open road driving, therefore produces less exhaust. Unlike open road driving, however, emissions at idle are disproportionately affected by temperature, accessory load, idle speed, fuel-air mixture, and engine tuning [11]. The EPA offers the following advice, "You will save gas by turning the engine off and restarting it again if you expect to idle for more than 30 seconds. You will also prevent pollution by avoiding long idles [10].

To summarize, the literature shows that traffic modeling using simulation is an appropriate technique. Additionally, the literature suggests that traffic congestion has negative impacts on society. However, most traffic modeling literature focuses on urban areas. In this project, the focus is on a high growth rural bedroom community.

FORMULA FOR FUEL CONSUMPTION AND CARBON FOOTPRINT

The formula for CO_2 consumption due to waiting and idling is:

[X number of vehicles] x [(wait Y minutes) x (.00833 gallons/minute x 19.6 pounds of CO_2/gallon)] = Z lbs. of CO_2

The formula for fuel expense due to waiting and idling is:

[X number of vehicles] x [(wait Y minutes) x (.00833 gallons/minute x $3.75 per gallon)] =$Z.ZZ

SYSTEM DESCRIPTION

Medina Middle School, like any elementary school, is searching for the best way to combine child safety with increasingly efficient traffic control during morning drop-off and afternoon pick-up times. The current system provides an excellent skeleton for efficient traffic flow: (1) west-bound traffic has a left-turn lane; (2) cars turn into the car line and move forward as space becomes available; (3) once visible in some part from the porch, the car is allowed to pick up children; (4) full cars are allowed to move forward as they are able toward the exit, where a traffic officer determines which lane has the right-of-way as indicated in Figure 1.

While this system is typical of most elementary schools, several problems may arise from overlooked details. First, there is unnecessary congestion in the eastbound traffic lane as a result of the combination of school and other traffic. Second, cars are not encouraged to move forward as far as possible, wasting space and time in front of cars that choose to stop before the most forward open space. Finally, children who are allowed to go to cars that are not completely visible from the porch could create safety hazards, as they may not be seen by the teachers on guard or by the drivers of other cars.

The goal of the model is to look to further define the specifications of the current traffic system, as well as offer a fine-tuned critique of its details. Any solution will include suggestions for decreased congestion, increased efficiency of time usage, and, most importantly, an unwavering dedication to the ultimate safety of each student.

METHODOLOGY

Discussions were held with the middle school principal to (1) expose him to the benefits of simulation modeling on strategic planning and (2) gather ideas on what system to study. SIMUL8 software under the direction of a faculty advisor to model the traffic system was used for model building. Model building includes reproducing the actual system in the model, as well as validating, which is proving that it represents reality. Analysis includes testing different policies and evaluating their effectiveness on key performance indicators (kpi) such as average waiting time, maximum waiting time and throughput.

DATA COLLECTION

Data collection was a process that required at least two people and several days to complete, with three people making the job easier and more efficient. Collection involved driving to Medina Middle School in Medina, Tennessee and arriving about ten to 15 minutes prior to the start of the afternoon pick-up traffic. This free time allowed discussions with the administrators, designating counting zones and performing pre-flow counts, or assessments of the system before operation.

In addition to counting cars, the software also needed time-specific data in order to realistically represent the current level of efficiency in the model. The pick-up zone is a section of the driveway that is marked off with white paint to designate the area in which children are supposed to be allowed to walk to their cars. This area can hold an average of four cars per lane, or eight cars total, so long as each car follows the car in front of it for as long as it is moving, or until it reaches the second line.

Pickup begins at 2:45. Approximately 200 cars arrive to collect middle school students. The time between cars was assumed to be exponential. The average pickup time was 39 seconds for the lane closest to the school and 35 seconds for the lane farthest. The reason for the discrepancy was that the cars in the closest lane often had to wait for students to cross in front.

The average time in the system, which included waiting to reach the pick-up zone, picking up children, and leaving the system was about 4 minutes.

MODEL BUILDING

The SIMUL8 model is an object-oriented programming language that also provides a procedural language for complex decisions. The SIMUL8 code is available upon request. An easy way to explain the process is to look at an individual car in the system. A car is created coming from the west and returns to the west after it has picked up a child. As the car enters the system, it immediately starts to run the program code. The first code is whether to turn into the school's driveway or not. Despite the school traffic clogging up the road, there are cars that continue straight on the road rather than enter the school.

Once the car enters the pick-up circle, it follows other cars to the pick-up area. This process can take a few minutes, and if one lane becomes stagnant, the car may switch to another lane to decrease its total wait time. Once in the designated pick-up zone, the car goes through of series of logic programs to pass through in the most efficient manner.

If the car entered from the west and never changed lanes, it simply follows the same lane back to the main road and waits for the traffic officer to allow it to turn back to the west. If it switched lanes prior to the pick-up zone, it must first switch lanes again to turn back to the west once it reaches the main road. The traffic officer either waits for traffic to clear or stops the main road traffic before permitting the cars to exit to prevent bottlenecks in the middle school exit driveway. To do this productively and efficiently, the traffic officer simulation code checks the west bound lane of traffic and the exit driveway of the school every second. If the car queue is long, the officer will stop all traffic from the east and west and let the cars leave the school grounds.

MODEL VALIDATION

To fine tune the model and validate that the model represented the real system, a series of ten trials were run. To find key performance indicators (KPIs), the simulation results were compared to the data collected as indicated in Table 1.

The p-values from t-tests of the means show that no difference existed between the system and the model for most KPIs. For the last KPI, Max Queue (west bound), the original data collection only included counting cars in the left turn lane and did not include counting cars in the lane that fed the left turn lane.

ANALYSIS

Once validated, an increase in the traffic volume representing the expected additional traffic when 3rd grade is moved from the elementary school to the middle school in 2013 modified the system. An additional 100 cars is expected in two years as indicated in Tables 2, 3, and 4.

The impact of the increased traffic creates a system with very long lines and waiting times. The average time in system jumps to almost 9 minutes. Potentially, 100 cars could be in the system at the same time, creating public road congestion. This amount of congestion prevents emergency vehicle access; increases frustration and rash decisions; wastes fuel and increases the carbon footprint.

Results were shared with the Medina Middle School principal. Although surprised, he definitely believed the model results. As a result, additional pickup locations and policies are currently being developed. The model can be modified to test future design proposals prior to implementation.

CONCLUSIONS AND REFLECTIONS

Traffic simulation modeling leads to a better understanding of the afterschool pickup system at Medina Middle School. During the first and most basic step, collecting data, it quickly became more complicated than anticipated. Even with three people collecting specific data, it could quickly become overwhelming. Between counting and timing multiple lanes of traffic, it was not difficult to fall behind. By the second time, enough data was collected and it became somewhat more organized. Once the most efficient manner was discovered the flow of the pickup process was figured out. Ultimately, the importance of the data collection process and how accurate it must be in order to represent a true-to-life model of the system was discovered.

The next step, modeling, gave everyone a much better understanding of SIMUL8's software operations and capabilities. The software forced abstract thought and creativity to build logic from scratch using the software. The entire modeling process was a continuous learning experience. Through trial and error areas were slowly realized that had been overlooked or needed improvement. One of many possible examples was an issue with model cars lining up so far back in the road that the other cars could not exit when they were finished. The software does not automatically allow them to come through at random like the vehicles would in reality. Therefore, the solution was to direct it to do so by writing code. This is an example of a situation that was not initially anticipated but was corrected upon discovery. This experience gave a better understanding that many projects, whether in this field or others, are going to require time and patience in order to produce the best possible finished product. There is no textbook method to solving all possible kinds of issues, and this provided an experience to know how to better correct them.

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TABLES AND FIGURES

Figure 1. Medina Middle School Pickup Layout

Table 1. Model Validation Results

KPI	System	Model	P-value
TIS (min:sec)	3:59	4:30 (included some public road time)	0.23
NIS	21.6	20.2	0.12
Max Queue (east bound)	8	7	0.35
Max Queue (west bound)	6 (only counted left turn lane)	20	<.001

Table 2. Data Collection Results

KPI	200 (CURRENT)	250	300
AVG TIS (minutes)	4.5	6.5	8.6
AVG NIS (cars)	20	36	58
Max Queue – east bound cars	7	14	31
Max Queue – west bound cars	20	59	96

Table 3. Average Time in System

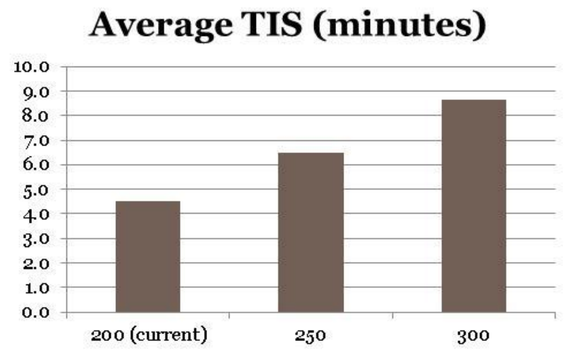

Table 4. Maximum Queue