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## Optimizing High Volume Traffic Surges using Discrete Event Simulation

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OPTIMIZING HIGH VOLUME TRAFFIC SURGES USING DISCRETE EVENT  
SIMULATION

By

Claire L. Johnson

A Thesis Submitted to the  
Department of Human Factors & Systems  
in Partial Fulfillment of the Requirements for the Degree of  
Master of Science in Human Factors & Systems

Embry-Riddle Aeronautical University  
Daytona Beach, Florida  
May 23, 2011

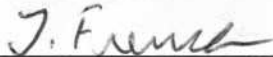
# OPTIMIZING HIGH VOLUME TRAFFIC SURGES USING DISCRETE EVENT SIMULATION

By

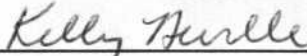
Claire L. Johnson

This thesis was prepared under the direction of the candidate's thesis committee chair, Jon French, Ph.D., Department of Human Factors & Systems, and has been approved by the members of the thesis committee. It was submitted to the Department of Human Factors & Systems and has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Human Factors & Systems.

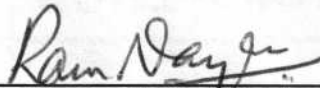
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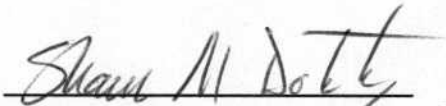
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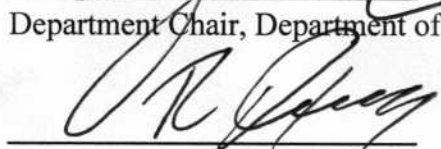
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## ABSTRACT

The purpose of this applied research study is to determine the fidelity of a discrete event simulation tool called the Evacuation Simulation Prediction Tool (ESP) in predicting transit times during a high volume surge in traffic flow. The ESP tool was developed for the purpose of predicting and optimizing large-scale evacuations of counties or regions as an aide in emergency and disaster preparedness planning. The goal of the ESP model is to ascertain the balance of traffic flow capacity by managing the human factor events that impinge upon orderly highway travel without immobilizing the travel route. The objective of this discrete-event simulation is the application of optimization techniques to create models with a variety of outcome reliabilities. For this study, evacuation of a large number of vehicles was estimated by the traffic surge that results annually from the Daytona International Speedway (approximately 100,000) immediately following the NASCAR™ Nextel Cup Daytona 500. These results were used to determine the effectiveness of the ESP predictions before it could be used to recommend ways to optimize traffic surges during emergencies. The results of this study indicated that the ESP tool accurately predicted the outcome of the Daytona 500 traffic surge under the study conditions. After the predictability of the ESP tool in predicting traffic flow during the race-day surge was validated, optimization techniques were applied to further study the usefulness of the model for other large traffic problems. The parameters were incorporated into the ESP tool to determine the accuracy of the outcome. The results of this study may be useful in considering modifications to traffic flow during real world emergencies such as hurricanes or other potential disasters.

## **ACKNOWLEDGEMENTS**

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A special thank you goes out to my friend and my boss, Kristen Nagrani, you have continually encouraged me to make more of myself even in the face of adversity, and for that, I am truly grateful.

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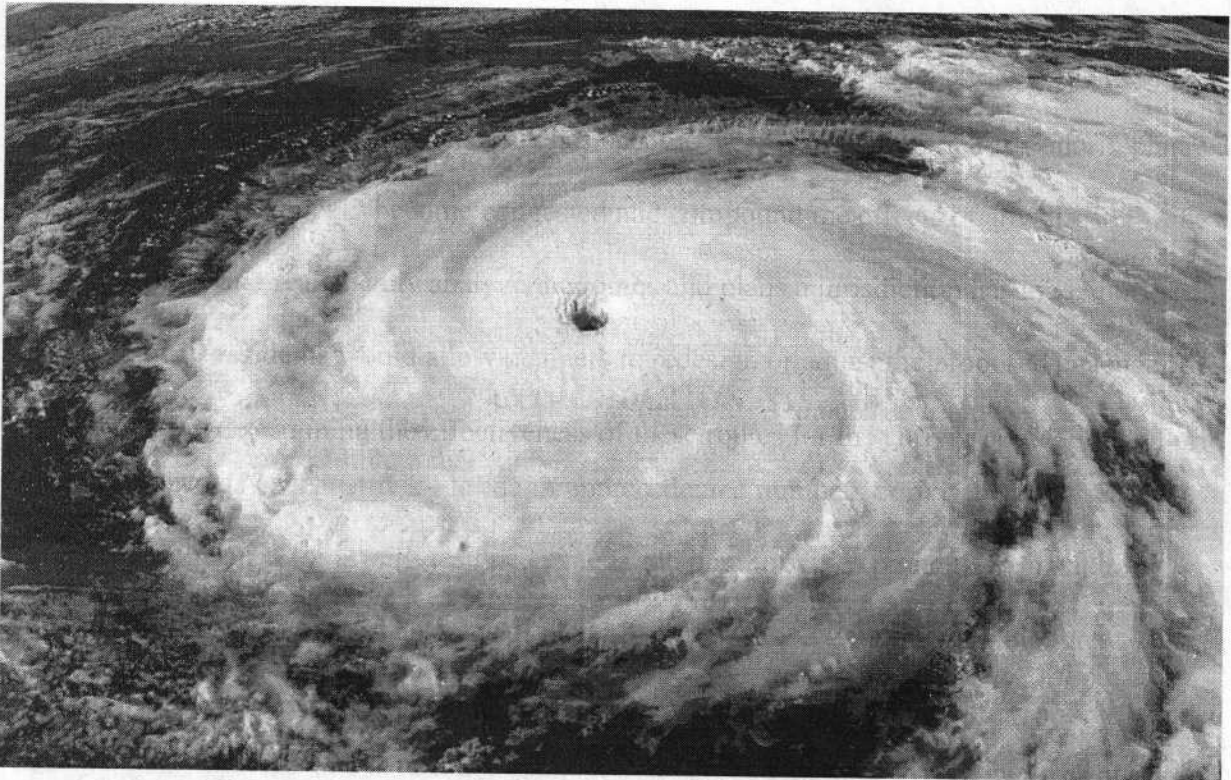


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## INTRODUCTION

The hurricanes that struck Florida in unprecedented numbers during the 2004 season demonstrated the need for a well-designed evacuation plan for cities prone to such natural disasters. With many of the urban areas of the U.S. growing, and with the possible threat of terrorist attacks, mass evacuation planning has become increasingly important. A poorly planned evacuation route can quickly become congested and compound the effects of any disaster. The ability to rapidly and realistically analyze the routes and plans a jurisdiction has made for the evacuation of its residents would allow planners to redesign or adjust the proposed evacuation routes and aid in determining the effectiveness of these routes for the current population, all prior to the event.



*Figure 1.* Hurricane Rita (2005) followed Hurricane Katrina. Rita landed near Port Arthur Texas and caused much concern because of the damage done by Katrina. Rita did far less damage but created evacuation problems.

Evacuation planning is a crucial task for managing public safety. Whether natural (flood, hurricanes, etc) or man-made (release of chemical or toxic substances, etc), disasters require that emergency personnel be able to move affected populations to safety in as short a time as possible. Despite the increased threat of disasters posed by global climate change and the rise of terrorism, however, current evacuation planning tools have serious limitations. Evacuations conducted during Hurricane Rita in 2005 were a stark reminder of how much can go wrong despite intensive emergency preparation. Most everyone remembers the damage caused by Katrina in 2005 because of the impact it had on Louisiana. Still, the evacuation was orderly and most everyone who could get out did so. Soon after the aftermath of Katrina, a weaker hurricane, Rita, hit the Texas coastline. Over a million residents fled Rita, perhaps panicked by the idea that the coastal regions would suffer a crushing blow. The traffic system was not designed for the crush of traffic and many days of problems resulted. For example, Figure 1 shows an overhead view of Hurricane Rita at her peak, and Figure 2 shows the miles of backed-up traffic that occurred as Houston residents followed orders to flee the path of Hurricane Rita. Efficient and effective tools are needed to produce plans that identify optimal evacuation routes and schedules, given a transportation network, road capacity constraints, destination, and population.

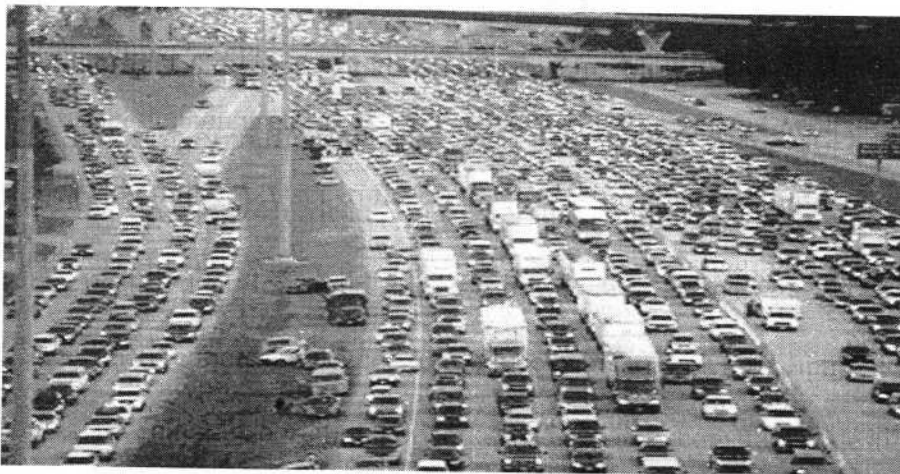


Figure 2. Traffic Conditions during Hurricane Rita (2005), the roadways were not designed for the volume that occurred during the evacuation for Rita.

Many thousands of dollars are spent studying past evacuations in hopes of determining how a more organized, safe, and efficient evacuation could be implemented the next time disaster strikes. However, these studies often take months to prepare and by the time they are presented they are no longer pertinent because conditions have changed; roadways under construction are open for example, and the wind and surge conditions are usually different for each hurricane. If planners had a tool that could adapt to the conditions they expect, the volume, the choke points, they might be able to conduct a more orderly, safe and effective evacuation.

### ***Emergency Preparedness***

The logistics of evacuating a major city are overwhelming. The evacuation of New Orleans during Katrina ran somewhat smoothly, with very few traffic accidents or fatalities, causing fewer traffic backups (Wolshon, Urbina, Wilmot, & Levitan, 2005). The evacuation plan enacted was the result of two botched evacuations for hurricanes Georges and Floyd, both of which fortunately passed east of the city. Committees of people went to work trying to improve the evacuation plans to allow everyone to get out of the city in the fastest and most efficient way possible. The result was the creation of contraflow patterns for traffic in the city (Wolshon, Urbina, Wilmot, & Levitan, 2005). Contraflow lane reversal refers to plans that alter the normal flow of traffic, typically on a controlled-access highway, to either aid in an emergency evacuation or as part of routine maintenance activities, to facilitate widening or reconstruction of one of the highway's carriageways. There were also some issues with getting everybody out of the city because many people did not own a car or were elderly and could not evacuate. Another major issue was a failure of communication. There was no way for officials to know which

routes out of the city were backed-up and which routes were flowing freely (Wolshon, Urbina, Wilmot, & Levitan, 2005).

There are three key factors to take into account when creating an evacuation plan, exit capacity, internal traffic flow, and the percentage of people who have access to a vehicle. In New Orleans, the exit capacity is roughly 67% (American Highway Users Alliance, 2006) which means that if the evacuation goes smoothly, the roads outside of New Orleans will be able to accommodate two-thirds of the population in twelve hours. To improve New Orleans, there would have to be wider roads with more entrance and exit points to prevent bottlenecking on the major highways. The contraflow plan helps with this figure.

Another useful figure that ties in with exit capacity is the internal traffic flow. This is a measure of traffic within the city during an evacuation. It is based on the average travel delay time during an evacuation. New Orleans did fairly well in this category with an average travel delay time of about 19%, corresponding to an internal traffic flow rating of 81% (American Highway Users Alliance, 2006). This is measured with the Travel Time Index, which uses the ratio of the commute in an evacuation to the time that it takes to travel that distance on any normal day (Bureau of Business Research, 2006). Therefore, in the case of New Orleans, it takes about 19% more time to travel from one part of town to the other when there is an evacuation going on compared to when there is no significant traffic.

The final major factor in determining the overall evacuating capacity of a city is the percentage of people who have access to a car. This does not mean that they own a car. It only means that they can find a ride out of the city, with either a neighbor, family member, or a friend. In New Orleans, about 91% of the population had access to a car. (American Highway Users Alliance, 2006) Finally, all of these factors were averaged together with different weights



to calculate the evacuation capacity of New Orleans. This figure was used to rank New Orleans amongst other major cities. In a study of thirty-seven major cities with a population of over one million people, New Orleans ranked twelfth with an evacuation capacity of 67.3% (American Highway Users Alliance, 2006). This number represents the likely percentage of people who will be able to evacuate New Orleans in the peak twelve hours of the evacuation process.

Another concern in an evacuation is the roadway capacity, or the percentage of people who can theoretically evacuate the city if the roads were the only limiting factor. This is found by averaging the internal traffic flow and the exit capacity to get 74%, which is higher than the evacuation capacity because the evacuation capacity takes into account the people who do not have cars (American Highway Users Alliance, 2006).

Overall, New Orleans had a reasonable plan in place. During Katrina, the people who evacuated did so with very few problems. The major issue they faced was how to deal with the people who could not or did not evacuate the city. To keep New Orleans safe, it is necessary to implement an evacuation plan that moves everyone to safety. Perhaps those that remained in New Orleans, and the many that lost their lives, were lulled into complacency not to evacuate because the city and the levees had survived all previous hurricanes. In spite of the severity of Katrina, they may have believed there was no danger. There is no need for people to be stuck on top of their rooftops waiting for boats and helicopters to come by and help them out if adequate evacuation plans for the entire population are available and if the dangers for each threat are made realistic and convincing to the public.

## ***Government Response***

On June 1, 2006, the U.S. Department of Transportation (DOT), in cooperation with the U.S. Department of Homeland Security, presented the *Catastrophic Hurricane Evacuation Plan Evaluation: A Report to Congress*. This study, when discussing the Gulf Coast region, stated that the actual operation of transportation systems throughout the course of catastrophic incidents is one of the most important parts of the evacuation and that understanding the time required for evacuations is essential for all those who must evacuate to do so safely (U.S. Department of Transportation, 2006).

Within this review of Evacuation Operations, the DOT further described that even though a number of evacuation planning operation models have been developed by federal agencies and are available to state and local agencies, many emergency managers forego study updates because their 25-percent share of the cost of the study is a significant constraint. The cost to develop and update plans varies based on the population, geography and surge areas, the number of potential evacuation routes to be analyzed, the demographics of the area, the number of neighboring jurisdictions to coordinate with, and other factors. According to the DOT report, the states do not appear to budget specific amounts for evacuation planning but include these costs within broader emergency management programs.

Additionally, the 2006 Report to Congress stated, "If outdated studies are used, the times required to evacuate may not take into account new development, highway improvements that have been made and other changes that have occurred." (U.S. Department of Transportation, 2006, p. 82) Availability, cost constraints and lack of up-to-date highway construction information may hold local emergency planners back from assembling accurate evacuation plans and routes in the critical days and hours leading up to an evacuation.

On February 14, 2006, Jack E. Little, Task Force Chairman, submitted the *Governor's Task Force on Evacuation, Transportation, and Logistics: Final Report to the Governor* to Texas Governor Rick Perry. This study was a joint effort among the counties of Texas to study the problems encountered with the evacuations preceding the landfall of hurricanes Katrina and Rita on August 29, and September 22, 2005 respectively. The purpose of this 14-member task force appointed by Governor Rick Perry in cooperation with Harris County Judge Robert Eckels and Houston Mayor Bill White was clearly defined by the Governor:

“Hurricane Rita highlighted the tremendous challenges associated with evacuating a major American city, as well as strengths and weaknesses in state, local and private evacuation plans. While we achieved the ultimate goal of moving millions of people to safety in a matter of hours, we can and must do better the next time we are faced with an emergency.” (Governor's Task Force on Evacuation, Transportation, and Logistics, 2006, p. 21)

As evidenced by these two reports, it seems obvious that more needs to be done with regard to emergency preparedness management. The occupants of the gulf coast region, having been devastated by these significant hurricanes, have asked what could have been done better. When faced with this type of situation, every available tool must be considered. A non-cumbersome and simple-to-use tool would give a good idea of when to disrupt the community by ordering an evacuation. The timing for an evacuation is crucial, and it needs to be based on the impact of the emergency events as well as the expected time all the residents who wish to leave to do so. This paper is about such a tool, an evacuation tool that will provide a rapid estimate so the time limits involved and the effectiveness of different optimization strategies may be considered.



## *Human Behavior in Evacuation*

When faced with an emergency, such as a hurricane, tornado, or other natural disaster, often the best solution for staying out of danger is evacuation. It is at times such as these that emergency management officials must ask themselves some difficult but pertinent questions. Will the number of vehicles on the highway be so great that a large number of vehicles may be unable to proceed, leading to a lack of fuel and a failed evacuation? Will drivers panic because they feel they are moving too slowly and are unable to reach safety?

We must begin evaluating these questions by first understanding the conditions that promote panic. Citing the works of Tierney, Lindell, and Perry (2001); Drabek (1986); and Dynes, Quarantelli, and Kreps (1981), Auf der Heide (2004) suggests that the following conditions are generally present concurrently to trigger panic: (1) the victim perceives an immediate threat of entrapment, (2) escape routes appear to be rapidly closing, (3) flight seems to be the only way to survive, and (4) no one is available to help (Auf der Heide, 2004). Panic can sometimes occur in a natural disaster, however with the amount of public notification provided by the media prior to hurricane landfall, it seems unlikely that all the conditions leading to panic would simultaneously occur and elicit a widespread panic among evacuees. The media certainly aides in preparing the community for the impending disaster, but it is also the media that continues to contribute to the misconception of panic. The media uses the term panic to entice people to watch; panic is exciting and excitement sells the story. The following example is provided in *Common Misconceptions About Disaster* (Auf der Heide, 2004):

Hurricane Carla, Galveston, Texas, 1961 was a category 5 hurricane, the highest level on the Saffir-Simpson scale. It was the worst hurricane to hit the Texas coast in 40 years, having sustained winds of over 150 miles per hour as it positioned

itself to strike the mainland. Headlines in several newspapers reported, "More than 100,000 persons flee in near panic." Actually, 70–80% of those on Galveston Island remained during Carla, even though most knew they would be cut off from the mainland. Islanders boasted of having had beach parties during the hurricane. After Carla, a Galveston professional man said that he was "very proud of not having evacuated." His parents had never fled before a storm, and neither had he. For those that did leave, the evacuation was reported as calm, business-like, and without panic (pg. 75).

Auf der Heide also asserts that a number of systematic studies of human behavior in disaster have failed to support news accounts of widespread panic. Citing Dynes, et al (1981), Auf der Heide notes that when panic does occur, it usually involves few persons, is short-lived, and is not contagious.

### ***Evacuation Planning***

Software tools enabling city/county/state managers and other disaster planning departments to estimate the effects of different evacuation plans save an enormous amount of time and funding. Software tools may be able to reach the same findings as a panel studying the problem; only the software tool completes the job in hours instead of weeks or months, and allows managers to draw conclusions based on the most current information as opposed to older data. Software tools permit managers to explore the consequences of multiple plans by allowing them to manipulate different parameters.

One of the tools currently available is the *Urban-to-Rural Evacuation Modeling Tool* developed by the Western New York Public Health Alliance. "The Urban to Rural Evacuation

Modeling Tool is an online, map-based application that predicts rural and suburban population surge following potential urban disasters and provides information on county resources important to preparedness planning.” (Western New York Public Health Alliance, 2010, p. 1) It was developed primarily to estimate the numbers and travel directions of urban evacuees in order to stimulate effective preparedness planning. Users can currently choose from three planning scenarios: dirty bomb, pandemic flu or chemical incident. The model uses scenario-specific variables to determine how urban residents are "pushed" into surrounding areas. "Pull" variables are based on the resources, distances and other aspects of neighboring counties. The result is an easy-to-use interface allowing users to view the number of evacuees predicted to arrive within each nearby county or the change in county populations that would result. The tool also displays the available resources of each county, such as hotel rooms, campgrounds and hospitals.

Another tool currently in use is the *Evacuation Plans and Procedures eTool* available from the United State Department of Labor: Occupational Safety and Health Administration (OSHA). This particular tool aides business in creating an emergency action plan (EAP). The purpose of an EAP is to facilitate and organize employer and employee actions during emergencies. “Well developed emergency plans and proper employee training will result in fewer and less severe employee injuries and less structural damage during emergencies.” (Occupational Safety & Health Administration, 2010, p. 2)

These methods suffer from three limitations: they may not scale up to large (e.g. more than 50,000 vehicles) transportation networks in urban evacuation scenarios as they use time-expanded networks requiring large amounts of computer storage and aim at computing optimal solutions incurring exorbitant computational costs; they require users to provide an estimate of the upper bound on the total evacuation time (incorrect estimate of the upper bound may lead to failure of the model); and the evacuation plan produced by linear programming methods only

gives traffic flow on each road segment. The users have to conduct post-processing to obtain origin-destination routes, which are critical information to direct evacuees in a real evacuation scenario (Shekar & Lu, 2004).

Contending with various types of concurrent emergencies has emerged as one of the priority tasks for responsible government agencies. Depending on the nature of attacks or the emergency event, different parts of the impacted network may suffer different levels of severity over different time windows. Thus, to minimize the impacts on those under urgent conditions and to prevent the surge of traffic demand due to the concurrent evacuation, it is essential to issue the evacuation order for different zones in an optimized sequence. By doing so, one can best utilize the capacity of the available evacuation network, minimize the potential bottlenecks due to surges in some local demands, and efficiently evacuate all evacuees based on their safety time windows (Shekar & Lu, 2004).

Through a review of transportation planning, emergency management, and evacuation literature, it is clear that each evacuation is unique and has critical components. Two important questions often asked of community leaders and managers in an evacuation event are, how long will it take to evacuate an estimated number of vehicles, and will emergency managers be equipped with resources to manage the volume of vehicles on the major evacuation routes? Few of these variables are well defined, easy to study or manipulate, and to date have yet to be fully understood due to the difficulty in predicting human behavior. Most evacuation tools are complex in both input and output and do not allow for manipulation of the data. The tool developed for this project is unique in that it is based on empirical data; data collected from actually driving an evacuation route under different conditions.

## *Simulation*

Simulation is the imitation of something, whether a real thing, a state of affairs, or a process. Simulating something generally entails representing certain key characteristics or behaviors of a system. For the purpose of evacuation planning, simulation is the process of designing and creating a computerized model of the real system to conduct numerical experiments and give the user a better understanding of the system's behavior under a given set of conditions (Kelton, Sadowski, & Sturrock, 2007).

Simulation can be used in many situations, including the modeling of natural or human systems in order to gain insight into their execution. Other situations include simulation of technology for performance optimization, safety engineering, testing, training and education. Simulation can show the real effects of alternative conditions and courses of action. Simulation can also be used when the real system cannot be engaged because either it is not accessible, or it is too dangerous or unacceptable to engage, for example in the case of evacuation planning.

There are two types of simulation models: physical and logical simulation models (Kelton, Sadowski, & Sturrock, 2007). A physical model consists of a physical replica or scaled model of the system. Physical models are used to evaluate the effects of design changes in the transportation or manufacturing industry and to train employees who work in highly complex environments. A logical model is a set of approximations and assumptions about the way the system works. Complex systems with many questions to be answered are generally modeled using discrete-event simulation. Logical models allow for experimentation with and greater understanding of the system, thus the investigation process is shortened and made less expensive. Difficult to answer questions of how the real world works can be answered through the manipulation of the simulation's inputs. The use of logical modeling allows mistakes to be made

and corrected inexpensively, whereas mistakes made in physical modeling are often quite costly (Kelton, Sadowski, & Sturrock, 2007).

Discrete-event simulation is a simulation method used to model real world systems that can be decomposed into a set of logically separate processes that progress chronologically. Essentially, it is a computer-aided form of flow-charting. Each event occurs on a specific process, and is assigned a timestamp. The result of this event is an outcome that is then passed onto one or more other processes. The outcome may result in the generation of new events to be processed, or it may result in the end of the simulation.

Discrete-event simulation provides significant advantages for system modeling. According to Law and Kelton (1991), most real-world systems have stochastic elements (random input) that are very difficult and sometimes impossible to be evaluated with purely mathematical models. In addition, discrete-event simulation provides the flexibility necessary to evaluate a system under different operating conditions, to predict alternative pre-specified performance measures and/or find a better solution within limits. Simulation also provides better control over experimental conditions, compared to testing a change through physical system changes.

Discrete-event simulation also allows a system to be recreated in virtual time instead of real time. Time can be exponentially increased by the simulation, so that many runs of the simulation take only seconds to prepare versus hours with a physical model. Multiple runs are necessary to ensure accuracy and correlation of the data and results.

### ***Optimization***

Optimization is the design and operation of systems or processes to make them as useful as possible in some defined sense. If the tool developed for this project can be shown to

successfully reflect real world expectations, then it could be used to study the effectiveness of different optimization techniques. Optimization approaches are varied and depend on the type of system involved, but the goal of all optimization procedures is to obtain the best possible results, subject to constraints that are imposed. While a system may be optimized by treating the system itself, by adjusting various parameters of the process in an effort to obtain better results, it generally is more economical to develop a model of the process and to analyze performance changes that result from adjustments in the model. In many applications, the process to be optimized can be formulated as a mathematical model; with the advent of high-speed computers, very large and complex systems can be modeled, and optimization can yield substantially improved benefits (McGraw-Hill Concise Encyclopedia of Engineering, 2002).

Optimization is applied in virtually all areas of human endeavor, including engineering system design, optical system design, economics, power systems, water and land use, transportation systems, scheduling systems, resource allocation, personnel planning, portfolio selection, mining operations, blending of raw materials, structural design, and control systems (McGraw-Hill Concise Encyclopedia of Engineering, 2002). Decision makers use optimization in the design of systems and processes, in the production of products, and in the operation of systems.

The first step in modern optimization is to obtain a mathematical description of the process or the system to be optimized. A mathematical model of the process or system is then formed based on this description. Depending on the application, the model complexity can range from very simple to extremely complex. An example of a simple model is one that depends on only a single nonlinear algebraic function of one variable to be selected by the decision maker. Complex models may contain thousands of linear and nonlinear functions of many variables. As part of the procedure, the user may select specific values for some of the variables, assign



variables that are functions of time or other independent variables, satisfy constraints that are imposed on the variables, satisfy certain goals, and account for uncertainties or random aspects of the system (McGraw-Hill Concise Encyclopedia of Engineering, 2002). The ESP tool developed for this project used a discrete event simulation to mathematically model the evacuation process. Consisting of nodes and branch points, the timing and pass-through processes in the ESP model are described mathematically according to a probability level worked out through empirical observation of routine traffic events.

System models used in optimization are classified in various ways, such as linear versus nonlinear, static versus dynamic, deterministic versus stochastic, or time-invariant versus time varying. In forming a model for use with optimization, all of the important aspects of the problem should be included, so that they will be taken into account in the solution. The model can improve visualization of many interconnected aspects of the problem that cannot be grasped based on the individual parts alone. A given system can have many different models that differ in detail and complexity (McGraw-Hill Concise Encyclopedia of Engineering, 2002). Certain models (for example, linear programming models) lend themselves to rapid and well-developed solution algorithms, whereas other models may not. When choosing between equally valid models, therefore, those that are cast in standard optimization forms are preferred.

The model of a system must account for constraints that are imposed on the system. Constraints restrict the values that can be assumed by variables of a system. Constraints often are classified as being either equality or inequality constraints. The types of constraints involved in any given problem are determined by the physical nature of the problem and by the level of complexity used in forming the mathematical model.

Constraints that must be satisfied are called rigid constraints. Physical variables often are restricted to be nonnegative; for example, the number of vehicles on the road during an



evacuation is required to be greater than or equal to zero. Rigid constraints also may be imposed by government regulations or by customer-mandated requirements. Such constraints may be viewed as absolute goals (McGraw-Hill Concise Encyclopedia of Engineering, 2002).

In contrast to rigid constraints, soft constraints are those constraints that are negotiable to some degree. These constraints can be viewed as goals that are associated with target values. The amount that the goal deviates from its target value could be considered in evaluating trade-offs between alternative solutions to the given problem.

When constraints have been established, it is important to determine if there are any solutions that satisfy all of the constraints. Any such solution is called a feasible solution. The set of all feasible points constitutes the feasible region. If no feasible solution exists for a given optimization problem, the decision maker may relax some of the soft constraints in an attempt to create one or more feasible solutions.

A key step in the formulation of any optimization problem is the assignment of performance measures that are to be optimized. The success of any optimization result is critically dependent on the selection of meaningful performance measures. In many cases, the actual computational solution approach is secondary. Ways in which multiple performance measures can be incorporated in the optimization process are varied (McGraw-Hill Concise Encyclopedia of Engineering, 2002).

Several factors can make optimization problems fairly complex and difficult to solve. One such complicating factor is the existence of multiple decision variables in a problem. Relatively simple procedures exist for determining the profit-maximizing output level for the single-product firm. However, the typical medium- or large-size firm often produces a large number of different products, and as a result, the profit-maximization problem for such a firm requires a series of output decisions—one for each product. Another factor that may add to the

difficulty of solving a problem is the complex nature of the relationships between the decision variables and the associated outcome (McGuigan, 2008). For example, in public policy decisions on government spending for such items as education, it is extremely difficult to determine the relationship between a given expenditure and the benefits of increased income, employment, and productivity it provides. No simple relationship exists among the variables. A third complicating factor is the possible existence of one or more complex constraints on the decision variables (McGuigan, 2008). For example, virtually every organization has constraints imposed on its decision variables by the limited resource over which it has control. These constraints must be incorporated into the decision problem. Otherwise, the optimization techniques that are applied to the problem may yield a solution that is unacceptable from a practical standpoint.

Optimization as defined by Merriam-Webster is “an act, process or methodology of making something as fully perfect, functional, or effective as possible.” (Merriam-Webster Dictionary, 2011) In mathematics and computer science, optimization refers to choosing the best solution from some set of available alternatives. In the simplest case, this means solving problems in which one seeks to minimize or maximize a real outcome by systematically choosing the values of real or integer variables from within an allowed set. In software, optimization is the process of modifying a system to make some aspect of it work more efficiently or use fewer resources. A computer program may be optimized so that it executes more rapidly, is capable of operating with less memory storage or other resources, or draws less power.

Modern day optimization first emerged during World War II to solve large-scale military logistics problems (Kirby, 2003). More recently, optimization techniques have been used in planning civilian production and transportation schedules and in calculating economic growth.

### ***Evacuation Software Prediction (ESP) Tool Summary***

For Embry-Riddle University, Micro Analysis & Design (MA&D) designed and built a discrete-event simulation model to analyze traffic flow in an evacuation setting. The model is designed to help analyze current traffic conditions as well as help improve evacuation routes when disasters occur at different areas of the country. The model simulates how long it takes a pre-defined number of vehicles to travel from one location to another. The model begins execution by creating a user specified number of vehicles on a highway at time zero. Once all vehicles in the model have been created, each vehicle updates its current position every second. The model continues until all of the vehicles have ended their journey. A journey will end either with a vehicle having an accident, reaching its goal distance, or leaving the highway before reaching its destination, for example, a vehicle stopping for gas. Once the model has ended its execution, the user can look at a number of reports to analyze how efficient traffic is given the number of vehicles traveling on the highway.

Vehicles in the simulation are defined by a number of parameters. A vehicle can be one of several types of generic vehicles, each of a different length. A vehicle will also have an optimal speed, and a required following distance. Each vehicle's optimal speed and following distance are calculated using the normal distribution.

Once the model has added all of the vehicles to the simulation, the vehicles begin moving forward to their goal destination. After each second in the simulation, a vehicle is closer to reaching its goal based upon its speed. When each vehicle moves forward, the model calculates its new location using its current speed. The model then compares the vehicle's new location to the location of every other vehicle around it. If there are no conflicts, the vehicle's location is updated and the process is repeated until the goal location is reached.

If however, a vehicle's new location conflicts with a vehicle around it, the driver of the vehicle has one of two choices: a) reduce speed or b) change lanes. If the driver reduces speed, the vehicle will slow down so that no collision occurs and it maintains ideal following distance with the vehicle ahead. This reduction in speed can cause a chain reaction with the vehicles behind the slowing vehicle, as they also may have to reduce their speed to avoid a collision. In the simulation model, this can cause drivers to stop completely if enough vehicles are on the highway in the same lane. Before a driver reduces its speed however, they will first attempt to change lanes. The driver determines if it is possible to change lanes by comparing their vehicle's new location to the locations of any other vehicles in the lane they are trying to enter. If any conflicts exist, the driver will not change lanes and instead will reduce the vehicle's speed. A driver can also be forced to change lanes when they approach a lane closure, a lane reduction, or an accident. If during the simulation a driver reduces their speed to below the desired speed, then the driver attempts to accelerate back to their desired speed as soon as possible. Figure 3

shows the flowchart version of how the model works.

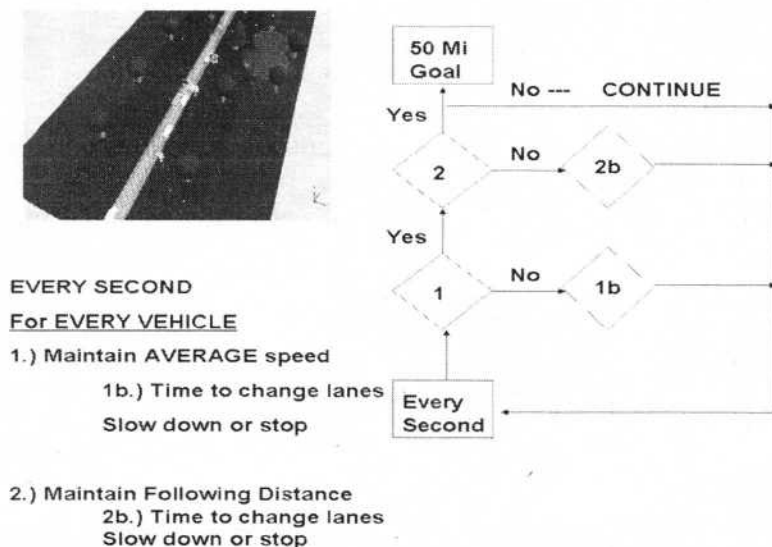


Figure 3. Micro Saint model. This shows some of the calculations per second for each vehicle in the model. The decision nodes correspond to the text on the left. The animation shows the vehicles on the model's highway.

Before any traffic simulation analysis is performed by the tool, the analyst must define several parameters. The parameters are broken into three main parts: a) highway parameters, b) vehicles parameters, and c) general system parameters. Parameters used for this experiment are shown in Appendix A. The highway parameters are defined by how many lanes the highway has and how far the vehicles will travel on the highway. All vehicles in the simulation will start at the same location and travel the same distance. The user also has the ability to define if a multiple lane highway reduces the number of available lanes that vehicles can drive in. After the highway has been defined, general vehicle information needs to be specified. This includes the probability that a vehicle will be of one type or another, the mean and standard deviation speed the vehicles will travel, the mean and standard deviation following distance the drivers will keep between each other, how much time the vehicles will spend traveling before giving up and leaving the highway, and the judgment accuracy the drivers will have. It should be noted that judgment accuracy should be very high since it is used continuously in the model. Finally, the user needs to define the general system parameters, these parameters affect how long the model will run. The system parameters include the number of vehicles simulated and the number of vehicles exiting early,

After the initializing information has been defined, the model can be executed. Once model execution has finished, the user can look at results and determine how traffic affects the time it takes to travel a stretch of highway. The results file includes (French, 2007):

- distance traveled,
- number of vehicles generated,
- number of vehicles finished,
- number of accidents,
- number of vehicles that left early,

- average time for a vehicle to complete the distance,
- maximum time a vehicle took to complete the distance,
- minimum time a vehicle took to complete the distance,
- Average vehicle speed,
- Maximum vehicle speed, and
- Minimum vehicle speed

The purpose of the ESP tool is to provide the ability to rapidly and realistically analyze the routes and plans a city/county/state emergency management department has in place to evacuate its citizens in case of an emergency. It also allows the emergency management team to quickly determine the effectiveness of these plans. The ESP tool can provide rapid access to the results of simulated evacuations with regard to traffic flow, time, and congestion, for any number of vehicles under certain variable conditions. It can also provide information on the effect of stalled vehicles or accidents that can occur in fully populated mass transit systems even during orderly evacuations.

The goal of the ESP model is to ascertain the balance of traffic flow capacity without immobilizing the travel route by managing the human factor events that impinge upon orderly highway travel. **(French, 2005)** This discrete-event simulation model is designed to consider the balance of traffic ebb and flow, and the effectiveness of countermeasures at predicted points of gridlock.

### ***Previous Validation Studies***

In 2005, a preliminary validation of the prototype's forecast of travel was tested during high capacity daily rush hour traffic periods as defined by official transportation authorities. The



2005 study, provided by the Embry-Riddle Aeronautical University Human Factors and Systems Department, revealed a significant correlation between observed data and simulation under a variety of speed and travel distance conditions (**French, 2005**). Figure 4 provides the project's data collection sample from 2005.

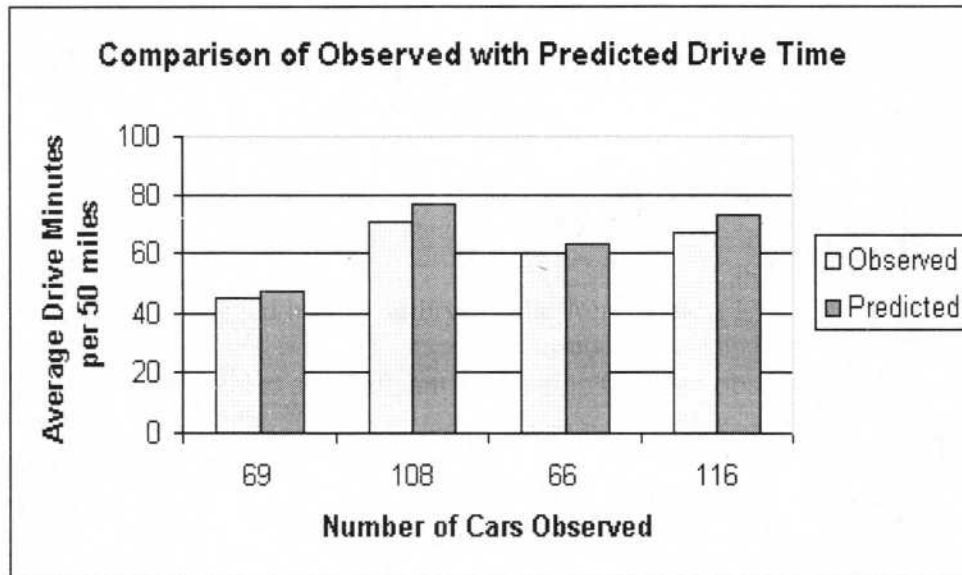


Figure 4. Comparison of Observed with Predicted Drive Time across differently sized samples of cars.

Following the preliminary study, more research was conducted by Kay Borglum in a thesis submitted to the Human Factors and Systems Department at Embry-Riddle Aeronautical University, entitled, *A Macroscopic Validation of the Evacuation Simulation Prediction Tool on Highway Travel Times*. This study compared ten (10) I-4 field data trip times with the comparable travel defaults input to the ESP tool program. FDOT traffic counter data collection locations along Interstate 4 were reviewed in a strategic search to select data collection based on high traffic volume travel periods. The Florida Department of Transportation traffic counter data provided hourly vehicle counts, average speed, and historical numbers for a specific day of the week (Monday, Tuesday, Wednesday, etc.) and time.

The ten trips were conducted over a range of time from January 2006 to November 2006 that were appropriate for the study. Samples of westbound and eastbound traffic during high

vehicle volume periods (rush hour) were collected in an effort to test varying levels of volume on travel time predictions.

Under non-crash and crash traffic flow conditions during peak travel periods, the ESP tool travel estimates demonstrated a highly predictive fit with the variance accounted for,  $r^2=0.993$ . A linear regression analysis was conducted to evaluate the slope of the best-fit line. Further, analysis of variance was used to test the deviation zero slope and demonstrated that the model data was considerably different  $F(1,7) = 9808$ ,  $p<0.0001$ . The results of this study were useful in the continued calibration and validation of the ESP tool in preparation for use by local emergency managers and first-responder administrators.

The combination of these two previous validation studies provided the basis for this study, to further validate the ESP tool by evaluating its ability to predict evacuation times from the Daytona International Speedway following the NASCAR™ Nextel Cup Daytona 500.

### ***Nextel Cup Daytona 500***

The NASCAR™ Nextel Cup Daytona 500 occurs the third Sunday of February annually. This decidedly large event provides a perfect validation opportunity for the ESP model. With approximately 167,000 extra people in town for this event, the city of Daytona Beach has the unique task of figuring out how to get these people into and out of the Daytona International Speedway in a timely and orderly fashion. The exodus from the Speedway at the conclusion of the race provides us with an orderly evacuation to study and subsequently compare to the results from the ESP model.





Figure 5. Daytona International Speedway

### ***Summary***

Preparing and executing an evacuation requires accurate, flexible planning on the part of city managers who must know when to start the evacuation, balancing the earliest time to get everyone out safely without starting it too early to require sheltering. There are affordable and easily accessible simulation tools that can help equip emergency managers with a variety of best- and worst-case scenarios that relate to the community they are commissioned to direct.

Evacuation experts state that the decision-making is the responsibility of local level management in an evacuation event, but the June 1, 2006 Department of Transportation Report to Congress identified the wide gaps in tools available to local leaders due to cost and training involved.

Local managers are often left without recourse if these tools are not affordable. They often rely on old traffic data to provide the egress timetable to safer ground. Local emergency operations centers are left with providing the best decisions they can, learning from mistakes after each threat in order to improve their responsiveness. Thus in most cases of local emergency control they are prepared to evacuate from the previous hurricane threat than the current threat.

The motivation behind the development of the Evacuation Simulation Prediction (ESP) tool was to help provide an affordable and effective planning tool for evacuations at the county and city level for hurricanes and other possible disasters. It is the goal of this study to provide a validation test of the ESP tool.

### ***Statement of Hypothesis***

It is hypothesized that: there will be a significant difference between the drive times for each driver on Pre-Race Day and Race Day; there will be no significant differences between the actual observed drive times for Race Day and the drive times predicted by the model; and optimization techniques that are applied will improve the success of the ESP tool in predicting the time necessary to evacuate large numbers of people. The model will be used to determine which of these optimization recommendations would prove useful in a real-world setting.

## METHODS

The objective of this applied research is to build upon the two previous validation studies of the model to test the strength of linear relationships between the field data and ESP model data by comparing real world travel times for a fifty-mile travel range leaving the Daytona International Speedway following the Daytona 500.

### *Participants/Data Collectors*

The primary participants in this study were nine graduate and undergraduate students who drove in the traffic leaving the Daytona International Speedway after the end of the Daytona 500. They traveled individually in nine cars, three waves of three cars each, joining the traffic flow exiting the stadium every hour for three hours, beginning at the end of the race, and proceeding down I-4 West via SR 400 (Beville Rd). The students collected data on time to travel fifty miles along their route and took note of any accidents/incidents they observed.

All students participated in a complete dry run of the fifty-mile transit one week prior to the event, which produced baseline data for the ESP model. A separate group of eighteen students, stationed at exits along the I-4 route, counted the number of cars entering and exiting the same travel path as the data collectors.

Prior to conducting this study, all the students in vehicles were asked to read and sign the informed consent form in Appendix B. The purpose of the consent form was to recognize agreement between the student and the study goals and to allow the data to be collected. Also all drivers were required to provide a valid driver's license, registration of their vehicle, and proof of insurance.

### ***Materials and Apparatus***

The research was conducted by comparing ESP tool predicted times with the field data. The drivers performing the road data collection were provided with handheld tape recorders, and every 5 minutes, they verbally recorded their current speed. They were provided with the data sheet in Appendix C. Prior to leaving the stadium, they recorded their name, type of vehicle, and the time; at the end of their trip, they recorded the time, and then counted and recorded the number of vehicles proceeding by them for a total of ten minutes. Once the field data was collected, it was then entered into the model and the ESP tool was run to produce the comparison data.

The students performing the data collection at the entrance and exit ramps were provided with a handheld counter, and the data sheet in Appendix D. They recorded their name, the time they began, the types of vehicles entering and exiting the highway, and the total number of vehicles entering and exiting the highway. They performed this data collection for three hours beginning when the first wave of drivers left the speedway parking lot.

### ***Design***

Due to the small number of observations ( $n=9$ ) and the subjective estimates required to fill out some of the missing details in the determination of the number of vehicles on the road with the participants; non-parametric tests were used to evaluate the data. The alpha level was set at  $p<0.05$  and all tests were two tailed.

To determine the fidelity of the ESP model, Spearman's nonparametric correlation coefficient was used to test how well the model predicted the actual observed data. It was

expected that there would be a high correlation between the actual drive times and the predicted data produced by the ESP model.

To determine whether differences existed between Pre-Race Day and Race Day, a Wilcoxon matched-pairs test was used. This test shows whether there was a difference in the number of vehicles and whether the number of vehicles affected the observed time-to-complete fifty miles.

### ***Optimization Techniques***

The first optimization technique applied to the ESP model was the use of contraflow. Contraflow lane reversal refers to plans that alter the normal flow of traffic, typically on a controlled-access highway, to either aid in an emergency evacuation or as part of routine maintenance activities, to facilitate widening or reconstruction of one of the highway's carriageways.

The model was executed with the same number of vehicles, going the same speed, with first only two lanes available, and then four lanes available. It was estimated that this would result in a statistically significant difference. The significance was determined by using a Mann-Whitney U test.

The second optimization technique applied was the simulated pre-positioning of Road Rangers along the designated evacuation route, operationalized as a shortened accident clearance time. It is believed that the positioning of these Road Rangers will allow accidents to be cleared faster, thus allowing traffic to continue moving in an orderly fashion.

In order to simulate an accident where Road Rangers were present, the model was run at a normal evacuation speed of 56 mph for twenty miles, at a slow speed of 10 mph for five miles, and then back to a normal speed of 56 mph for the last twenty-five miles. These times were then averaged to obtain a total drive time for fifty miles. To simulate an accident where Road Rangers were not present, the model was run at a normal evacuation speed of 56 mph for twenty miles, at a slow speed of 2 mph for five miles, and then back to a normal speed of 56 mph for the last twenty-five miles. These times were then averaged to obtain a total drive time for fifty miles. The difference between the accidents with and without pre-positioning of Road Rangers was tested using a Mann-Whitney U test with a Kruskal-Wallis test for variance.

## RESULTS

There were 8,625 vehicles estimated to be on the I-4 route on Pre-Race Day and 11,439 on Race Day that were input into the ESP model. The average speeds were 74mph for Wave 1, 70mph for Wave 2, and 71mph for Wave 3 during Pre-Race Day and 63mph for Wave 1, 51mph for Wave 2, and 24mph for Wave 3 on Race Day. Three runs of the ESP model were made for comparison to each wave to simulate the three drivers used in each of the waves. During Pre-Race Day there was a significant correlation between ESP estimates of travel time and actual data with a Spearman  $r(7)=0.73$ ,  $p=0.031$ . During Race Day there was also a significant correlation between ESP and actual drive times with a Spearman  $r(7)=0.95$ ,  $p=0.0004$ . An examination of Figures 6 and 7 indicates the strength of the relationships between the model results and the actual observed drive times.

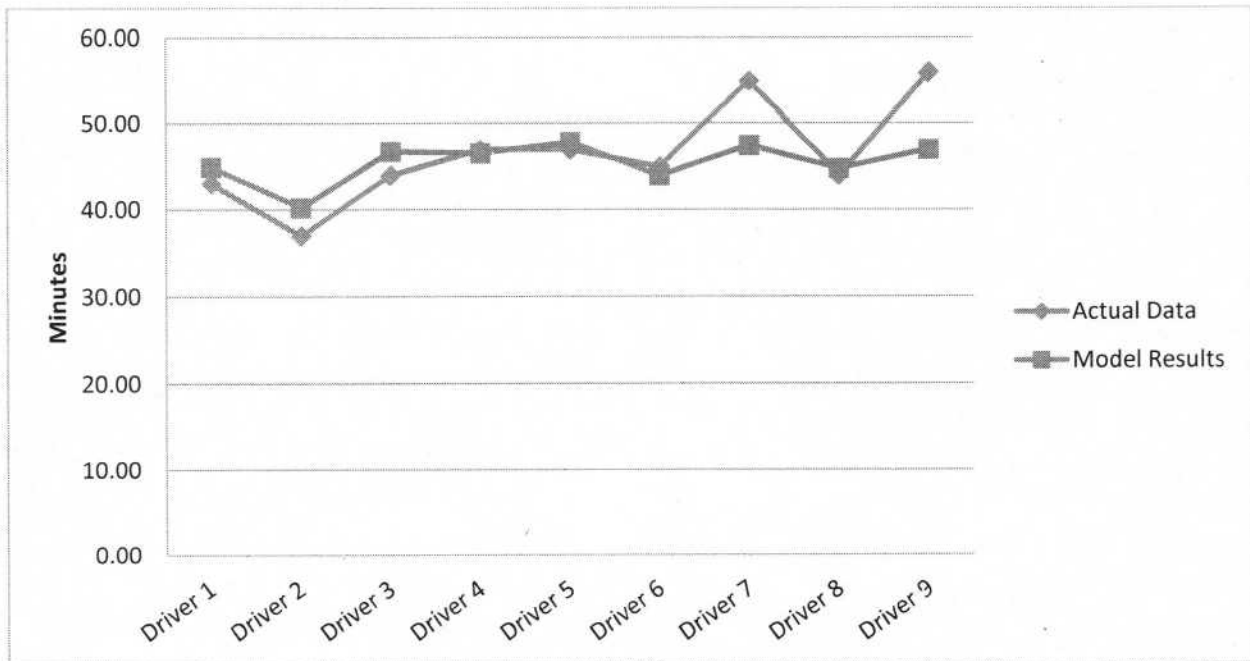


Figure 6. The drive times for 9 drivers during Pre-Race Day plotted against ESP model estimates of drive times under crash free conditions. The average time to transit 50 miles on the evacuation route is shown.



There was a fatality on Race Day that dramatically affected the third wave (drivers 7, 8 and 9) as seen from Figure 7; in order to account for the larger differences, the speeds entered for those 3 drivers included all their speeds over the entire fifty miles, including 70 minutes at a complete stop. The model used the ideal speed together with the standard deviation and makes second by second calculations for multiple decision points.

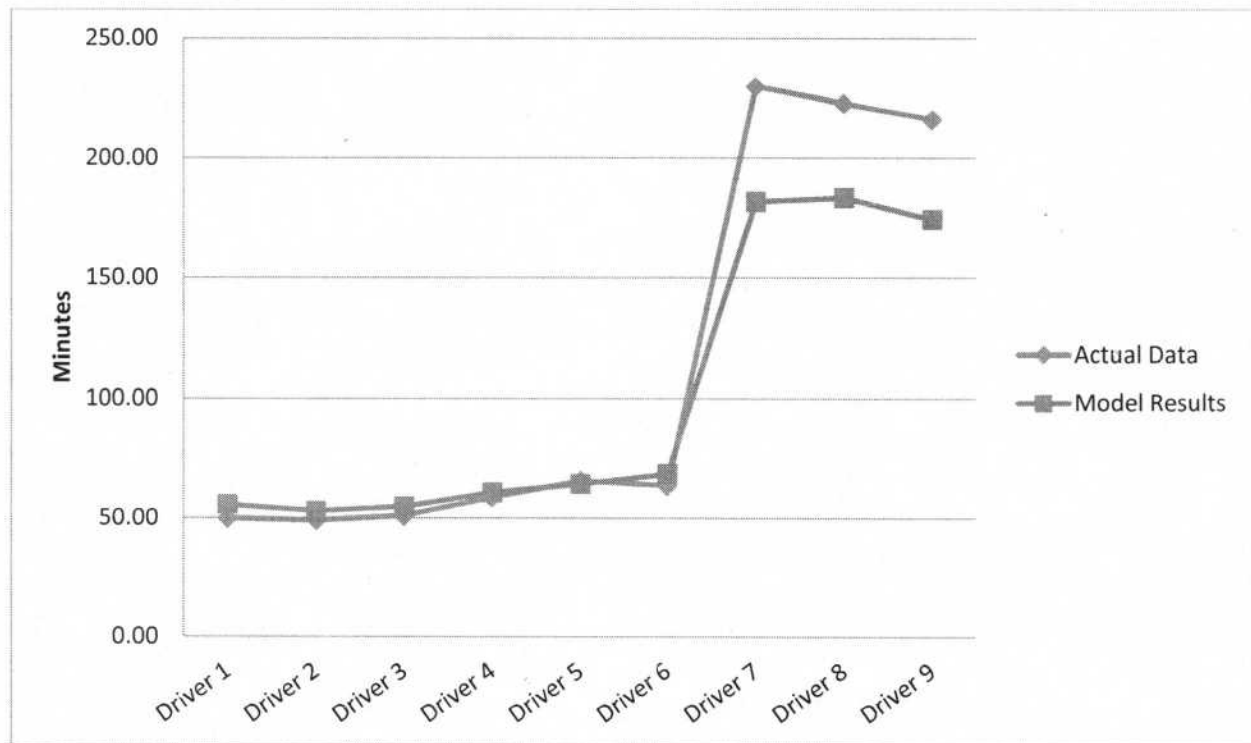


Figure 7. The drive times for 9 drivers during Race Day following the Daytona 500 plotted against ESP model estimates of drive times. The average time to transit fifty miles on the evacuation route is shown, predictions reflect adjustments to model parameters to account for the fatality that occurred during the third Wave.

The length of time for each driver to complete the fifty-mile stretch was statistically different from Pre-Race to Race Day. The median times for Pre-Race (Wave 1 median=43, N= 3, Wave 2 median=47, N=3, and Wave 3 median=55, N=3 ) were significantly shorter than the times for Race Day (Wave 1 median=50, N= 3, Wave 2 median=64, N=3, and Wave 3 median=223, N=3). A Wilcoxon matched-pairs signed rank test with a two-tailed  $p(7)= 0.0039$ ,



indicates the differences between median times on Pre-Race and Race Day were statistically significant. Figure 8 shows these results.

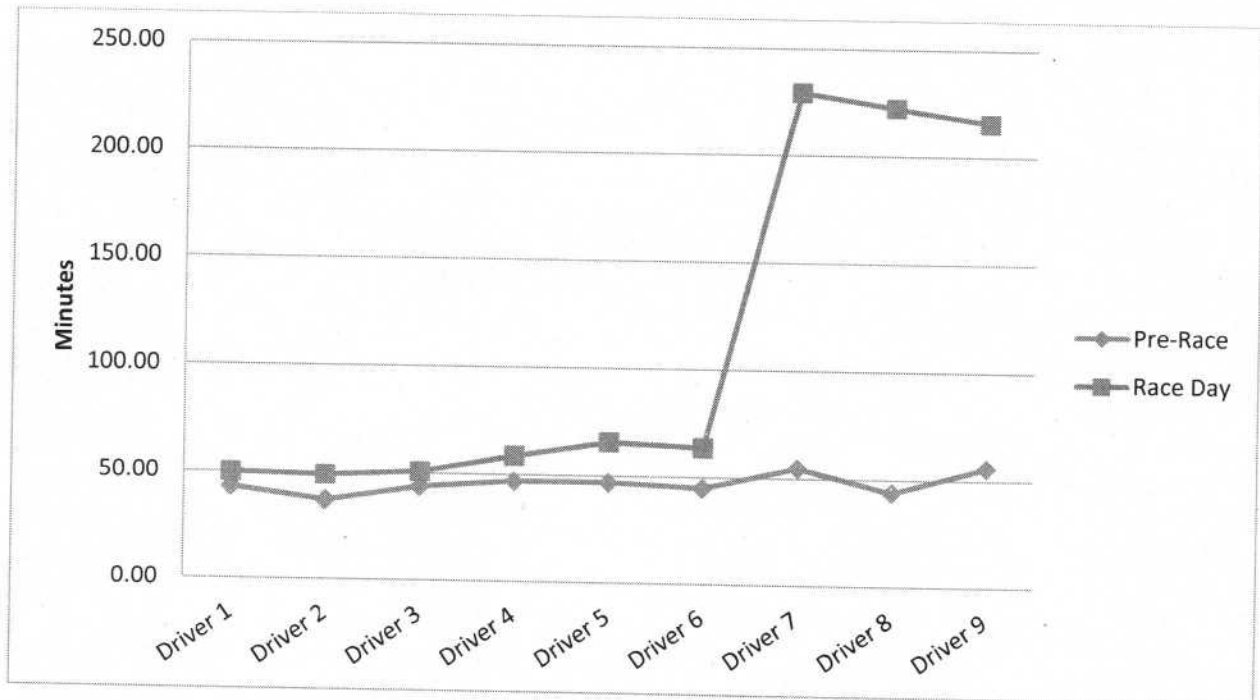


Figure 8. The drive times for 9 drivers during both Pre-Race and Race Day following the Daytona 500. The time to transit fifty miles on the evacuation route is shown.

Figure 9 shows the average drive times generated by the ESP model when there are varying numbers of vehicles on the road. There is a linear relationship between the number of vehicles and the average time to complete a fifty-mile drive. That relationship is extended out to 100,000 vehicles by the linear regression lines shown in figure 9.

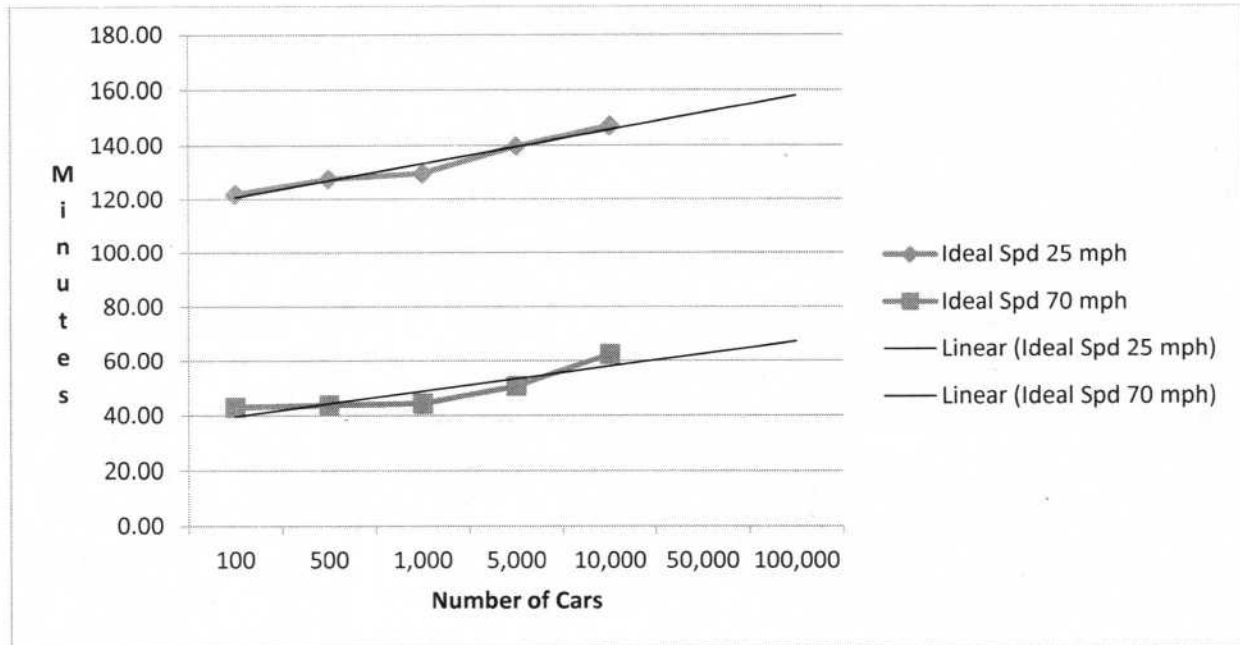


Figure 9. Micro Saint Model runs, average drive time for fifty miles.

The maximum drive time to complete the fifty-mile stretch generated by the model was statistically different when four lanes of traffic were used instead of two. The maximum times for four lanes (1250 vehicles median=59.90; 2500 vehicles median=64.47; 5000 vehicles median=74.23; 7500 vehicles median=83.85; 10000 vehicles median=93.67) were shorter than the times for two lanes (1250 vehicles median=63.33; 2500 vehicles median=72.95; 5000 vehicles median=91.95; 7500 vehicles median=107.92; 10000 vehicles median=122.92). Table 1 shows the results of the Mann-Whitney U test.

Number of Cars	df	Mann-Whitney U	P value
100	19	=160	<0.3101
500	19	=190	<0.7448
1000	19	=0.00	<0.0001
1250	19	=0.00	<0.0001
2500	19	=0.00	<0.0001
5000	19	=0.00	<0.0001
7500	19	=0.00	<0.0001
10000	19	=0.00	<0.0001

Table 1.. Mann-Whitney results for the comparison of drive times in 2 lanes vs. 4 lanes using maximum drive times.

Differences between conditions (two lanes versus four lanes) are found at traffic volumes of 1,000 vehicles and greater and are indicated by an (\*) as shown in Figure 10 below.

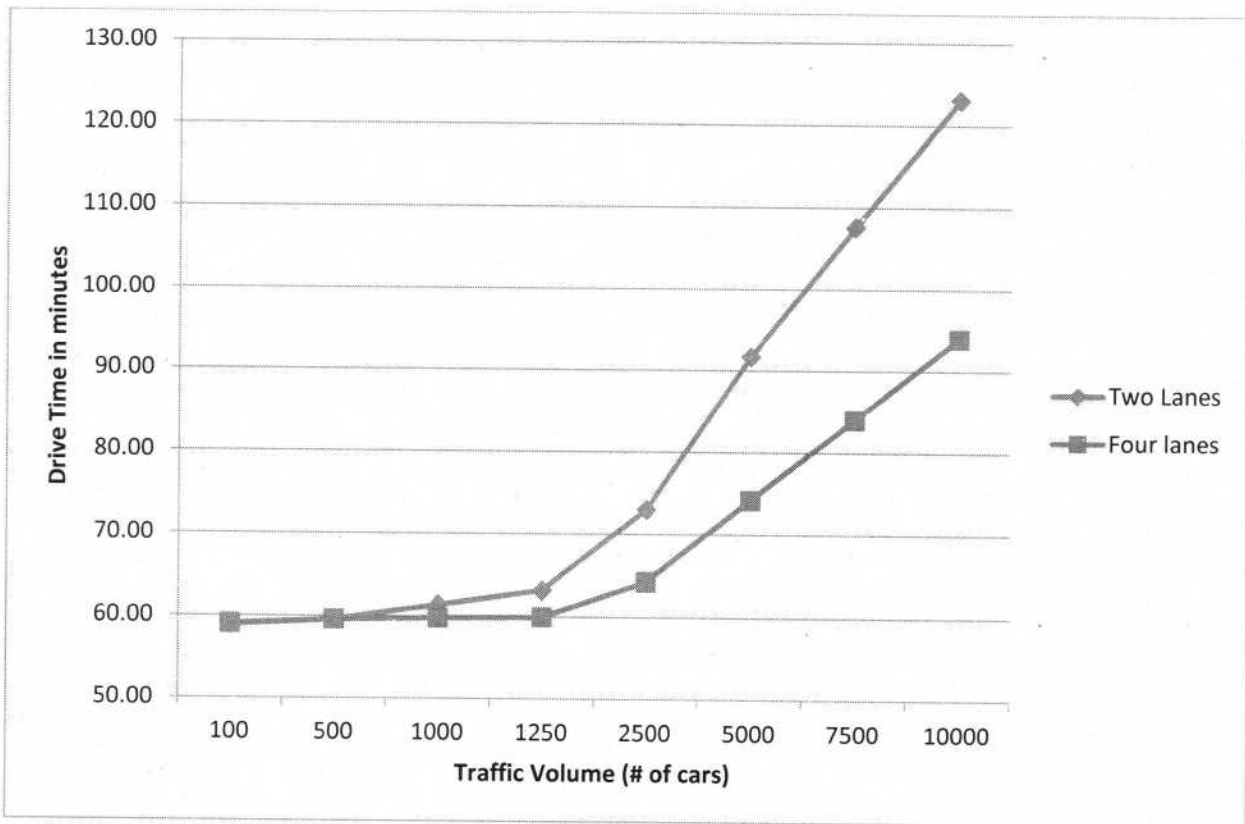


Figure 10. Maximum Drive Time to fifty-mile destination  $\pm$  standard deviation.  $p < 0.01$  indicated by (\*)

The simulated accidents with and without pre-positioning of Road Rangers were significantly different from each other and from the normal drive times. Using a two-tailed Mann-Whitney test, the difference between the major accident and the minor accident was tested. During the accident without Road Rangers (median=44 minutes) drive time was proved to be significantly longer than during the accident with Road Rangers (median=92 minutes) with a p-value of 0.0011. Using the Kruskal-Wallis test for variance, the difference between the accident times and the normal drive times was tested. With a Kruskal-Wallis statistic of 21.6 and  $p < 0.0001$ , it can be determined that the accident drive times are significantly different from the normal drive times. These results are shown in Table 2 below.

Accident without Road Rangers				
Run #	Miles 0-20 at 56mph	Miles 21-25 at 2mph	Miles 26-50 at 56mph	Total Time to Drive 50 miles
1	27.16	107.57	32.05	166.77
2	27.01	93.30	32.50	152.81
3	26.59	91.77	32.81	151.16
4	27.15	91.20	32.76	151.11
5	27.84	82.63	32.46	142.93
6	26.98	91.53	32.60	151.11
Median	27.08	91.65	32.55	151.14
Accident with Road Rangers				
Run #	Miles 0-20 at 56mph	Miles 21-25 at 10mph	Miles 26-50 at 56mph	Total Time to Drive 50 miles
1	27.16	43.48	32.05	102.68
2	27.01	43.94	32.50	103.45
3	26.59	44.23	32.81	103.63
4	27.15	43.97	32.76	103.88
5	27.84	43.55	32.46	103.85
6	26.98	43.69	32.60	103.27
Median	27.08	43.81	32.55	103.54

Table 2. Simulated accidents with and without the pre-positioning of Road Rangers.

## DISCUSSION

The results of this study indicate that the ESP model reasonably predicted the times involved in traveling fifty miles along a major evacuation route during an orderly evacuation, the Daytona 500 NASCAR™ Race. This was a validation study of the ESP tool during a high volume evacuation. The model may be useful to regional and local city and county planners for rapidly considering alternative evacuation strategies using only a desktop computer. In a few minutes, the time to evacuate can be estimated by changing only a few defaults in the model such as the number of people to be evacuated and the routes to be taken.

Additionally, the results of this study indicate a highly predictive fit and indicate an acceptable range of performance of the ESP model under the studied terms. Because field experiments occur in natural settings, it is not possible to control all possible contaminating or confounding variables. The data collected for this experiment was collected using simple, consistent, empirical methods that were designed to test the baseline prediction ability of the ESP under typical and unusually high vehicle travel volumes that had not been tested before. The model was also limited by the number of vehicles that it was able to generate and that the data collectors observed.

There was significant statistical correlation ( $r=0.73$  on Pre-Race Day, and  $r=0.95$  on Race Day) between the actual observed data and the data generated by the ESP model. This indicates that the model is able to accurately predict both normal and abnormal traffic situations.

The results of the applied optimization techniques indicated a significant improvement of the flow of traffic during the observed evacuation. The purpose of applying such techniques is to show city and county managers the available options during a planned evacuation. This allows these managers to make plans that are more accurate and publish safer and more effective routes during a non-planned evacuation. In order for an evacuation to remain orderly and for people not

to succumb to panic, the evacuation must be very carefully planned out and the ESP model can help city and county managers to make better more informed plans.

Additional research is needed to further test the prediction abilities of the ESP model. Further testing should include a more accurate count of vehicles on the road, and a more consistent method of determining each vehicle's speed at certain times during the evacuation. In addition, even though the field data within this study included an evacuation event during the 2007 Daytona 500 NASCAR Race, a larger, less-orderly evacuation (perhaps an impending hurricane) should be studied to ensure complete accuracy within the ESP model.

The limits of this study did not test the area of traffic-behavior and prediction. More research is needed in order to evaluate if a relationship exists between the volume of traffic and the number and intensity of crashes that occur under specific traffic conditions. This research will help emergency managers and planners to more accurately predict and prepare their community for when and how to evacuate to safety if they are at risk of a catastrophic event.

The study was also unable to study the predictions of the model under a true evacuation scenario. During an emergency evacuation, there would be significantly more variables to consider; there would be many more people participating in the evacuation and it is likely they would need to travel farther than fifty miles. This would necessitate the factoring in of variables such as vehicles stopping for gas and restroom breaks as well as the higher potential for accidents. It is recommended that the next validation study consider studying the model under these conditions.

## **CONCLUSION**

The function of this applied research study was to determine the fidelity of a discrete event simulation tool called the Evacuation Simulation Prediction Tool (ESP) in predicting and optimizing transit times during a high volume real world surge in traffic flow following the annual NASCAR™ Nextel Cup Daytona 500. The ESP tool was developed for the purpose of predicting large-scale evacuations of counties or regions as an aide in emergency and disaster preparedness planning.

For this study, evacuation of a large number of vehicles was simulated by the traffic surge that results annually from the Daytona International Speedway (approximately 100,000) immediately following the Daytona 500. The results of this study indicated that the ESP Tool was able to accurately predict the travel times of the Daytona 500 traffic surge under the study conditions.

Once the accuracy of the model in predicting the real world event was established, the ESP tool was used to optimize other traffic flow scenarios. The results of this study may be useful in considering modifications to traffic flow during real world emergencies such as hurricanes or other potential disasters.



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## APPENDICES

### A. ESP Parameters Used

Variability = 1; //whether or not to pull speed and closeness from distribution (1-variable, 0-not)

NumLanes = 2; //number of lanes

\*NumCarsInSystem = 4150; //Number of cars

\*MeanSpeed = 70.22; //mean speed mph target (ideal)

\*SpeedStdDev = 12; //std dev speed mph target

MeanClose = 8; //mean ideal distance between cars- ft

CloseStdDev = 1; //std dev distance between cars

Accuracy = 1; //probability a car will make a mistake, 1.0 = 100% accurate (no mistakes)

TotalDistance = 50 \* 5280.0; //Distance to Travel in feet

NumCarsToExit = 0; //number of cars to leave before end

DistanceTillExit = 30.0 \* 5280; //distance to early exit point

SectorLength = 50\*5280; //50//sector division lengths in feet

UpdtTime = 2; //time to generate cars and drive down highway update

\*These parameters serve as an example of those used in the execution of the ESP model during the first wave of the Race Day test. Each driver in each wave tested had different data entered into these variables.

## B. Informed Consent

### Speedway Validation of ESP Tool

Conducted by Claire Johnson  
Advisor: Jon French, Ph.D.  
Embry-Riddle Aeronautical University  
Daytona Beach, FL 32114

The experiment you are about to participate in is concerned with the orderly evacuation of the Daytona International Speedway following the Daytona 500. The purpose is to investigate the validity of the ESP tool in predicting traffic flow.

The experiment will consist of two sessions, one practice and one live. During each session, you will drive your car 50 miles from the designated parking area and stop at the end to tally cars for ten minutes. The practice session is expected to last approximately 1.5 to 2 hours; the live session is expected to last 3.5 to 5 hours.

The risks involved are the same as any other driving experience, however, we estimate that due to the slow nature of the traffic flow at the time, the risks will be somewhat reduced.

With regard to compensation, you will be provided a meal, the monetary amount of your gas, and an additional \$50.

Thank you for your participation. If you have any questions, please ask prior to the experiment or call me at (386) 212-1617.

### Statement of Consent

I acknowledge that my participation in this experiment is entirely voluntary and that I am free to withdraw at any time. I have been informed as to the general scientific purposes of the experiment and that I will receive remuneration at the completion of the study. If I withdraw from the experiment before its termination, I will receive my total fee earned to that point at that time.

Participant's name (please print): \_\_\_\_\_

Signature of participant: \_\_\_\_\_ Date: \_\_\_\_\_

Experimenter: \_\_\_\_\_ Date: \_\_\_\_\_

C. Driver Data Collection

Name \_\_\_\_\_

Type of Vehicle \_\_\_\_\_

Beginning Driving Time \_\_\_\_\_

Any Crash Events Observed?      Yes              No

If yes, level of crash event?      1              2              3

Ending Driving Time \_\_\_\_\_

Begin Counting Time \_\_\_\_\_

End Counting Time \_\_\_\_\_

Number of Vehicles Observed \_\_\_\_\_

D. Counter Data Collection

Name \_\_\_\_\_

Parking Lot Position \_\_\_\_\_

Beginning Time \_\_\_\_\_

End Time \_\_\_\_\_

Number of Cars Observed \_\_\_\_\_

Number of Non-Car Vehicles Observed \_\_\_\_\_

Total Number of Vehicles Observed \_\_\_\_\_

Any Crash Events Observed?                      Yes                      No