Evacuation Strategies

Evaluation of their effects during an evacuation in an urban area using a micro simulator

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Management Summary

In this research, several evacuation strategies have been tested to establish their effects on a multimodal evacuation in an urban area. The main goal has been to analyze what the effects would be of a new evacuation strategy that has been developed by University of Florida student Ashwin Arulselvan. He developed a methodology to find efficient paths for cars and bus frequencies for any multimodal evacuation. Unfortunately, his computer model was not able to produce useful results within the time frame of this research. Therefore, this research analyzed eight other strategies and their effect on the evacuation of an urban area. Besides the analysis of the strategies, a manual has been written that can be used to implement and analyze other strategies in the developed network. This paper will only consider the effects of eight tested strategies. The strategies that have analyzed are:

1. **Base case**
   Regular traffic operations without any specific traffic control measures.
2. **No access towards campus**
   This strategy blocked the traffic that wanted to access the roads on the campus during the evacuation. It was expected that this strategy would reduce the congestion on the campus.
3. **Contraflow on the campus**
   This strategy involved the redirection of incoming lanes for outgoing traffic. This strategy only reversed lanes on the campus, to reduce the congestion and evacuation time.
4. **Contraflow on the campus and in Gainesville**
   This strategy expanded the previous one with contraflow lanes in whole Gainesville. The base case has been used to establish the most congested roads. With the deployment of contraflow on these roads, it is expected that the traffic will experience less congestion.
5. **Increasing green time at the ramps**
   It has been observed that the traffic lights that grant access towards the interstate, had a capacity that did not match the demand during the evacuation. Therefore, the green time for the most congested directions has been at least doubled to increase the intersection capacity.
6. **Increasing green time at the ramps and in Gainesville**
   This strategy is the same as the previous one, but also includes more green time for congested directions at intersections in whole Gainesville.
7. **Staged evacuation**
   This strategy came forth out of the literature. With this strategy, the origins start evacuating in a sequence. This will spread the flow of traffic more over time and is expected to reduce congestion.
8. **No control**
   In this strategy there is no form of control. All traffic lights have been removed and stop signs do not exist.

Two cases have been designed to analyze the effects of these strategies. Both cases are build around the evacuation of the sold out football stadium from the University of Florida. This stadium accommodates about 90.000 people during games and is located at the campus area of the University of Florida in Gainesville, Florida. The first case analyzed the effects of the strategies, if there is only evacuation traffic on the network that is generated by the spectators. The second case analyzed the results if besides the evacuation traffic, background traffic is present on the network.

The micro simulator Corsim has been used to analyze the effects of the strategies. Multiple runs have been carried out to find the evacuation time, number of cars evacuated, total travel time, delay time ratios and travel speeds for each of the strategies in the two cases.

The results indicated that the 'No control' strategy is very effective in the first case. Its efficiency dropped during the second case. However, future research should consider how the no control strategy can be implemented into a real network to analyze its effects outside the micro simulator. Within the control strategies, increasing the green time at the ramps seems most efficient. It reduces the evacuation time by more than three hours compared to the base case. And in the second case it evacuated about then percent more vehicles than the base case. Also the other performance measures indicate that this strategy has a significant positive impact on the evacuation results.

The evacuation time is even more reduced, if the previous strategy is expended with an increase of green time on the main streets. However, some of the network performance measures show results that are not as good as the previous strategy. To implement this strategy will also take more effort and therefore this strategy is not preferred over the increase in green time just at the ramps.

The staged evacuation showed good results. Although the evacuation time did not reduce a lot in the first case, the second case showed a significant improvement between this strategy and the base case. The average travel time did support the idea behind this strategy that people experience less individual congestion and thus less delay time which improves their average speed and travel time. The strategy did also indicate a shorter evacuation time for the traffic on the campus area. The traffic will experience less delay outside the direct vicinity of the campus and is able to flow faster out of the endangered area.

The deployment of contraflow on the campus area and in Gainesville, resulted in more promising results. The evacuation and travel time is reduced and it resulted in the highest number of evacuated vehicles. Although the performance measures did not always indicate the same results, this strategy is definitely worth considering.

The deployment of contraflow on the campus area gave a small reduction in evacuation time, but did not score good results within the total travel time and the network performance measures. The strategy is able to evacuate vehicles faster from the campus area but moves the congestion outwards the campus area.

The 'no access' strategy is not effective in improving the overall evacuation time and the quality of the network. However, it has been observed that the traffic on the campus site experience less congestion and is evacuated faster than in the base case.

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Introduction

Every modern city is exposed to various potential disasters. Hardly a day passes without some form of disaster or tragedy hitting the headlines. These threats include not only natural hazards such as hurricanes, but also terrorist-induced and technological emergencies like biohazard attacks and nuclear leakage. It is impossible to rule these risks out. With the understanding of the potential threats, the focus of protection measures should not only be aimed at prevention. The focus should also include preparation and response measures that are fully developed and can be used in case an emergency occurs. One of the measures that policy makers can develop for these phases is the development of evacuation plans and the simulation of evacuations in order to respond effectively and in a timely manner during a disaster *(Drennan & McConnell, 2007)*.

Although the focus on the development of large-scale evacuation plans is relatively recent in the Netherlands, the United States of America know a longer history in the development and research regarding evacuation plans and policies. The difference lies partially in the fact of the frequent presence of tornado's and cyclones in some areas of the US and a culture that is more concerned about their safety and security (*for instance terrorist attacks, hazardous materials spills etc*.), and is willing to spend more money on their homeland security than most other countries *(Wolshon & Meehan, 2003)*. Wolshon and Meehan (2003) also underline the task for scientists to help policy makers by developing strategies and plans that can increase the efficiency of an evacuation.

The focus of this research project lays on the evacuation of people out of an endangered zone. Disasters that require some type of evacuation are relatively common, but large scale evacuations (*for instance the clearance of an entire city*) are relatively rare. One of the differences between normal conditions and emergency situations lies in the fact that these emergency situations are so rare, that people cannot learn from their experience which route will minimize their evacuation time *(Lindell & Prater, 2007)*. The threat of the disaster and the panic and chaos that exists by people, make it almost impossible and definitely undesirable, to test some form of evacuation strategies during a real-time evacuation. This emerges the need to develop and test evacuation plans using simulation software. In this research such a simulation program, Corsim, has been used to analyze the effects of different evacuation strategies on the evacuation time for an urban area when a sold out football stadium needs to be evacuated. The obtained results will be partially used to validate a new strategy developed by graduate student Ashwin Arulselvan. His strategy is aimed to find the most optimal solution for a multimodal evacuation problem by considering the use of buses and cars *(Arulselvan, Multimodal Solutions for Evacuation Problems (Draft), 2008)*.

This research serves two purposes. The main goal has been to analyze what the effects are of several evacuation strategies during a multimodal evacuation on an urban area. The second goal has been to create a framework that can be used to analyze the effects of other and new multimodal evacuation strategies on an urban area. This resulted in two papers. This paper will discuss the effects of several evacuation strategies. There is another short paper available which can be used as a manual for the developed model.

1. Problem domain

As stated in the introduction, modern cities are exposed to various potential disasters. The ever increasing role that humans play in both creation and destruction has provoked grave concern for the continued existence of the human race and the global environment. At the same time, modern science and technology have made great strides, which, in theory at least, have been accomplished for the betterment and safety of human society and the environment in which it lives. It is therefore ironic that many of these achievements are responsible for a considerable proportion of the disasters and human tragedy occurring today. Paradoxically, people often again turn to technology to find solutions to these problems and prepare to deal with them when they occur *(Nisha de Silva, 2000)*. In order to increase the safety for the human populations, a number of approaches are possible *(Pidd, de Silva, & Eglese, 1996)*. In the case of industrial or man-made disasters, people can try to reduce the probability of such incidents by making better and safer designs. Another approach is not to reduce the probability, but the impact of these incidents. For instance, the sighting of hazardous installations at what is believed to be a reasonable safe distance from populations' centers. According to Pidd, de Silva & Eglese (1996), the third approach to cope with risks is to produce well tested evacuation plans which can be used to transfer people out of danger zones, should an incident occur.

An evacuation plan coordinates all necessary activities for the organization of an evacuation. It can be described as the set of measures to fully control dispersal, withdrawal or removal from people out of endangered areas. An evacuation plan is usually part of a more general disaster plan. It is therefore only one of the aspects in the complete process of decision-making by the crisis team *(van Zuilekom & Zuidgeest, 2006)*. A well designed evacuation plan is a plan that helps the authorities by taking the right and effective actions when a disaster occurs. An important part of large scale evacuation plans consists of the actual evacuation strategy, or how to get people as fast and safe possible out of the endangered area. The strategy includes different traffic operation measures that can be issued by local or state authorities. Some of these measures require modifications on the network prior the emergency and others do not. Some require the deployment of extra personnel and others do not. The evacuation problem has been analyzed for the last decades, but it can be concluded that especially in the last decade new strategies have arisen.

Most of these strategies do not recognize the difference between different modes of transportation. Arulselvan (2008) concluded in his research that there is a shortage of strategies that include the use different modes of transportation during evacuations *(Arulselvan, A Review of Evacuation Problems, 2008)*. He presented an analytical technique for establishing the most efficient paths for cars between their origin and destination in combination with the frequency of the buses along their predetermined routes, without exceeding the capacity of the roads. His strategy includes the predetermination of routes for private cars and the determination of bus frequencies in order to evacuate an urban area in its most efficient way.

However, Arulselvan is not a transportation student and has no experience in modeling complicated traffic networks and assessing the results of his methodology. Therefore, this research has been carried out. It created a test network and provided some results from other strategies that can be used by Arulselvan to indicate if his methodology reduces the total evacuation time.

2. Literature review

To get an idea about evacuation strategies and planning, a literature research has been conducted. In this chapter, relevant literature is briefly reflected. Firstly, some common aspects about evacuation plans are described. In the second part is discussed how the evacuation plans can be evaluated in a laboratory environment.

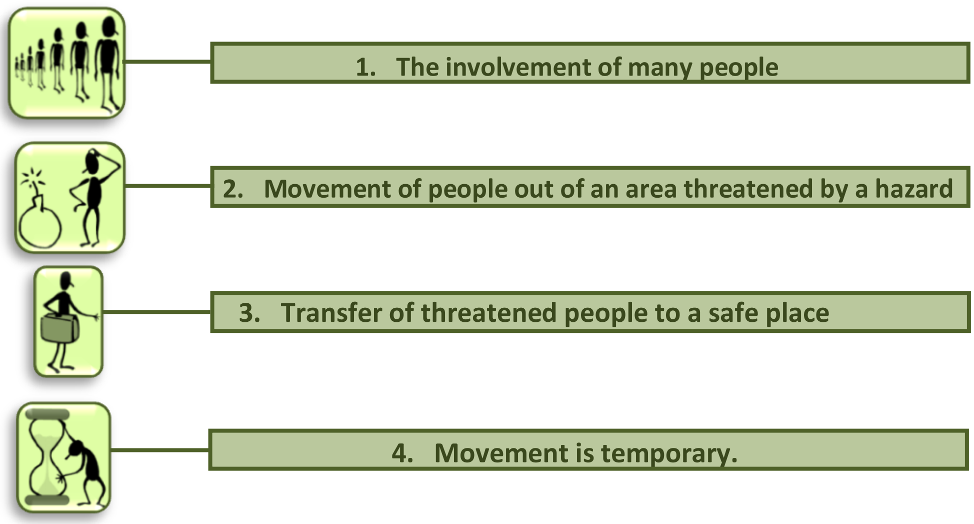
2.1 Evacuation planning

2.1.1 Defining evacuation

There have been, are and always will be the need for evacuations to get people out of an endangered zone. Still, not a single evacuation will be exact the same as a previous one. There are so many variables and unexpected events involved, that it is almost impossible to have evacuation plans ready which covers all the angels when a disaster strikes.

But it is important to be prepared and have plans in place that will help by making decisions. This emerges the need for an evacuation plan: such a plan coordinates all necessary activities for the organization of an evacuation. It can be described as the set of measures to control dispersal, withdrawal or removal from people out of endangered areas. A good evacuation plan is a prepared plan that helps the authorities by taking effective actions when a disaster occurs. The evacuation plan is usually part of a more general disaster plan. It is therefore only one of the aspects in the complete process of decision-making by the crisis team *(van Zuilekom & Zuidgeest, 2006)*.

It is useful to develop a common understanding about the meaning of evacuation. In the literature are various definitions given for the term 'evacuation'. Common aspects of these definitions are:



Within these aspects, Frieser (2004) developed a common definition about evacuation:

An evacuation is a temporary removal of people at risk to a safe place, beyond the reach of the hazard, it is initiated by an evacuation warning disseminated by the authorities and takes place in a (relative) organized way (Frieser B. , 2004).

2.1.2 Design procedure evacuation plans

During an evacuation there is a process of matching supply and demand as in normal traffic situation although the setting in case of an evacuation is quite specific. Russo et al.(2004) presented two approaches that can be used in the design of the evacuation plan. The first approach is the 'What-if' procedure. Within this approach a scenario is modeled and the results are analyzed. The scenario is then iterated to obtain better evacuation results. This is maintained till no further improvement seems possible. The final result is interpreted and translated into an evacuation plan *(Russo & Vitetta, 2004)*. The other approach is known as the 'What-to' or 'How-to' procedure. In this approach the result is determined by the objective function, the constraints and structure of the model *(van Zuilekom & Zuidgeest, 2006).* This is in contrast with the 'What-if' approach were the final result depends on the interpretation and adjustments of the modeler. Russo's (2004) model for the development of evacuation plans, the 'What-if' and 'What-to' approach, is a model to represent the interaction between supply and demand in case of a preventive evacuation. It is in this way somewhat related to the normal traffic situation process, where there is a need for matching the supply towards the demand. The classical four-step transportation forecast model, can help by forecasting the relation between supply and demand. Russo (2004) showed that by influencing several factors the supply-demand interaction within evacuation conditions will change. He showed that strategies will influence either the demand or the supply from the system by influencing the classical phases of trip generation, distribution, modal split or assignment. The examined strategies will be reflected towards their impact in the classical model and therewith in the supply-demand interaction.

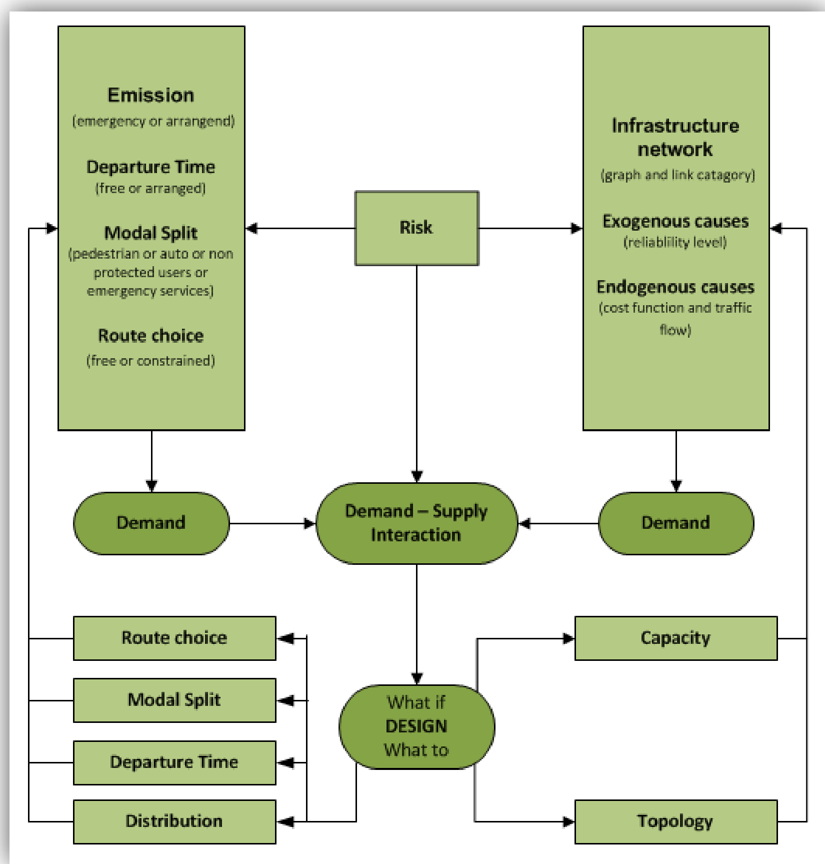


Figure 1: Global procedure for the design of an evacuation plan (Russo et al. (2004))

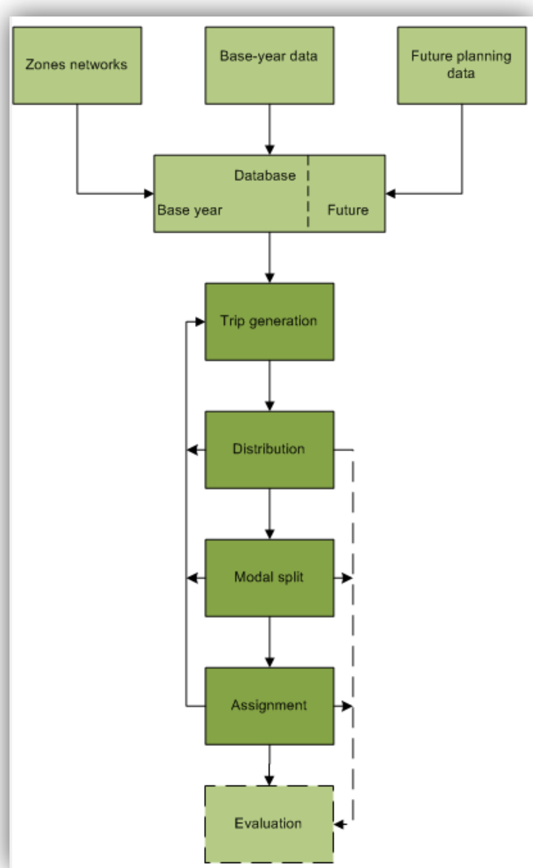


Figure 2: Classical four-step transportation forecast model (Ortazur et al. (2007))

2.1.3 Evacuation process

Every evacuation can be divided in the same phases, the so called evacuation process. Understanding about this process is required since it helps by the development of a useful evacuation plan. Frieser (*2004*) provides a common definition about the evacuation process. He describes four different phases:

- Phase 1: Observation & prediction of the hazard and evacuation decision making
- Phase 2: Warning
- Phase 3: Response
- Phase 4: Evacuation

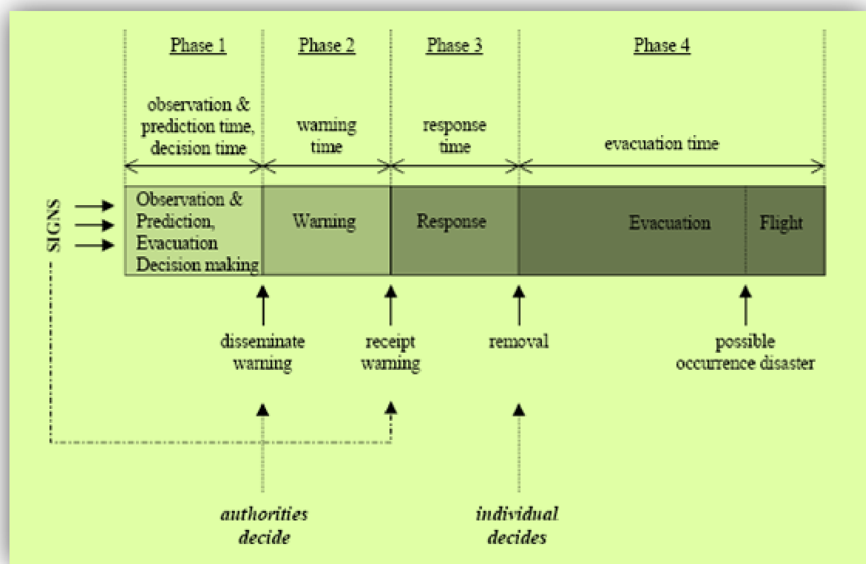


Figure 3: Design of evacuation process by Frieser (2004)

The evacuation process is initiated by receiving signs of a possible disaster. Subsequently the development of the hazard is observed. Collected data of the hazard are used to predict its occurrence, magnitude, time and location of the possible impact. If occurrence of the disaster has been predicted and the authorities decide to evacuate people that are present in the risk area, an evacuation warning is disseminated to notify the population at risk. Response is the reaction of a person on the evacuation warning. The time it takes for people to respond can greatly influence the overall evacuation time. People can decide to evacuate to a safe place outside the risk area or seek for shelters within the area. However, people may also take other (unintended) actions like continue working. Very important is the time that people need to decide to evacuate. Many factors affect this individual evacuation behavior (*especially personal risk perception*). Factors like experience, actual signs of the threat and the information disseminated by the authorities affect the leaving time *(Gwynne, Galea, Owen, & Lawrence, 2002)*. Response time is defined as the time span between the warning receipt and the action performed by the individual at risk. The duration of phase 4, the actual evacuation, depends on the time it takes to evacuate the population.

2.1.4 Decision makers

A critical part of an evacuation plan, is the dedication of the authority to start evacuations. In the United States, the emergency response command structure differs in almost every state. By law, in most states have governors the ultimate authority to order evacuations. However, for emergency evacuations, governors delegate this authority to local-level officials. This can be the mayor, city councils, sheriffs, county judges, county presidents or fire officers. These officials have a better knowledge of local characteristics, can act faster and are better informed on current local conditions when disaster strikes. They are therefore authorized to start with evacuating without the formal approval from the governor, if lives are at stake *(Urbina & Wolshon, 2003)*.

2.1.5 Evacuation types

As stated before, not a single evacuation will be exactly the same. Though it is possible to classify different types of evacuation. It is important to distinguish these different types during the development and planning of new strategies, since every one of them requires different actions for and expectations by both authorities and evacuees. There are several ways to make a difference between the types of evacuations. The following types are characterized by Frieser (2004), and are mutually distinguished by their time of occurrence :

- **Evacuation**: removal of people before occurrence of the disaster (*graph a*)
- **Flight**: removal of people after occurrence of the disaster (*graph b*)
- **Evacuation and flight**: the disaster occurs during the removal of people (*graph c*)

These different types are visualized in figure 4. In this figure, the course of the hazard has been depicted through a one-dimensional region (*distance, vertical axis)* as a function over time (*time, horizontal axis*) *(Frieser, 2004)*.

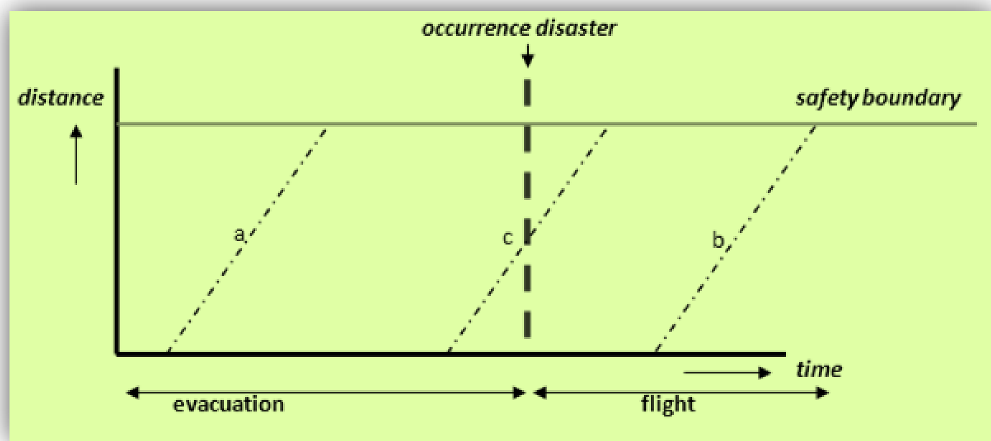


Figure 4: Evacuation types (Frieser, 2004)

People will behave different in these types of evacuations. Before the disaster occurred, people tend to respond in a relative calm, not panic-like way to warnings of an impending disaster. Most people act in a rational way and are willing to obey the authorities. People will try to get to their self chosen destinations. When there is a flight, people tend to panic and act in a less rational way by following their instincts. They are less willing to obey orders from the authorities and their behavior could be considered as non-adaptive *(Gwynne, Galea, Owen, & Lawrence, 2002)*. This has also got an impact on the actions that have to be taken by the authorities. To prevent the flight from turning into a uncontrollable massive flight, there are more officers and authorities needed that use their power more strict by telling people what to do and were to go. Since people need to get as soon as possible out of an area, people won't be able to use their self chosen destinations. They are to a certain extent forced to use other destinations or so called exit point. This has an impact on the transportation forecast since the distribution of trips between origins and destinations will change. *(Han & Yuan, Global Optimization of Emergency Evacuation Assignments, 2006)*

Another way of dividing different types of evacuations, is proposed by Urbina and Wolshon (2003). They describe evacuation types as voluntary, recommended or mandatory. The types differ in the magnitude of the hazard, the available time between the moment of prediction and occurrence of the disaster and required total evacuation time *(Frieser, 2004) & (Urbina & Wolshon, 2003)*. These types are mostly known and understood by the public and therefore used to inform the people during hurricane evacuations in the United States of America*:*

- **Voluntary**: The most vulnerable people are evacuated, others may remain if they choose.
- **Recommended**: Decisions to leave are left to individuals, and a few transportation arrangements are made.
- **Mandatory**: Maximum emphasis on encouraging evacuations and evacuation transportation plans go into effect. The authorities are responsible to make sure that everyone is able to leave the area or use a shelter.

In most cases a voluntary order is disseminated prior to a recommended or mandatory order. In the voluntary phase, people can decide for themselves whether they evacuate or not. Households are more likely to leave given a mandatory relative to a voluntary or recommended order. For example during a fire emergency in Ephrata, PA (USA) all people left town when they were ordered to do so. Prior to this mandatory evacuation, a recommended evacuation warning had been sent out to the people but only 21 percent of the civilians responded by leaving the town *(Fischer II, Stine, Stoker, Trowbridge, & Drain, 1995).*
When the classic four-step transportation forecast model is taken into account, a voluntary evacuation has minimal effect on the trip generation. It will be a minor difference from normal conditions. People who live in the affected area, tend to ignore more often a voluntary evacuation warning. Visitors and workers, tend to evacuate a little faster out of a threatened zone, given a voluntary evacuation warning. There will be a few more trips generated in affected areas and destinations that are stated as safe will see a minor difference in the trips they attract. But in most cases, voluntary evacuations do not cause significant capacity problems. It should be noticed that background traffic in combination with evacuation traffic can cause congestion problems at the routes that are used for so called 'through traffic' (Urbanik T. , 2000). For the authorities the different types of evacuations, come with a difference in possible actions to take. During a voluntary evacuation no special traffic control or transportation measures are usually taken. The authorities stay on high alert and advice people about congested routes and possible alternatives. Crisis Action Teams (CAT) initiate communications with and between local emergency offices and state agencies like the Departments of Transportation, Environmental Quality, Health Services etc. They also provide the public with information about evacuation routes and shelter places, through the use of various media outlets *(Urbina & Wolshon, 2003)*. Users of the network normally have a great freedom of action. The authorities can inform them about possible and best routes, but the users are allowed to make their own choices.

During recommended evacuation, the trip generation shifts upwards in a more significant way. Almost all people that do not live in the area and are free to move, will leave during this evacuation phase. This includes groups of people that only visit or work in the affected area. It is known that people who live in the appointed area will stay as long as possible in their homes, although this depends on their type of home (*for instance, people in mobile homes tend to leave earlier than others*) and the type of disaster *(Baker, 1991)*. Residents who hear recommendations about the evacuation in their area mostly understand that they are advisory, only 15 to 25 percent will be interpreting them as orders *(Baker, 1991)*. Baker also found that officials disseminating evacuation notices sometimes unintentionally blur the distinction, causing a higher rate of respondents and therewith a higher trip production.

During a recommended evacuation a few transportation measures are made by the authorities, in a way to start taking control over the taken routes. The purpose is to get more control over the traffic assignment process. The freedom of action of the traffic is somewhat restricted. Parts of the inbound traffic are restricted and arrangements are made to provide transportation for low-mobility groups. They are taking measures to get more control about the traffic assignment, should the recommended evacuation turn into a mandatory evacuation. The department(s) of transportation will collect more information about traffic volume data on key routes and information about spotted congested and evacuation routes will be disseminated towards the public. Local shelters are opened for people who are not able to leave the area *(Urbina & Wolshon, 2003)*.

During a mandatory evacuation, the traffic demand will be higher than during the other two phases. Normally, the highest peaks in traffic demands occur when mandatory evacuations are enforced. This means that there will be far more trips generated in a shorter time span than in normal conditions. Certain 'safe points' or 'exit points' will attract more traffic than in normal conditions are expected. This will lead to capacity problems, and thus undesirable congested routes. That is one of the reasons why in this stage all evacuation transportation plans go into effect. The authorities influence traffic patterns by executing their evacuation strategies. The actions of freedom for drivers will be reduced, depending on the strategy, to minimal conditions. People are enforced to take certain routes, inbound lanes are closed and sometimes used for outbound traffic, signal controls are adjusted or overruled and all other traffic measures that are observed in the evacuation strategy go into effect *(Urbina & Wolshon, 2003)*. All these measures effect the traffic assignment over the network. The strategies tend to spread the traffic in such a way that the capacity of the network is used in a more optimal way than without the traffic measures. It is clear that the strategies influence the traffic assignment, but they can also act on the mode choice of people. During mandatory evacuations are also strategies are possible that enforce people to use public transportation or allow a maximum of one vehicle per household. In this way it influences the mode choice and traffic demand of evacuees.

2.2 Evacuation Strategies

An important part of the evacuation plan contains the actual evacuation strategy; how to get people out of the endangered area. Over the years, several traffic measures have been developed that can be issued by local or state authorities. Some require modifications on the network prior the emergency and some do not. But all of these measures can be part of the strategy that is developed within the evacuation plan with the aim to get as much people as fast and safe possible out of an endangered area. In this section several strategies that are known within the literature are being discussed.

Sinuany-Stern and Stern (1993) make a difference between strategies that reflect traffic measures, and strategies that differ because of their route choice mechanisms *(Sinuany-Stern & Stern, 1993)*. The strategies known within the literature and the new strategy from Ashwin Arulselvan are briefly discussed. Also their expected influence on the transportation forecast will be discussed:

2.2.1 Evacuation strategies within the literature

With regards to the traffic management strategies and belonging traffic measures, Wolshon and Meehan (2003) explain possible fields of remedial actions. They sketch different areas that can be influenced in order to develop smoother evacuation plans. The areas that Wolshon and Meehan describe can also be found in the procedure for the development of evacuation plans as developed by Russo (2004) and presented in chapter 2.1.2.

2.2.1.1 Maximizing capacity

One of the areas that Wolshon and Meehan (2003) describe, is maximizing the potential capacity of the infrastructure. Within this area, there are several possible measures:

- **Elimination of crossing traffic flow:** The crossing streams of traffic are a source of waiting times and disturbances. In many urban networks, the intersections determine the capacity of the network. Crossing streams of traffic are a source of waiting times and disturbances and therefore they should be avoided *(Cova & Johnson, A network flow model for lane-based evacuation routing, 2003)*& *(van Zuilekom & Zuidgeest, 2006).* To get better results on the evacuation time, these crossing flows should be avoided as much as possible. Diverging traffic, the traffic that is coming from one area and using different exits, introduces a choice problem for drivers and thus problems for the local traffic management authority. Therefore, diverging traffic is ideally not allowed. Traffic flows should be converging rather than diverging. It is important to use appropriate capacity values at the exit points from converging routes, since it has great potential to become a bottleneck *(van Zuilekom & Zuidgeest, 2006)*.

  This measure will have impact on the distribution of the traffic over all the exit points. People are not allowed to choose their own exit points but are directed to a predefined destination. This measure will also impact the assignment of traffic over the network, since crossing flows are being avoided. This leads to other routes and the aim is to develop routes that generate fewer costs to the users. It is expected to positively influence the total travel time, but the methodology can lead to a larger overall distance traveled by the evacuees.
- **Contraflow**: Contraflow, or reverse laning as it is also known, involves the reversal of the traffic flow in one or more of the inbound lanes. The usage of inbound lanes for outbound traffic, adds capacity for the outgoing traffic. The average increase of road way capacity, with the use of contraflow lays between 50 and 70 percent ((Wolshon & Meehan, 2003) & ((Larson, Metzger, & Cahn, 2006)). An important aspect of the use of contraflow is the termination points and the location of

these segments. Termination points are critical because they move traffic from the reverse-flowing lane into the normal flow direction lane. With the decrease of capacity at these points, they largely influence the effectiveness of the contraflow operations *(Lim & Wolshon, 2005)*. Lim and Wolshon (2005) advise to maintain all lanes through the termination point with split rather than merge designs. Also, it is advantageous to reduce the volume entering the termination point by maintaining exit points along the route. The study suggests that merge zones located after exits, instead of before them, and the use of channelization or separation devices well in advance of forced maneuvers can enhance the quality of the flow through the termination vicinity.

Contraflow affects different aspects in the transportation forecast. The extra capacity will make certain links become more attractive, since these links have a greater capacity and therefore produce lower costs for the users. This will have an impact in the trip distribution over the network, since during an evacuation people want to get as soon as possible out of the endangered zone. When a certain link has more capacity and helps people exiting the area faster, zones at the end of these links will probably attract more traffic than other zones. It will also have an impact on the trip assignment. The links with extra added capacity can carry more traffic without disturbing the users' costs and thus the network equilibrium in a negative way. It is expected that more traffic is assigned to the links that uses contraflow than in normal conditions would occur.

- **Shoulder lanes**: Instead of using inbound lanes for outbound traffic, also shoulder lanes can be used. There's a need for preparing these shoulder lanes for traffic, and it is usually only valuable for highways since there are almost no shoulder lanes on urban roads *(Wolshon, Urbina, & Levitan, 2001)*

  This measure influences the traffic assignment since it makes it possible for certain links to carry more traffic without negatively influencing the network equilibrium.
- **Merging traffic**: Another way to prevent delays on the road network, is to develop evacuation routes where merging traffic is (mostly) avoided. This measure can have a great impact on the intersection capacity. The disadvantage of this measure is that less frequent merges and conflicts, lead to a higher value for the average shortest-distance-routing-plans *(Cova & Johnson, 2003).*

  The avoiding of merging traffic, has impact on the assignment of traffic. The expectation is that there will be less congestion on the network and this will bring down the costs at converging links and therewith make certain routes more attractive.
- **Traffic Police**: Instead of the use of special traffic signal timing systems, also police or traffic officers can be used to direct traffic at intersections to facilitate traffic flow *(Technical Data Report, 2005)*The presence of the authority at the intersection will make it possible to assign long green intervals, to congested routes. If it is done through a computer device like a signal control, it is very likely that the signal will be disobeyed by the less congested flows resulting in an increased risk of crashes and subsequent delays *(Franzese II, Schumpert, & Sorensen, 2003)*. With officers, traffic management can also make use of real-time evacuation modeling programs. These real-time evacuation programs, monitor the current flows on the network during an evacuation and update the prescribed routes continuously. Officers can respond by directing traffic towards the routes that the real-time simulation model provided them with. They also can provide the models with up to date information about congestion and are able to respond quickly to the (renewed) information provided by the real-time evacuation systems. When officers are used,

costs can be saved since there's no need to adjust intersections or signal timing programs. Another advantage of the officers is the better compliance from evacuees with the pointed directions, and so a better compliance with determined evacuation routes (Aved, Hua Ho, Hua, Hoang, & Hamza-Lup, 2006). Disadvantage is that it takes time to position officers at crucial intersections during an emergency evacuation.

In the transportation forecast, the traffic police will have about the same impact as the traffic signal timing. It affects the assignment of traffic over the network since the costs from certain routes will be reduced because of the more green time, and thus less delay they experience.

- **Traffic Signal Timing**: Traffic signals can have a tremendous impact on the movement of urban populations in an evacuation. A traffic signal is a device that trades off delays for safety, but at the expense of decreasing intersection capacity and creating overall delay. By developing special traffic signal systems that in case of an emergency apply more green time for evacuation routes, can greatly reduce the overall evacuation time *(Chen, Chen, & Miller-Hooks, March, 2007)*. There are different strategies for these special signal timings programs. It is possible to develop and use pre-determined control plans, which are static to changes in demand. The other strategy is the use of actuated control plans, which uses real-time info and can respond to changes in demand *(Hamza-Lup, Hua, & Peng, 2005)*. The predetermined and actuated traffic signal timing will have effect on the assignment of traffic over the network. Evacuees will choose routes that have minimal costs. When a certain route has more green time, their overall costs will be reduced and therefore the link with more green time attracts more traffic. The overall costs of busy routes will reduce since they experience less red signals.

2.2.1.2 Limiting demand

Instead of maximizing the capacity, measures can also be aimed at limiting the demand *(Wolshon & Meehan, 2003).* This will affect the trip generation within the classical transportation forecast and therewith the supply-demand interaction as described in chapter 2.1.2. In the literature review were four relevant demand limiting measures discovered:

- **Staged Evacuation:** Staged evacuation, also known as phased evacuation or zoned evacuation, is another widely used control strategy to guide evacuation flows. Without changing the network geometry like contra flow design or enforcing route choice restrictions, staged evacuation aims to achieve more efficient network utilization mainly through a better distribution of evacuation demand over the allowable time window. It is expected that staged evacuation will reduce the so called "shadow evacuation". Shadow evacuation occurs when people living outside the danger zones unnecessarily evacuate increasing congestion on roadways *(Koutink, 2000)*. Officials issue evacuation orders at an earlier time to those zones with higher levels of urgency (e.g., with a shorter safety time window or with higher concentrations of hazardous chemicals) and start evacuating the low urgency zones some time later. This measure can effectively limit the surge in evacuation demand, reduce overall network congestion and, more importantly, avoid or at least mitigate potential casualty and stress levels caused by evacuees being blocked in more dangerous areas *(Liu, 2007)*. It is critical that the evacuees comply with the evacuation order. Otherwise, the chance for chaos and a less arranged evacuation increase dramatically.

  This measure impacts the generation of traffic. Since evacuees leave in sequential stages, the generation of traffic will be spread out over time. This means that there are fewer vehicles at one point of time than in a non-staged evacuation. It will also influence the assignment of traffic over the network. Since the demand is more spread out, some links will become more attractive since they are less congested.

- **Road Closures**: It is believed that the closure of inbound arterial streets to the emergency planning zone, can be a very effective measure. However, the effectiveness drops if the network is already congested when the evacuation starts *(Kwon & Pitt, 2005)*.
  The idea behind this measure is that it will diminish the generation of traffic. There will be fewer vehicles in the network since main inbound lanes are closed. Therefore it has a positive impact on the production of traffic within the considered network.
- **HOV-priority:** HOV *Priority* refers to strategies that give priority to *High Occupant Vehicles* (also called rideshare vehicles), including transit buses, vanpools and carpools. HOV Priority is a major component of many regional traffic demand management programs. Two, three or four occupants may be required to be considered an HOV, depending on circumstances. Also public transportation buses belong to HOV. This is opposed to Single Occupant Vehicles (SOVs). Experience indicates that the best way to quickly evacuate a large city is to give buses and perhaps other high occupancy vehicles priority in traffic and fuel access, and then accommodate as many low-occupancy vehicles as resources allow. Individuals can choose between accepting a free and fast bus ride, or driving a private vehicle and facing congestion delays *(Victoria Transport Policy Institute, 2008)*.
  This measure is expected to influence the traffic generation. Since people share vehicles, there will be fewer vehicles on the road and thus less traffic is being produced. The effect will be that fewer cars are needed to evacuate all people out of the emergency planning zone. It will also influence the modal split of evacuees; if busses or other public transportation are getting priority with evacuations, it is expected that more people will choose to use public transportation and thus another mode of transportation.
- **Maximum number of cars:** This measure refers to the use of cars during an evacuation. It is known that during an evacuation, people tend to take all the cars they have with them. This leads to a higher demand of capacity for the roads. One of the measures to decline the traffic generation is to encourage people to evacuate with more than one car per household. The Natural Hazards Observer of 2004 recommended that authorities should encourage or set a maximum on the number of cars that people use during their evacuation *(Laska, 2004).*

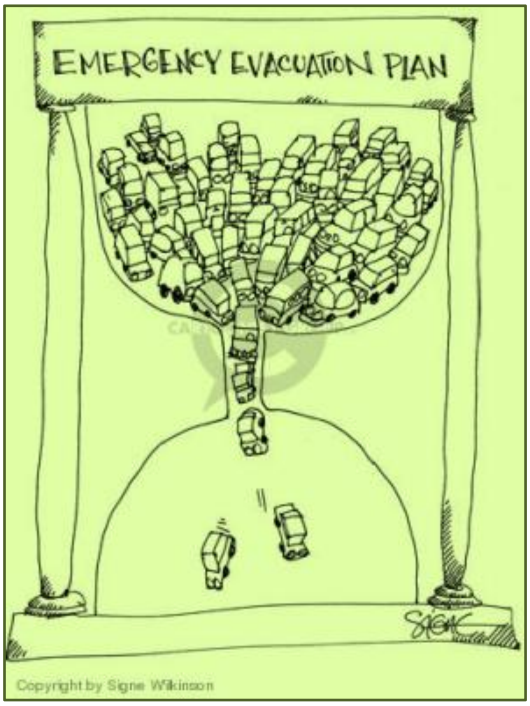


Figure 5

2.2.1.3 Improving communication

Another area that Wolshon and Meehan (2003) distinguish, are measures that effect the communication between transport management and evacuees. The most important measure that is part of this area, is the use of Intelligent Transportation Systems that can communicate with the evacuees and provide them with up-to-date information:

- **ITS**: Dissemination of information to the motorists is one of the most important factors during any evacuation program. ITS technologies are strongly recommended in managing the evacuation program, they reduce delay due to diversion so more efficient traffic management can be achieved. There are different forms of Intelligent Transportation Systems:
    - **Highway Advisory Radio**: Maybe not as relevant for city evacuation, but this system disseminates information about current traffic conditions and route diversion by playing messages repeatedly on a radio frequency.
    - **Variable Message Signs**: VMS are programmable traffic control devices that display messages of letters, symbols or both. These systems can be considered as the most effective visual aid and can provide motorists with all kinds of information and recommended or forced routes. They are flexible and provide real-time information.
    - **Interaction between cars**: New inventions make it possible for vehicles to interact with each other. In case of emergency evacuation, they can update each other with current information about traffic loads, congestions, road blocks and accidents.

  The use of ITS is expected to influence the distribution of traffic. People are informed about alternative exits. This means that people can change their destination towards a better reachable exit point. It will also influence the assignment of traffic over the network. Evacuees are informed about congestion and alternatives that are more effective given their travel costs. This means that the traffic is more effective spread over the network resulting in a lower evacuation time.

2.2.1.4 Multimodal Evacuation Strategy

Arulselvan (2008) developed a new methodology to cope with a multimodal evacuation problem. The methodology considers the use of two modes, namely the use of private cars and the use of buses. Arulselvan (2008) indicated that there was a shortage of analytical techniques in multimodal evacuation studies *(Arulselvan, 2008)*. He developed a methodology to establish efficient evacuation routes with bimodal transportation. Cars and busses are considered as the available modes of transportation. His developed methodology establishes efficient paths for the cars and determines the frequency of the buses along their predetermined routes, to create a most optimal solution. In this most optimal solution, where the efficiency is based on the cost structure, the attempt is made to stay within the capacity of the links *(Arulselvan, Multimodal Solutions for Evacuation Problems (Draft), 2008)*.
This strategy affects the assignment of vehicles over the network. Efficient paths are determined for the available modes of transportation. To use the results of the methodology, people are not free to choose their own routes, they are directed towards the route that will allow the system to create the most optimal solution.

2.3 Ways to evaluate strategies

When the evacuation plans are formulated, they need to be evaluated. It is important to analyze and test all the aspects of the plan, to make sure that when needed the evacuations take place in an (relative) organized and efficient way. To organize evacuations, strategies are being developed in the plan. These strategies need to be simulated to test their effectiveness. One way to test these strategies is with the usage of traffic simulation models. They also help practicing scenario's and strategies by simulations, so that during a real evacuation the authorities know better what to expect and how to respond. The traffic simulation models can be used to evaluate evacuation plans in a laboratory environment, without the immediate need for real-time evacuations.

There have been many attempts to develop simulation models for use in evacuation planning and it is helpful to try to classify these as to understand the approach taken in different models. Over the past decade, a number of computer models have been developed to assist in emergency evacuation planning, for mitigating disasters ranging from nuclear power plant failures to hurricanes. Studies in the 1980s focused on evacuations due to the Three Mile Island incident that occurred in 1979 *(Urbanik & Desrosiers, 1981)*. Much recent research has focused on hurricane evacuation, because a number of extremely devastating hurricanes have hit the U.S. in the 1990s, as well as in 2005 *(PBS&J, 2000)*. After the 9-11 incident, there is growing concern about mass evacuation due to terrorist attacks *(VDEM, 2005)*. All of the models are designed to simulate the way in which the demand uses the supply system, producing flows on network links that in turn generate travel costs. The approaches to simulate the interaction between supply and demand, can be divided in two classes, the static models and the dynamic models *(Russo & Vitetta, 2004)*.

Static models use static transportation information or assume network link flows to be at steady states. Static models do not provide real-time traffic information or allow en route-dynamic routing. It assigns each trip, when loaded on the network to the best route at the time, although once en route vehicles do not have real-time information for rerouting. Most geographic-information-system-based models or static traffic assignment models fall into this category *(Chiu & Mirchandani, 2008) & (Han & Yuan, 2006)*.
Dynamic models disseminate traffic conditions and routing information to enable drivers to select better routes to their destinations. Each evacuee will still proceed to a pre-assigned destination, perhaps via a better route *(Han & Yuan, 2006)*.

To help evaluating the strategies within the evacuation plans, computer simulation models can be used. There are several models available, each with its own characteristics and capabilities. All of the available simulation models can be classified within the next three classes:

- **Micro-simulators**: In micro-simulators, an attempt is made to track the detailed movement of individual entities in the network being simulated. These entities might be vehicles, such as private cars, buses or trucks. They might also be people, single or in groups. The idea would be that the entities are taken from the evacuation zones and then proceed to find their way to the safe destinations or martial control *(Southworth, 1991)*.
  The obvious advantage of these micro-simulators is that the simulation should be able to track the fine detail of individuals. This makes it much easier to introduce real-life factors such as traffic congestion, evacuee behavior, police intervention and breakdowns of vehicles which might block the progress of an evacuation *(Pidd, de Silva, & Eglese, 1996)*.

- **Macro-simulators:** These simulators make no attempt to track the detailed behavior of individual vehicles and they are based on equations which stem from analogies with fluid flows in networks. Some macro-simulators are relatively static in that they can only cope with steady state conditions, but this may not be adequate in the dynamic and sometimes chaotic, environment of an emergency evacuation *(Southworth, 1991)*.

  Macro-simulators can handle traffic on large networks and distances like highway traffic. There is no need to maintain the state information about thousands of individual entities, instead state variables are updated at intervals by dynamic state equations *(Pidd, de Silva, & Eglese, 1996)*. Macro simulation technology does not attempt to track detailed behaviors of individual vehicles, they are based on equations that treat traffic as flows on networks *(Chen, Meaker, & Zhan, 2006)*
- **Meso-simulators**: are a compromise between the two approaches discussed above and they usually involve a discrete simulation which tracks the movements of groups of vehicles. This approach evolved because of a need to find some way to reduce the computational demands inherent in a micro-simulation without losing the need for relatively detailed interactions *(Pidd, de Silva, & Eglese, 1996)*.

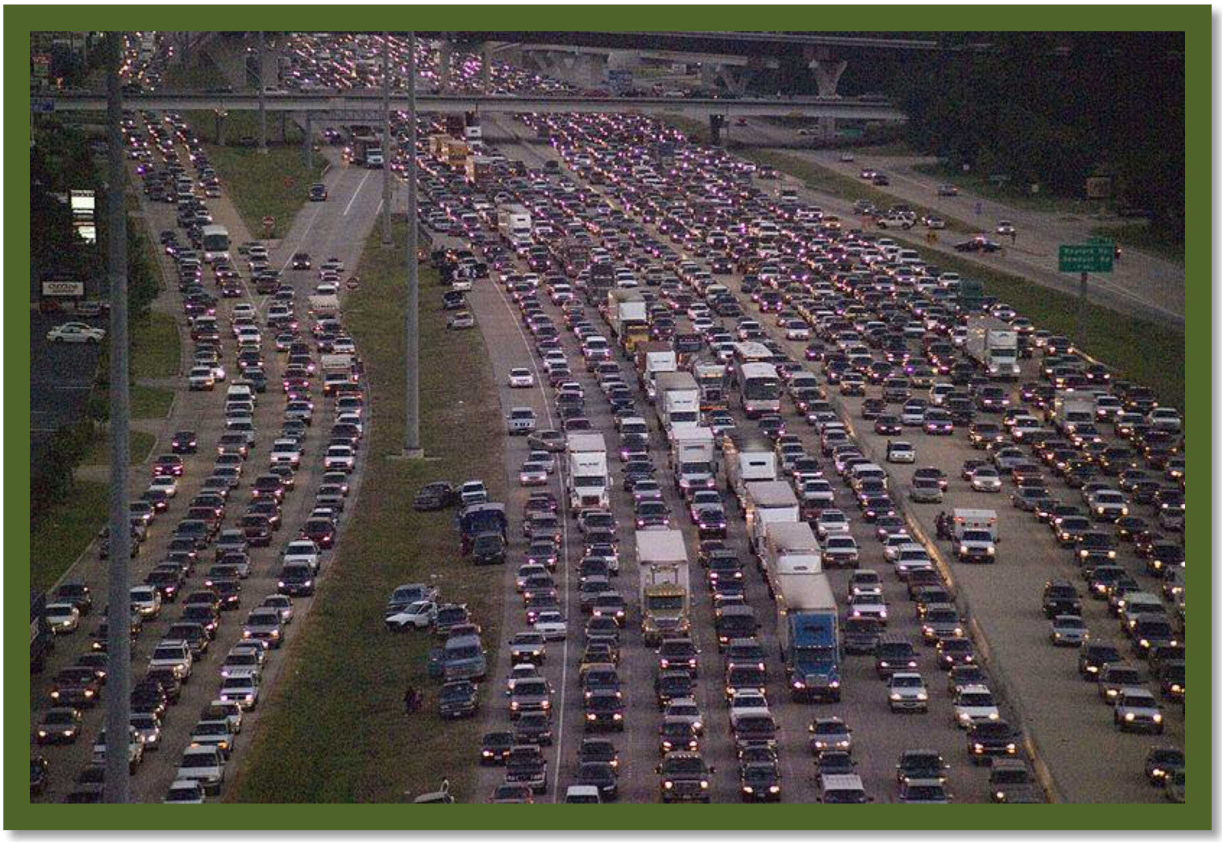


Figure 6: Evacuation of Houston in advance of hurricane Rita, with deployment of contraflow

2.4 Evacuation assessment studies

There have been studies that compared the effectiveness of different evacuation strategies. Sinuany-stern and Stern (1993) examined the sensitivity of network clearance time to several traffic factors and route choice mechanisms, in a radiological emergency situation. They examined the effects when interaction with pedestrians was modeled and what changes in intersection traversing time and car ownership meant for the results. They also examined the shortest-path and myopic behavior for the route-choice mechanisms. They found that evacuation time comes closer to reality when interaction with pedestrians and a uniform distribution of intersection traversing time are assumed (Sinuany-Stern & Stern, 1993). Curch and Sexton (2002) investigated how evacuation time can be affected under different evacuation scenario's, such as opening an alternative exit, invoking traffic control or changing the number of vehicles leaving the household. They found that the opening of an alternative exit can have a great impact on the evacuation time. Also the invoking of traffic control is a measure with great benefits towards the needed evacuation time *(Church & Sexton, 2002)*. Cova and Johnson (2002) applied agent-based micro-simulation to test neighborhood evacuation plans in an urban-wildland interface. They were able to assess the spatial effects of a proposed second access road on household in a very detailed way *(Cova & Johnson, 2002)*. Batty et al (2002) described an agent-based model to simulate the changing of the route of annual Carnival event over two days each year. They demonstrated how congestion problems (*mainly for pedestrians*) and problems over safety can be resolved by introducing traffic controls, like the closure of streets and use of prescribed routes *(Batty, Desyllas, & Duxbury, 2003)*. Chen (2005) examined the effects from staged and simultaneous evacuation on different road-networks. Chen found that when the traffic is in a free flow mode and there is no congestion o the road, simultaneous evacuation is the fastest, but under a congestion situation staged evacuation strategies are more effective than the simultaneous evacuation strategy on the grid network. There was no obvious advantage of the staged evacuation strategy on the ring and the real road network *(Chen X. , 2005).* There are more works that analyzed the effectiveness of different strategies. Franzese and Han (2001) developed a methodology to analyze and evaluate the impacts of different factors affecting large-scale emergency evacuations from a traffic operations perspective. It is possible to use their model to evaluate the impacts of factors such as regional traffic operations coordination, the deployment of rural ITS technology, and the implementation of certain unusual traffic management techniques (e.g., counter/contra flow and staggered departing time strategies) on an evacuation exercise *(Franzese & Han, 2001)*. Kwonn and Pitt researched the effectiveness of alternative strategies for evacuating the traffic in downtown Minneapolis, Minnesota, under a hypothetical emergency situation that included the evacuation of a sellout crowd in the Metrodome *(Kwon & Pitt, 2005)*. They analyzed three strategies. The first strategy involved only the arterial links and freeway exit ramps approaching the downtown area were blocked when evacuation starts. Within the second strategy, in addition to the first, all the incoming freeway links located inside the network were blocked to prevent vehicles from entering the evacuation area. The third strategy involved the transformation from all the inbound-outbound freeway links in the inside network to one-way outbound links, known as contra flows. They found that the third strategy was the most effective one, but had little impact on the total evacuation time. After some further research, they found that using this third strategy in combination with an increased capacity of the entrance ramps, reduced the needed evacuation time more significant *(Kwon & Pitt, 2005)*. Sisiopiku et al. (2004) tested several emergency scenarios for Birmingham. They analyzed response actions like traffic diversions, altering signal timings, roadway clearance and access restrictions under different scenarios. Their first case showed significant improvement of network performance with the traffic diversion strategy. This led them to the conclusion that ITS would provide a great advantage in traffic management under emergency conditions *(Sisiopiku, Jones, Sullivan, Patharkar, & Tang, 2004)*.

3 Description of cases

Two cases are build to test the strategies and their results under different circumstances. Both cases are build around the evacuation of the sold out football stadium at the University of Florida. This stadium accommodates about 90.000 people during most games. A lot of people travel all over Florida and other states to join the popular university football team. In normal conditions, a lot of people spend the night in Gainesville and travel homewards during the next day. Normally, some spectators leave before the game ends, and some will wait after the game ended before they leave. This results in a more spread and steady outgoing flow of the spectators than there will be in an evacuation situation. During evacuations, the exceptional situation will occur where everybody is forced to leave the stadium. This will lead to the situation were the flow will be maximum and the demand for traffic capacity exceeds the normal levels. Therefore, this situation is suitable for the assessment of the different strategies under extreme circumstances with a high demand and concentrated flows.

In both cases an emergency occurs that require the evacuation of the spectators out of the stadium. The stadium is expected to be sold out during the game which starts at the time of 12.30hr. At 14.00hr an emergency occurs that requires the evacuation of the people out of the stadium. It also requires the movement from the people towards their house in- or outside Gainesville. To limit this research, the evacuation of the whole Gainesville population is let out of consideration. It is expected that people are safe when they have reached their home. People who don't live in Gainesville are forced to leave to the Gainesville area. This creates flows to destinations both inside Gainesville as outside the city.

In the scenario, the spectators can choose between two modes of transportation. The car and public transportation. Most other evacuation evaluating studies do not consider a multimodal evacuation problem. The cases will use special bus routes and frequencies that are used during game days.

3.1 Case 1: Evacuation traffic

The first case only considers evacuation traffic. All other traffic flows that are normally present, are left out of consideration. This indicates a situation where the traffic network is empty when the evacuation starts and will not be loaded with other than evacuation flows. In normal conditions, there will be traffic present on the network that is not generated by the spectators. The simplification of the reality will make the distribution and assignment of traffic over the network easier. The results will also give an indication of which strategy is most effective for the evacuation traffic.

3.2 Case 2: Evacuation and background traffic

The second case has been developed to test if the results in the first case, will be the same in the second one. In the second case, background traffic is considered. The implementation of background traffic will lead to more traffic flows on the network when the evacuation starts. Also, the directions of these flows will differ from the evacuating vehicles. It is expected that this will lead to more conflicts in the network. For the first two hours, the background traffic will flow into the network while the evacuees only flow outwards the network. It is expected that this will influence the effects from several strategies. But if the results of the first case are valid, they should hold up in the second case.

Due to restrictions of Corsim, it has not been possible to load the network with background traffic under normal conditions before the evacuation starts. This would be more ideal and closer to the reality but Corsim is not able to allow changes in the network during the simulation. For some of the strategies this is needed. For instance, contraflow needs adjustments of the lane characteristics. Corsim is not able to adjust these characteristics during the run. Therefore, background traffic starts flowing at the beginning of the simulation when the evacuation starts. After two hours, it is assumed that the incoming background flows are blocked by the police in order to clear the network. At this point, only outgoing flows will exist.

Figure 7: Buses at the begin point of their route, during a football game

4. Simulation

In this chapter all information can be found that is related to the simulation. There will be explained which simulation program has been used, how it works and what its restrictions are. Further there will be explained which assessment criteria will be used and how the research and evacuation road network look like. Information about trip generation, distribution, the modal split, trip assignment and the output can be found in the last few paragraphs.

4.1 Corsim

4.1.1 How it works

The simulation program that has been used for this research is called CORSIM. CORridor SIMulation is a microscopic traffic simulation program. The ability to evaluate microscopically is unique in that microscopic models track individual driver behavior whereas macroscopic and *(to a certain extend)* mesoscopic models view all vehicles in the traffic stream as platoons exhibiting identical individual behavior characteristics.

CORSIM has been developed by the US Federal Highway Administration in association with the University of Florida. It is a computer model that has evolved over time from two separate traffic micro simulation programs, NETSIM and FRESIM. The combination made it possible to analyze complete systems, since NETSIM represents traffic on urban (surface) streets and FRESIM traffic on freeways. CORSIM is a stochastic model, which means that random numbers are assigned to drivers and vehicle characteristics and to decision making processes. The Measures of Effectiveness, MOEs that are obtained from a simulation are the result of a specific set of random number seeds. For example, one set of random number seeds may result in three very conservative drivers driving side by side on a three-lane road, blocking more aggressive drivers behind them. To gain a better understanding of the network performance, the network should be simulated several times using different sets of random number seeds *(US Federal Highway Administration, 2003) & (Corsim Help)*. The seeds that can be randomized are the headway seed, the vehicle seed and the traffic seed.
In Corsim, each vehicle is defined by fleet (auto, carpool, truck or bus) and by type. There are up to nine different types of vehicles. A driver behavioral characteristic, is assigned to each vehicle. There are op to ten different types of drivers. Each vehicle behavior can be simulated in a manner reflecting real-world processes.
Each time a vehicle is moved, its position on the link and its relationship to other vehicles nearby are recalculated, as are its speed, acceleration, and status. Vehicles are moved according to car-following logic, in response to traffic control devices and in response to other more car or fleet specific demands. Congestion can result in queues that extend throughout the length of a link and block the upstream intersection, thus impeding traffic flow. Signal controls and the bus routes are explicitly modeled.

An evaluation of CORSIM was made by Tagliaferri (2005). He pointed out that CORSIM is readily available and well known throughout the traffic engineering community. An advantage of CORSIM is that it models freeway and surface street links using separate algorithms, which allows roadway facilities with vastly different characteristics to be modeled with relatively little effort. Tagliaferri points out that the CORSIM simulation results are closer to what have been observed in real evacuation experiences than other programs like VISSIM *(Tagliaferri, 2005)*. CORSIM was also used by Sisiopiku et al. (2004), who tested proposed evacuation plans and response actions using the specifically designed capabilities of CORSIM for simulating traffic control systems *(Sisiopiku, Jones, Sullivan, Patharkar, & Tang, 2004)*. Also Chen et al. (2007) used CORSIM to test traffic signal timing for urban evacuation *(Chen, Chen, & Miller-Hooks, March, 2007).* It has also been used by Lim and Wolshon (2005) when they compared different contraflow evacuation termination points *(Lim & Wolshon, 2005)*.

4.1.2 Model assumptions and limitations

4.1.2.1 Multiple runs

Corsim is a stochastic simulation model. Unlike deterministic analytical models, these stochastic simulation models are driven by samples of random variable from probability distributions. These random variables may have large variances. In general, the variation caused by these stochastic models can be reduced by using a longer simulation period and increasing the number of runs. Although Corsim has adapted a so called variance reduction technique, it still is necessary to run the network multiple times varying the random number seeds to gain an accurate reflection of the performance of the network. Corsim has a built in multiple run capability and a built in output processor. The multi run capability of Corsim runs the network multiple times changing the random number seeds for each run. The output processor collects data for the selected measures of effectiveness over multiple runs for the selected links. The data from the multiple runs is summarized and using this option accounts with the stochastic nature of Corsim. To account for the stochastic nature, Corsim can vary the headway seeds, vehicle type seed and the traffic seed. It still is necessary to calculate the number of runs needed for valid conclusions. *(Corsim Help).*

To obtain the minimal needed number of runs, the following formula is used *(Strijbosch, 2006)*:

$$n = \left(\frac{Z_{a/2} \cdot \sigma}{E}\right)^2$$

where:
- n = required number of simulation runs
- $z_{a/2}$ = threshold value for a $100 \cdot (1 - a)$ percentile confidence level
- σ = sample standard deviation
- E = allowed error range

A level of confidence of 95 percent, creates a value for $z_{a/2}$ of 1,96. With a sample size of 10 runs for the discharge per link, the numbers of needed runs are calculated with an error range of 5 percent. Because of the high number of needed runs that were found using this margin of error, also the numbers of needed runs with an allowed error of 10 percent are calculated.

Required number of simulation runs

Link	5 percent	10 percent	Link	5 percent	10 percent
4 - 523	8	3	345 - 346	9	1
43 - 504	1	1	359 - 362	5	1
85 - 507	1	1	369 - 471	6	1
146 - 505	1	1	382 - 378	3	1
153 - 508	181	55	440 - 436	3	1
194 - 506	1	1	509 - 510	101	15
206 - 517	101	8	511 - 512	113	45
235 - 522	29	6	513 - 514	342	52
305 - 302	2	1	515 - 516	120	42
307 - 528	3	1	518 - 519	39	18
319 - 472	9	1	520 - 521	17	4
325 - 326	8	2	524 - 525	5	1
327 - 328	6	2	526 - 527	33	3
333 - 334	7	1			

It is found that, in order to cope with the 10 percent margin of error, at least 55 runs are needed. Another factor that will influence the how many runs are performed, is the time it takes to simulate a strategy. During the test run for the first case, it was found that Corsim needed to simulate about 9 hours to clear the traffic from the network. In order to set some margin, all the strategies in the first case are analyzed for 10 hours. The running time differs per strategy but the average needed time to perform 15 runs of 10 hours, was about 4 hours. Corsim needs additional time to write the results to an Excel file. The total average running time for the first case strategies is about 6 hours. This will lead to a total running time of 22 hours. This running time has been too long, and therefore it has been chosen to work with 15 simulation runs in the first case.

The second case leads to more problems. Corsim needs more running time since in the second case background traffic is considered. This leads to more traffic in the network and thus a higher calculation demand. During a test run, it was found that Corsim needed for 15 simulation runs and a simulation time of 15 hours, 26 hours to calculate the results. This included the time Corsim needed to write the results to an excel file. Due to time restrictions, this running time is not considered to be feasible. Therefore, the second cases are analyzed by running each strategy 10 times with a simulation time of 12 hours. This resulted in an average calculation time of 11 hours.

4.1.3 Preparations for evacuation traffic

Corsim is a standard traffic simulation program that has not specifically been developed to analyze evacuation strategies. This creates several difficulties. One of these difficulties involves the implementation of the number of vehicles that will leave the area. Corsim is able to cope with steady flows over one interval. In the evacuation analysis, only data about the number of cars are available. There is no specific data about flows available. Therefore, the model needed to be transformed towards a situation where only a fixed number of cars will be discharged on the network from each parking lot, and when the lot reaches this number, the flow should change to zero. The only solution was to use the 'vehicle count' option in Corsim. With this option, in the first interval of 5 minutes, an attempt was made to discharge every specified vehicle from the parking lot on the network. Since the 5 minutes are too short to empty the parking lots, the traffic will continue to be discharged over the next time intervals at the maximum possible flow. When the original vehicle count number is reached, the flow of vehicles discharged from the parking lot will stop and no more vehicles are being discharged on the network. This creates a situation where everybody wants to leave within the first 5 minutes, but since capacity restrictions apply are not able to do so. Corsim will then discharge the traffic at the maximum possible flow, over the next time intervals. At the point where the discharge equals zero, the parking lot is empty.

Figure 8: Queue gets formed at Archer Road after a game

4.2 Assessment criteria

It is necessary to establish effective assessment criteria, to measure the influence from the different strategies on the effectiveness of the evacuation strategies. Most studies in the literature use the Total Evacuation Time or so called Network Clearance Time as the most important criteria. The Network Clearance Time is the time required for all evacuees to physically travel out the evacuation area. Kwon and Pitt (2005) used in their study the time needed to evacuate all people out of the area. To estimate the total evacuation time, they selected four outbound links located at the boundary of the selected evacuation area, and used the time-variant traffic flow rates from the output files. When the flow on these links was equal to zero, they said that at that time the emergency planning zone was evacuated. There is a need however to check if this flow equals zero as a result of no traffic or if it is the result from congestion. Also Jha et al (2004), Urbanik (2000) and Chen et al (2005 & 2006) used the total time to achieve a complete evacuation as the main performance measures to evaluate different scenario's .

Apart from evacuation times, various performance measures for traffic conditions on the entire network have been considered for evaluating different evacuation operations. These include the number of congested links, the number of maximally utilized links, the origin-destination travel time, the total household travel time, the average speed, the density and the total delay during an evacuation *(Sisiopiku, Jones, Sullivan, Patharkar, & Tang, 2004) & (Murrary & Mahmassani, 2003).* Han et al. (2007) analyzed more measures of effectiveness like the loading time or loading delay time and delay of population before the onset of the evacuation process. They analyzed different measures of effectiveness and concluded that Total Evacuation Time, Total Travel Time, Individual Exposure Time, Time-Based Risk and Evacuation Exposure are useful performance measures (Han, Yuan, & Urbanik, 2007).

There are more measures to test the effectiveness from different strategies. In CORSIM it is possible to get the total travel time on the network for all vehicles. It is also possible to see the total delay time or the delay time per travel hour. Another way to assess the strategies is by analyzing the number of vehicles that have been discharged from the exit links since the beginning of the simulation. It can also be interesting to check the queue delay per vehicle or the control delay per vehicle, to assess different 'intersection-strategies'.

It is clear that there are many ways to assess the different strategies. It is now a matter of selecting the most use- and meaningful criteria that can help by evaluating the different strategies. One of the most common used criteria is the Network Clearance Time, also known as the Total Evacuation Time. The total evacuation time is used in many studies to analyze the results from traffic measures or route-choice mechanisms during an evacuation. It also is the aim of most strategies, in other words, most strategies aim to lower the evacuation time for an area. The Total Evacuation Time cannot be directly withdrawn from the Corsim output. Therefore it is expected that the total evacuation time will be reached at the point where the flow and density on all exit links equals zero. The second assessment criteria that will be used is the Total Travel Time. Han et al. (2007) state that evacuation time does not necessarily give a representative picture of average travel time or any possible delay experienced by evacuees. The total travel time is important since it can provide us with information about the exposure from the population to the risks. For instance, different strategies can have the same evacuation time, but scenario X has the highest total travel time. This means that in this scenario more people are for a longer period exposed to the threat. Since the results of drivers that actually evacuate differ between the scenarios, the average total travel time per vehicle is used as the second assessment criteria.

Besides these two main criteria, there will be looked at other factors. These factors can give information about the performance within the network. To analyze the handling quality, the following factors are analyzed:

- **Delay time ratio** ***(in delay time per travel hour)***
  The delay time ratio represents how much time of one travel hour the vehicles cannot travel at free flow speed. The lower this number, the less delay the drivers experience which indicates a better traffic handling within the network
- **Average Total Travel Distance** ***(in miles per vehicle)***
  The lower this number, the lower is the distance that people need to travel from their origin to their destination which indicates a better traffic handling and thus a better performance by the strategy.
- **Average Travel Speed** ***(in miles per hour)***
  The higher this number, the faster people can travel and the better the free flow speed is used. If the average travel speed comes closer to the average free flow speed, it indicates a higher level of service and a better level of traffic handling.

In the first case, where background traffic is let out of consideration, all of these criteria can be obtained and used to analyze the handling quality of the network. However, in the second case not all traffic is cleared from the network within the analyzed time period. This results in the uselessness of several assessment criteria. For instance, the evacuation time is no longer a usable criteria. Instead of the evacuation time, the second case will use the number of cars evacuated after twelve hours as the main criteria. This makes it possible to compare the results and effectiveness of the different strategies since it is expected that a more efficient strategy will clear the traffic faster, and thus evacuated more vehicles after twelve hours.
Also, it has not been possible to use the average total travel distance as an assessment criteria during the second case. This because the number of vehicles that have left the network and are on the network, will not be the same for each strategy. This makes it unfair to compare the different strategies by the total travel distance. Therefore the following criteria will be used to compare the strategies, in the second case:

- **Evacuated vehicles** ***(number of cars that have left the network after twelve hours)***
- **Total Travel Time** ***(in hours)***
- **Delay time ratio** ***(in delay time per travel hour)***
- **Average Travel Speed** ***(in miles per hour)***

4.3 Research Area

This paragraph focuses on the research area of this project, the city of Gainesville.

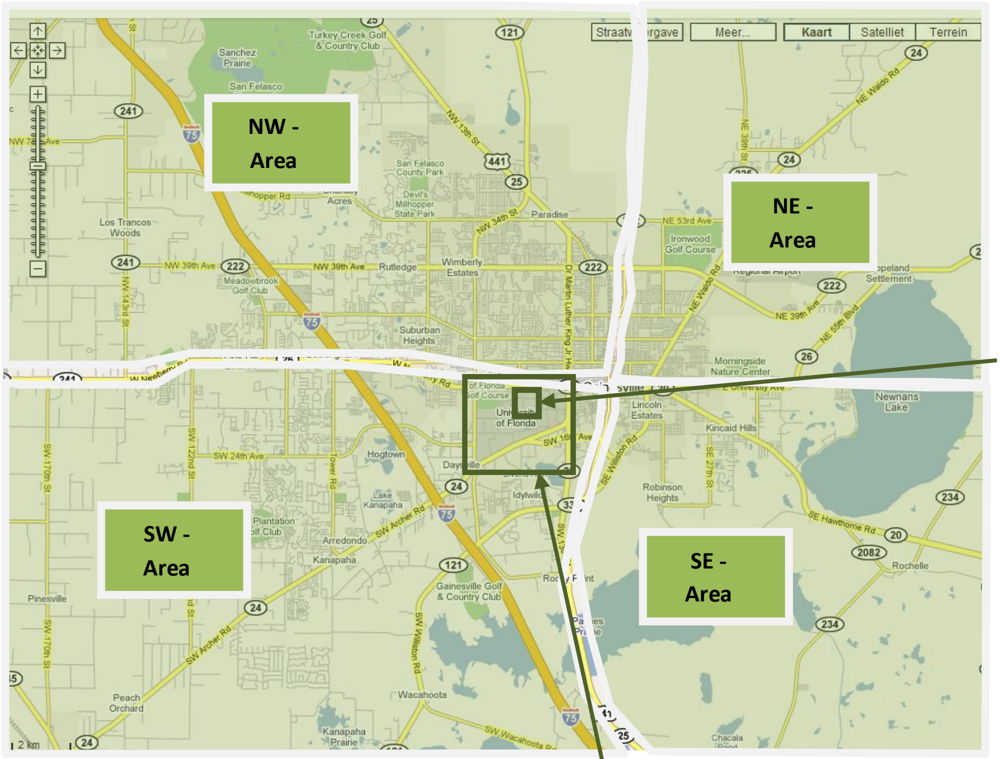
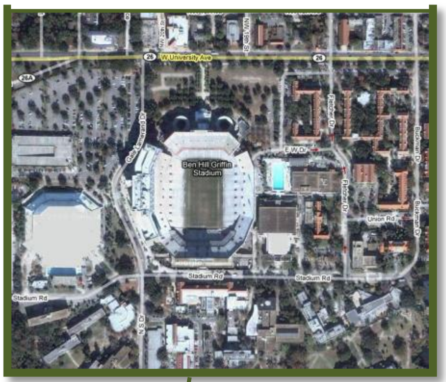


Figure 9: Map of Gainesville with its four quadrants

Figure 10: Stadium and its surroundings



The evacuation strategies will be tested on the road network within the city of Gainesville, Florida. Gainesville is the fourteenth largest city in Florida and the largest city in, and county seat of Alachua County, Florida. The U.S. Census Bureau estimated in 2007 a population of 114,375 *(U.S. Census Bureau, 2007)*. Gainesville is located halfway at the Interstate 75 between Atlanta and Miami. Gainesville has an extensive road system, which is served by Interstate 75, and several Florida State Routes, including State routes 20, 24, 25 and 26, among others. Gainesville is also served by US 441 and nearby US 301, which gives a direct route to Jacksonville, Ocala, and Orlando. The most important traffic attractions are the University of Florida, the Shands top medical institution and hospitals, and during game days the Florida Gators.

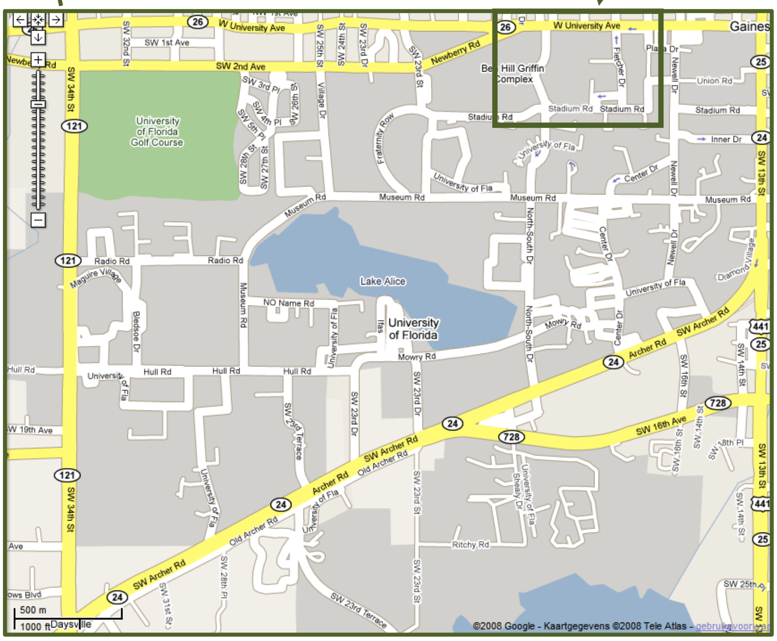


Figure 11: Campus area of the University of Florida

The city's streets are set up on a grid system with four quadrants (NW, NE, SW and SE). The quadrants are roughly sketched in figure 9. All streets are numbered, except for a few major thoroughfares which are often named for the towns to which they lead (*such as Waldo Road (SR 24), Hawthorne Road (SR 20), Williston Road (SR 121), Archer Road (also SR 24) and Newberry Road (SR 26*).

In addition to its extensive road network, Gainesville is also served by Gainesville Regional Transit System, or RTS, which is the fourth largest mass transit system in the state of Florida.

4.4 Evacuation road network

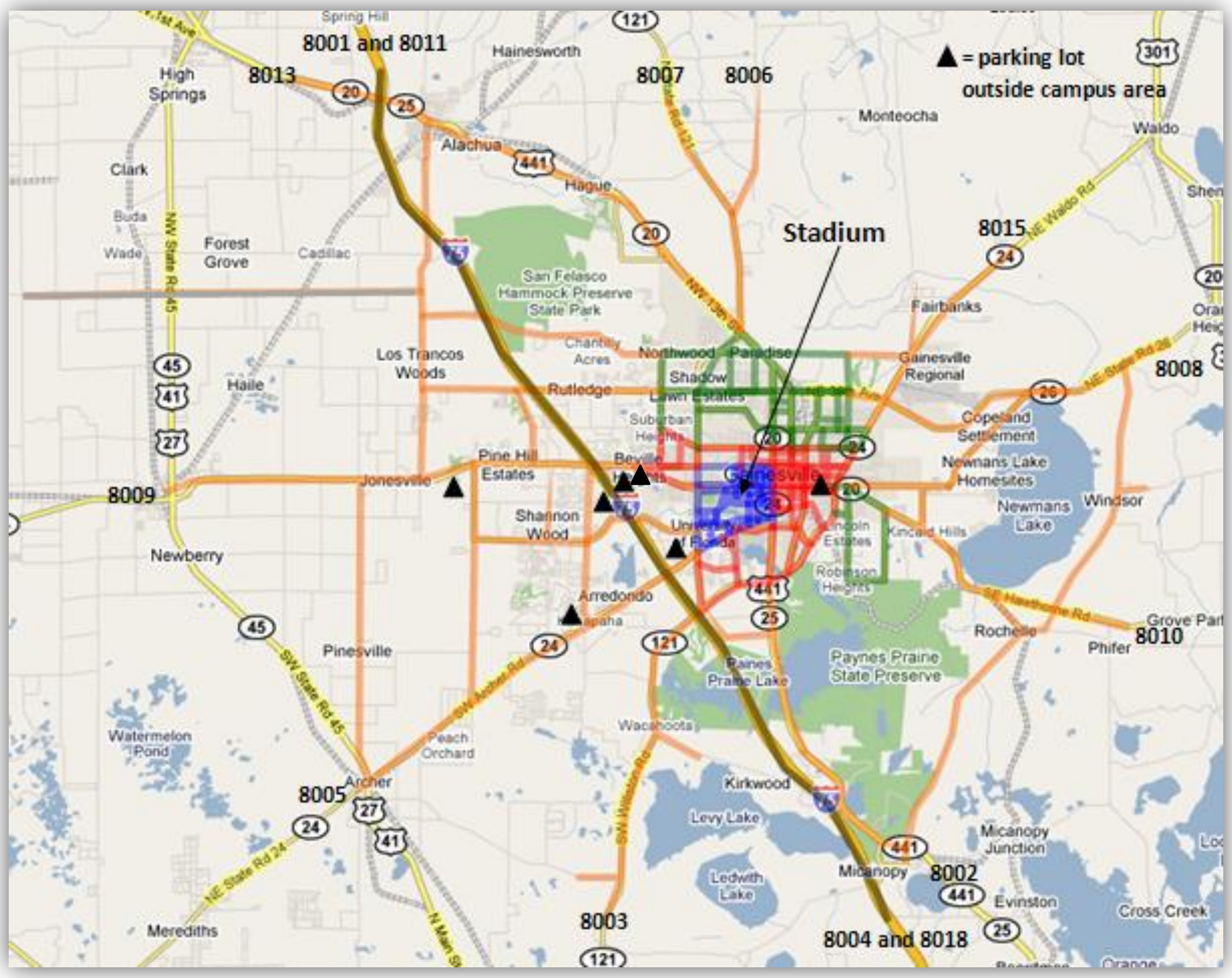


Figure 12: Roads that have been modeled in the network (colored)

The modeled network is build around the Benjamin Franklin Football Stadium at the campus of the University of Florida. Since the scenario is build around the evacuation of the football stadium, the campus has been modeled with more detail. All connecting lanes have been included in the modeled network. The campus area is represented by the blue lines in the figure above. The areas directly around the campus are modeled with less detail and the modeled roads are represented by the red lines. These areas include some main streets and the downtown area of Gainesville. The green areas represent roads in some main living areas. In these areas only main streets are modeled. The smaller interconnecting lanes that are present in these areas are left out of consideration. The orange lines represent main streets in the outsides of the city. Most of them lead towards the exit roads or are the modeled exit lanes. Almost all of the outgoing streets present in Gainesville have been modeled. Another important exit point is the Interstate that runs through the city. This interstate and its ramps have been modeled in the network. The interstate is represented by the black line that can be seen in figure 12. In appendix 18 can be seen how the network looks in Corsim.

An important part is how the intersections are modeled. For the modeled network, all intersections have been checked using street view images from Google maps. In this way it was possible to check how many lanes are present in each street and which intersections were controlled by traffic signals, stop or yield sign or did not have any form of control. The use of these images also made it possible to estimate the number of pocket lanes and their length at each intersection.
For the free flow speed, a standard Corsim value of 30 miles per hour has been used. This value has been adjusted when, using street images from Google maps, it was observed that 30 miles per hour was too high or too low. For the interstate, the value has been adjusted to the maximum free flow speed allowed in NETSIM, 65 miles per hour.
To model the signal control schemes, some basic rules provided by the Florida Department of Transportation have been used. The main congested directions had an increased green time opposed to other directions. To establish these main lanes, maps provided by Google have been used. An image of how the network looks in Corsim can be found in appendix 18.

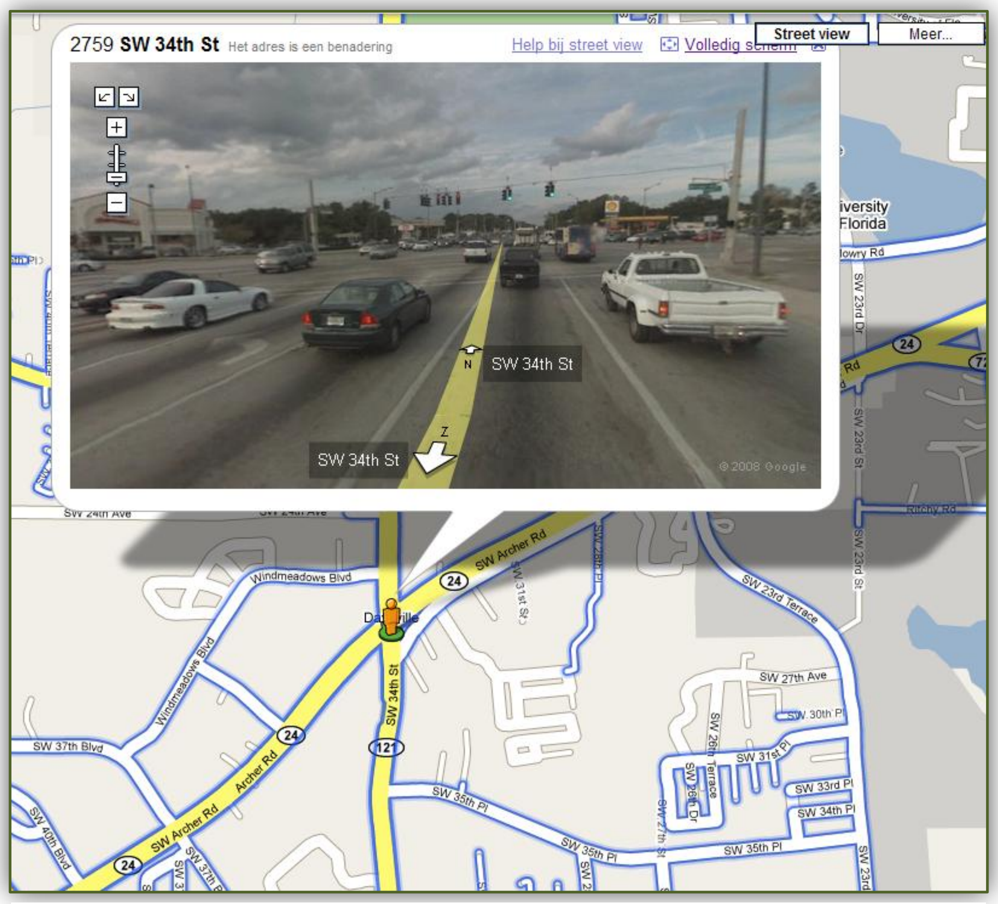


Figure 13: Capture of the Google street view

It is useful to give more information about the modeled traffic lights. It has been observed that in the modeled network, 106 intersections are controlled by traffic lights. It has been tried to obtain information about the actual signal schemes. However, it has not been possible to implement the real signal schemes into the network. Instead, a few basic guidelines that are provided by the Florida Department of Transportation are being used to design the signal schemes *(FDOT, 2007)*. In general, the images of Googleview have been used to find out which directions are expected to carry more traffic and have more green time in the real world. This will be sufficient enough to compare the different strategies and their effect on the base case.

4.5 Behavior parameters

Gwynne et al. pointed out that people behave different during evacuations than under normal conditions. Therefore, the standard behavior parameters used by Corsim, are adjusted. In this way, it is tried to model a more realistic driver behavior that will exist under emergency situations. It is expected that the cautious drivers will be influenced more in their behavior than the already more aggressive drivers. Since it is an evacuation before the disaster strikes, people will still behave in a relative rational way. This reduces the need for major adjustments. Still, people will be more stressed and accept to take more risks in order to get out the area as quick as possible. However, it is not expected that the modeled evacuation needs parameters that will cause a massive flight and uncontrollable behavior. The standard and adjusted values can be found in appendix 3.

Figure 14: Traffic starts forming a queue at the lane of an intersection which leads to one of the I-75 ramps

4.6 Trip generation

This is the so called first step in the conventional four-step transportation forecasting process. It predicts the number of trips originating in or destined for a particular traffic analysis zone. In other words, during the traffic generation trips generated and attracted by each zone are defined *(Maarseveen, 2007)*.

4.6.1 Trip production

Gainesville is known about the University of Florida and also accommodates the stadium for the University football team, the Florida Gators. The cases that are going to be used are built around the evacuation of this stadium. The stadium has a capacity of about 90.000 seats, and thus the cases will deal with an evacuation population of 90.000 people.

In both cases, the evacuation of the stadium is considered as the main source for the production of evacuation traffic flows. The parking lots that are being used during game days are considered as the origins of the traffic. In total, 27 parking lots are modeled in the network. Twenty parking lots are located at the campus area and seven are located around the city. The parking lots outside the campus area can be observed in figure 12. The locating of the modeled parking lots at the campus site can be found in the figure mentioned below.

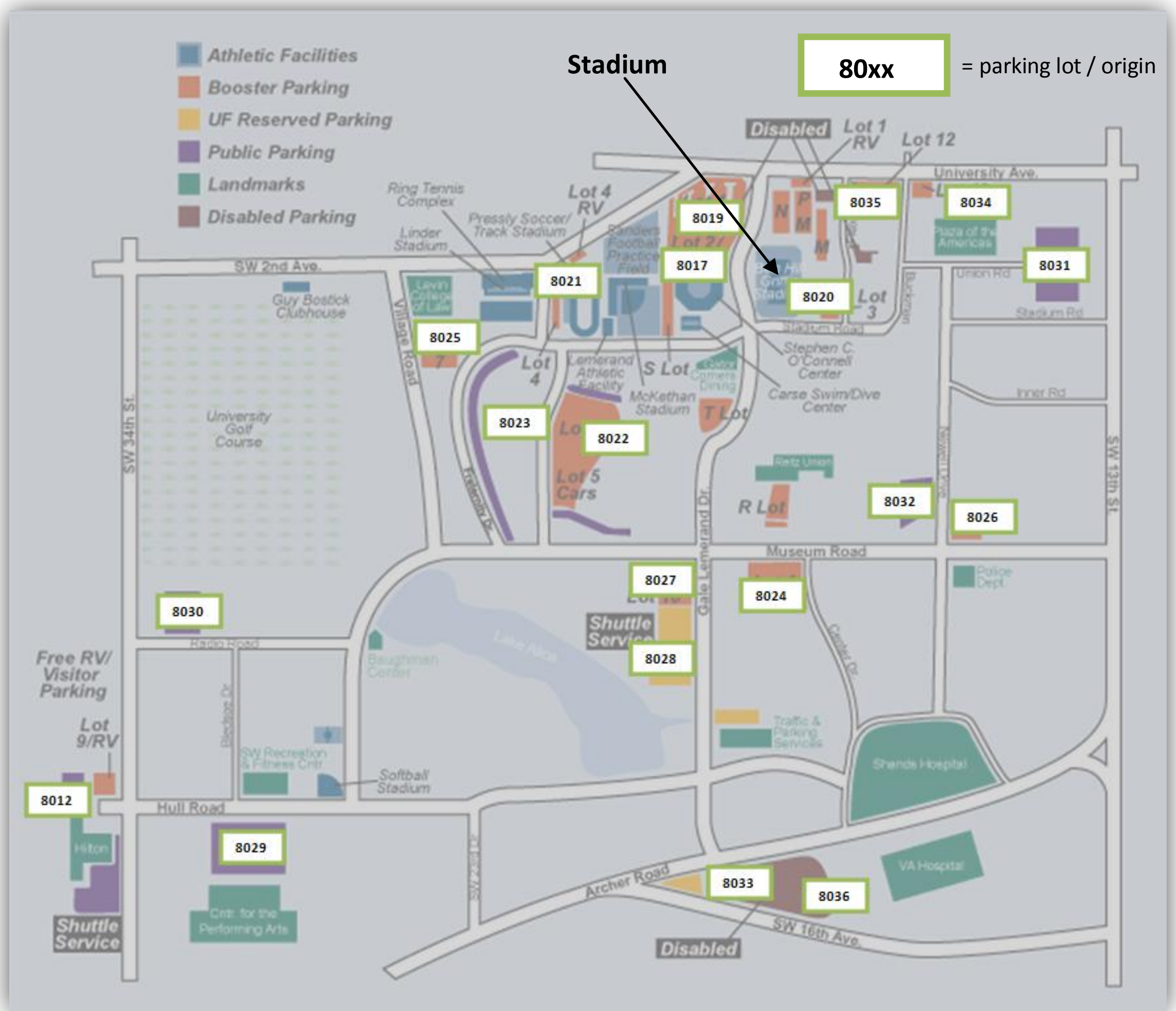


Figure 15: Location of modeled parking lots at the campus, including their origin number

To estimate the number of vehicles that spectators in Gainesville use during a game day, an estimation about the vehicle occupancy is needed. The literature has been reviewed to find vehicle occupancy of spectators during game days. The University of Washington found that the average vehicle occupancy for spectators during their game days lies at 2.3 persons per vehicle *(Husky Football Transportation Management Plan, 2000)*. Since these numbers are not available for the Florida games, this number will be used to estimate the number of evacuating cars.

The locations of the origins are known. Besides their location, there is information needed about the capacity of these parking lots and the number of cars they produce. There is information available for the capacity of several parking lots *(John Leffert, UFPD, 2006)*. However, most information is absent or non-valid for game days (*since these parking lots are adjusted*). To estimate the unknown number of parking spaces, the actual size of the lots are considered. This results for every origin in a percentage of the total production. This resulted in the following numbers. In total 17.395 parking spaces are modeled inside the campus area, and 16.778 outside the campus. The numbers per parking lot can be found in the OD-matrix which will be presented in appendix 1.

This research considers two modes of transportation. To estimate the number of cars, first an assumption has to be made about the bus usage. Section 4.6 will continue about the relation between car and bus usage and will provide the traffic production number.

Unlike the first case, background traffic is considered in the second case. This will produce more traffic on the network and will come closer to reality. To estimate the traffic production as a result of this traffic, information provided by the Florida Department of Transportation has been analyzed. The data made it possible to estimate the flows at exit and entry links located around the border of the research area. This indicates that the exit points as used in case 1, now also produce traffic and thus become also entry points. The information from the FDOT provided annual average traffic flows. The FDOT also provided parameters to adjust the annual values to average hourly flows. These flows have been used to estimate the number of cars that enter the Gainesville area *(Florida Department of Transportation, 2007)*. As stated in the description of the two cases, the background traffic will flow for two hours, at which the inbound lanes are blocked by the police. The flow of cars for each entry point can be found in the background traffic OD-matrix that will be presented in appendix 2.

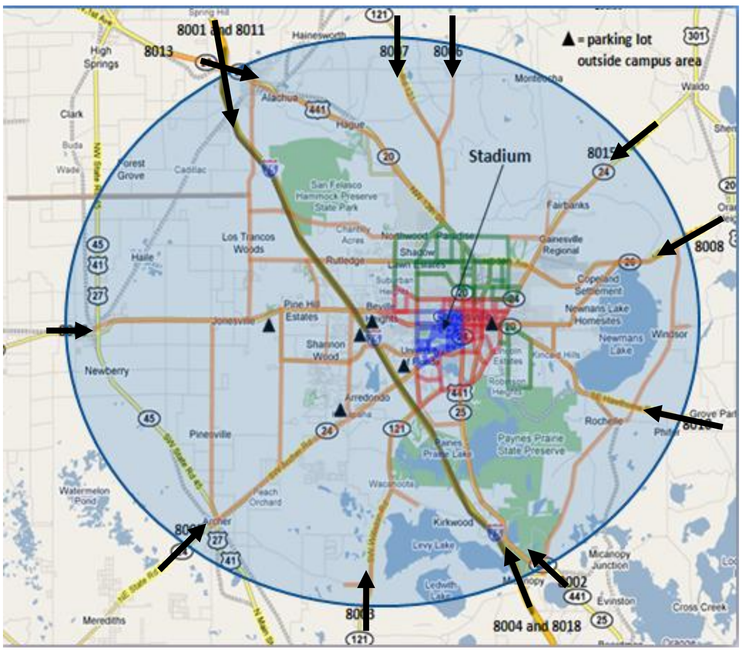


Figure 16: Entry points of background traffic

4.6.2 Trip attraction

In order to establish the attraction of trips by the different exit point, information about the destinations of the spectators is needed. To get an idea of the destinations from the visitors in the stadium, available zip codes are analyzed. The ticket information office of the Florida Gators Athletic Association provided information about the postal codes from 13.411 issued tickets. The information provided by the ticket office is the best available data and comes closest to the reality, therefore it is used to establish the destinations of the spectators and therewith the trip attraction from the used exit points.

To use the sample for conclusions about the destinations for every spectator, the sample needs to be representative. The reliability is determined by the size of the sample. The following thumb rule can be used to simply estimate the minimum sample size *(Groot, 2007)*:

$$N = \frac{p}{100} \cdot \frac{q}{100} \cdot \frac{z}{e/_{100}}^{2} \text{with;}$$

- N = Minimum Sample Size
- P = The percentage of people within the specified category
- Q = The percentage of data not belonging to the specified category
- Z = The value Z that belongs with the required level of confidence
- E = The required error margin

In the worst case scenario, P and Q have both values of 50 percent *(Groot, 2007)*. A level of confidence of 95 percent is considered, which makes the z-value 1,96. The margin of error is set to be 1 percent. This makes the minimum sample size $N = \frac{50}{100} \cdot \frac{50}{100} \cdot \frac{1{,}96}{1/_{100}}^{2} = 9604.$

So according to Groot (2007), with the availability of 13.411 postal codes, enough representative and reliable information is available to upgrade them towards 90.000 destinations within a 95 percent confidence level and a margin of error of 1 percent.

The data leads to places all over the United States. Considering the location of Florida, it is expected that all traffic towards destinations outside the state of Florida will use the northbound lane of the Interstate - 75. All of the destinations within Florida are manually located on a map, and their most logic route is estimated. By estimating the most logic route, the total numbers of cars heading towards each exit point are obtained. The number of cars per exit point can be found in appendix 1. The location of each exit point can be found in figures 12 and 16.

For the second case there is also information needed about the destinations of the background traffic. The Florida Department of Transportation provided traffic count numbers for the annual average traffic flows for each of the exit links. This information will be used to calculate the relation between each of the exit links. This results in an attraction factor which will be used to estimate the cars flowing from each origin to the destination. More information about this process can be found in chapter 4.8, about the traffic distribution.

4.7 Modal split

Information about zip codes is used to establish the number of evacuees. Since a multimodal simulation is considered, there is also the need to establish the relation between the number of bus passengers and the number of car users. The Gainesville Regional Transit System has been contacted to estimate the number of bus passengers during game days. The available data over three game days has been analyzed to estimate the average game day rider ship. The average number of total boarding's is about 10.000 for the available buses on each game day. This means that of the 90.000 spectators, 10.000 people will use the bus and 80.000 will be transported by car.

To simplify the trip generation, it is assumed that only people with their destination inside Gainesville will use the bus. Therefore, it is assumed that all people with destinations outside Gainesville will use the car as their transportation mode. To estimate the number of cars that are being used during a game, the found vehicle occupancy of 2.3 is used. This leads to a total of 34.782 cars that are used by spectators during game days.

The bus frequencies are obtained by the Gainesville Regional Transit System and represent actual bus frequencies as used during game days *(Harrison, 2008)*. Detailed information about the modeled bus routes can be found in appendix 19.

These are the results for the traffic generation per mode per case:

Case 1	
Cars	
Total Number of Spectators	90000
People using buses	10000
People using cars	80000
Estimated occupancy evacuation traffic	2.3
Evacuation traffic (*cars*)	34.783
Background traffic (*total after 2 hours*)	0
Total	**34.783**
Buses	**Frequency**
Line 1	6 per hour
Line 2	6 per hour
Line 3	12 per hour
Line 4	3 per hour
Line 5	3 per hour

Case 2	
Cars	
Total Number of Spectators	90000
People using buses	10000
People using cars	80000
Estimated occupancy evacuation traffic	2.3
Evacuation traffic (*cars*)	34.783
Background traffic (*total after 2 hours*)	28.360
Total	**63.143**
Buses	**Frequency**
Line 1	6 per hour
Line 2	6 per hour
Line 3	12 per hour
Line 4	3 per hour
Line 5	3 per hour

4.8 Trip distribution

Trip distribution implies the prediction of origin-destination flows, that is, the linking of the trip ends predicted by the trip generation model together to form trip interchanges or flows. From the trip generation models is known what the estimated numbers are of trips generated and attracted by each zone *(Ortúzar & Willumsen, 2006)*. For the assessment of the different strategies, two cases are being used. The first case only considers evacuation traffic generated by the stadium spectators, and the other case also includes background traffic. This implies the need for two different OD-matrices.

In the trip generation phase, the attraction of traffic by each destination or exit point is determined. It is now a matter of the distribution of the trips between each origin and destination. To simplify the filling of the OD-table, it is assumed that the cars heading for each destination are evenly distributed among the origins. This means that every origin accommodates cars heading towards each of the destinations. The capacities of the parking lots determine the distribution of cars over the lots.

Example 1:
Parking lot number X (origin X) has an estimated capacity of 5 percent of the total parking capacity. A total of 2.000 cars are heading towards destination Y. This leads to 5.00% x 2.000 = 100 cars that are traveling from origin 1 towards destination 1.

It was observed that the resulting production and attraction numbers for the origins and destinations did not correspond with the base data. To obtain the correct OD-table with corresponding values for each of the origins and destinations, a total of 4 iterations were needed. The resulting OD-table for the first case, with a fixed number of cars, can be found in appendix 1.

In the second case, evacuation and background traffic is considered. This emerges the need for an additional OD-table to cope with the background traffic flows. Traffic counts for the exit and entry points of the Gainesville area are available. This data has been used to establish the production and attraction of each entry and exit point *(Florida Department of Transportation, 2007)*. The OD-table has been designed in the same way as the OD-table for the evacuation traffic. It is also assumed that the traffic heading towards each destination is evenly distributed around each origin. Example 2 will show how the first OD-table for the distribution of background traffic has been filled. After 6 iterations, the origins and destination numbers matched with the base data. The resulting OD-table with flows per hour for the background traffic can be found in appendix 2.

Example 2:
The total production and attraction of background traffic is 20.000 vehicles per hour. Entry point X has a known production of 3.000 vehicles per hour. Entry and exit point Y attracts a total of 4000 cars and produces a flow of 5.000 cars. To estimate the number of cars heading from X towards Y, the production ratio for X is calculated. The ratio is obtained by dividing the production of entry X through the total production without production Y (no cars go from Y to Y):

Ratio X = 3.000 / (20.000 -5.000) = 0.20 = 20 percent.

Destination Y attracts 4.000 cars, when it is expected they are evenly distributed among the entry points, this leads to a flow of:

Flow from X to Y = 20 % x 4.000 = 800 vehicles per hour from X to Y

4.9 Traffic assignment

Corsim is capable of using origin - destination data to assign the traffic over the network. The assignment function will determine the volumes and turn percentages for the traffic at each node. During the assignment process, the service discharge rates for turns are held constant and are estimated initially for free-flow conditions. The assignment model serves two purposes. It converts the OD-trip table into actual network loadings for processing by the simulation model and second, it can be used to evaluate demand responses to operational changes. This will be helpful in analyzing the effects of the different strategies, since they will change the assignment over the network *(Corsim Help)*.

The traffic assignment model employs an impedance function that relates link travel time to link volume and link characteristics. The impedance function used in this research is the Federal Highway Administration impedance function. The FHWA impedance function is as follows *(Federal Highway Administration, 1996)*:

$$T = T_0 \cdot \left[1 + a \cdot \left(\frac{V}{C}\right)^b\right]$$

where
- T = Mean travel time on path-link
- T_0 = Free-flow (zero volume) travel time on the path-link
- V = Volume on the path-link
- C = Capacity of the path-link
- a = Default parameter = 0.60
- b = Default parameter = 4.00

The optimization technique used is the user equilibrium assignment. The criterion when the user equilibrium has been reached, is when no driver can reduce his journey time by choosing a new route. Corsim has a maximum of 20 iterations and is capable of performing a maximum of 5 capacity iterations per run. The algorithm that Corsim uses to assign the traffic is a Frank-Wolfe decomposition variation that generates all-or-nothing assignments at each iteration, using the link impedances produced by the previous iteration. Since an all-or-nothing assignment is used, at each iteration, all of the traffic is assigned to the shortest path and nothing is assigned to other paths. To get to the shortest path, a minimum path three is constructed for each specified origin node towards all other receiving network nodes. A label-correcting algorithm is used to build these threes at every iteration. At the end of every iteration, the network cost function is evaluated and a line search is conducted for the improved link flows that minimize the cost function. The iterative procedure ends when convergence is attained or when a specified number of upper bound iterations is reached *(US Federal Highway Administration, 2003)*.

The resulting traffic patterns are used to analyze the different strategies. Since every scenario with its strategy is different from other scenarios, similar routes will differ in their costs between the strategies. Therefore, the traffic assignment has been carried out for each different strategy. The results of the assignment procedure can be translated into a network with fixed intersection percentages, which are aggregated values for all traffic directions. For instance, intersection X aggregates the turning volumes for all traffic coming from direction Y and making a turn towards Z.

4.10 Output

Corsim can give results for selected measures of effectiveness. The selected data will be calculated per selected link. For this research, the flow on the exit links is the specifically selected output. The flow will indicate when the evacuation time is reached, since at that point the flow on all of the 27 exit links will equal and remain zero.

Corsim is able to write the simulation results into an excel file. This helps by analyzing the results. The first step involves the aggregation of the flow per interval per link for the multiple runs. Each interval consists of 60 seconds.

The second step involves the summation of the results per interval for all of the exit links. This will lead to the total number of exit trips per interval on the modeled network. With the results of this step, it can be analyzed when there are no more trips on the exit links.

The third step involves the summation of the resulting exit trips over the intervals. In this case the total number of evacuees after each interval can be obtained, and it is the base for the graph about the percentage of people evacuated at each interval.

Corsim also provides some common network wide statistics. These include the total travel time, total delay and moving time, average speed, total travel distance and the average network density. Other statistics include the delay time ratio per travel hour. These factors will be used in the analysis of the different strategies in the two cases. More information about the selected assessment criteria can be found in chapter 4.2.

```
                                          -------------------------------
                                          NETWORK-WIDE AVERAGE STATISTICS
                                          -------------------------------

 TOTAL VEHICLE- MILE = 1192033.38     VEHICLE-HOURS OF:  MOVE TIME = 31162.98 , DELAY TIME = 59560.87 , TOTAL TIME = 90723.85

 AVERAGE SPEED ( MPH)=      13.14     MOVE/TOTAL = 0.34       MINUTES/MILE OF:  DELAY TIME =     3.00 , TOTAL TIME =     4.57

 NETWORK-WIDE STATISTICS FOR SCRIPT PROCESSING
 1192033.38, 31162.98, 59560.87, 90723.85,      13.14, 0.34,     3.00,     4.57

 TOTAL CPU TIME FOR SIMULATION =     3158.09 SECONDS
 TOTAL CPU TIME FOR THIS RUN =     3158.09 SECONDS
0***** THERE WERE  24 WARNING MESSAGES.
0LAST CASE PROCESSED
```

Figure 17: Capture of the output file produced by Corsim

5. Description of analyzed strategies

During the literature review, a lot of promising strategies were found. For this research, just a limited number of these strategies could be selected to analyze. In this chapter it will be discussed which strategies are chosen and how they are implemented in the simulation model.

5.1 Base case

The first strategy is called the base case. This strategy can be referred to the normal traffic situation. No special traffic measures are deployed and it has been tried to model the reality as close as possible and needed. All parking lots start evacuating at the same time. This strategy is used to assess the effects of the other strategies.

5.2 No access campus

The first strategy that has been analyzed is the closure of inbound lanes towards the campus area. During the run of the base case, it has been observed that some campus traffic experienced a high delay time. One of the reasons why these queues could increase, is because of off-campus traffic that take the campus roads as shortcuts to their destination. This could be the source of congestion on the campus area. The congested lanes create queues in front of the parking lots. This blocks the traffic that wants to leave the parking lots could be the reason for an increase in the evacuation time. To assess the influence of the incoming cars on, this strategy will block all incoming lanes at the campus. It is however not possible to close all inbound lanes. The buses still need to be able to reach the stadium area to follow their prescribed route. Although these lanes are channelized as 'bus lanes', there is still a small number of cars disobeying this rule and use the bus lanes to travel on the campus site. It has not been possible to eliminate this behavior, but the reduction of traffic that wants to access the campus site is still significant. An image with the blocked lanes can be found in appendix 4. To analyze this strategy, the incoming campus lanes as modeled in the base case have been removed. The incoming lanes used by buses have been channelized as bus lanes causing a significant reduction in the use by private cars.

5.3 Contraflow campus

One of the current strategies deployed by the university police to flow the traffic of the campus area after a football game, is the deployment of contraflow on a few main streets *(John Leffert, UFPD, 2006)*. For this research it has been tried to add one extra lane to each of the outgoing directions. Further, some directions leading towards exits have been added an extra lane. The extra lanes have been created by removing one of the inbound lanes. For inbound links that consist only of one lane, this lane has been removed and redirected towards the exit point. Wolshon et al (2003) found that the capacity will increase by 70 percent. In order to model this assumption, the speed on the extra outgoing link has been reduced.

The termination of the contraflow always happened at intersections controlled by signal controls. Since the outgoing links have more than one lane, each lane became channelized towards a specific direction. If there were two lanes, the left lane has been channelized for traffic going left or through and the right lane has been channelized for traffic heading right or through. If there were more than two outgoing links, the most significant flow got an extra direction lane.

In appendix 5 a figure is presented, showing the directions of the contraflow lanes.

5.4 Contraflow campus and Gainesville

From the literature, it has been found that contraflow is a promising and frequently applied traffic measure to reduce the evacuation time. Therefore, contraflow all over the network is included in this research as one of the strategies.

From the base case, links have been identified that experienced a high traffic demand or even congestion. These links are analyzed to check if a contraflow policy would be possible. Most of these lanes lead towards an access point of the interstate. The directions where contraflow will be deployed can be found in appendix 6. The strategy includes the contraflow on the campus site. It is expected that the evacuation time will be lower than in the previous strategies. The termination of the contraflow always takes place at intersections controlled by signal controls. It has been done in the same way as in the third strategy.

5.5 Increasing green time ramps

In the literature review it has been pointed out that increasing the green time for the evacuation flows can greatly reduce the evacuation time. It has also been observed from the base case that a lot of traffic got stuck at the traffic lights that regulate the access to the ramps (*see figure 41 in appendix 18*) Therefore, this strategy will increase the green time for the directions that lead towards the Interstate 75. In appendix 7, the change in the signal schemes can be found.

5.6 Increasing green time ramps and main streets

Besides the increase in green time for the ramps, this strategy will also increase the green time at some of the main links in the modeled network. These links have been identified by observing the results of the base case. Traffic lights that had a significant impact on the queues, were adjusted towards more green time for the congested directions. In appendix 8 is shown which intersections and directions gained more green time.

5.7 Staged evacuation

Another strategy that is known within the literature and showed promising results in previous studies, is the so called staged evacuation. In the literature, staged evacuation is presented as an alternative strategy to reduce congestion and the evacuation time. Therefore, the effects of staged evacuation on the network are analyzed. The areas most close to the stadium will be evacuated first, since these parking lots are most vulnerable towards the threat. The evacuation of the parking lots will be executed in order of their distance towards the stadium. More detail about the used sequence can be found in appendix 9.

5.8 No control

When testing the model, it was observed that without any form of control the traffic acts in a more natural way. To see what the results of just this ‘natural’ behavior will be, a scenario is analyzed without any control measures in the network.

6. Results
6.1 Case 1
6.1.1 Evacuation Time
Introduction
These results indicate the time that is needed for each strategy to clear the traffic from the modeled network. The lower the evacuation time, the better the strategy. It is the main assessment criteria.

Results

Strategy	Description	Evacuation time (hours)	Rank
1	Base case	8.75	8
2	No access campus	8.62	7
3	Contraflow campus	8.17	5
4	Contraflow all	7.82	4
5	Green time ramps	5.58	3
6	Green time all	5.53	2
7	Staged Evacuation	8.58	6
8	No control	5.18	1

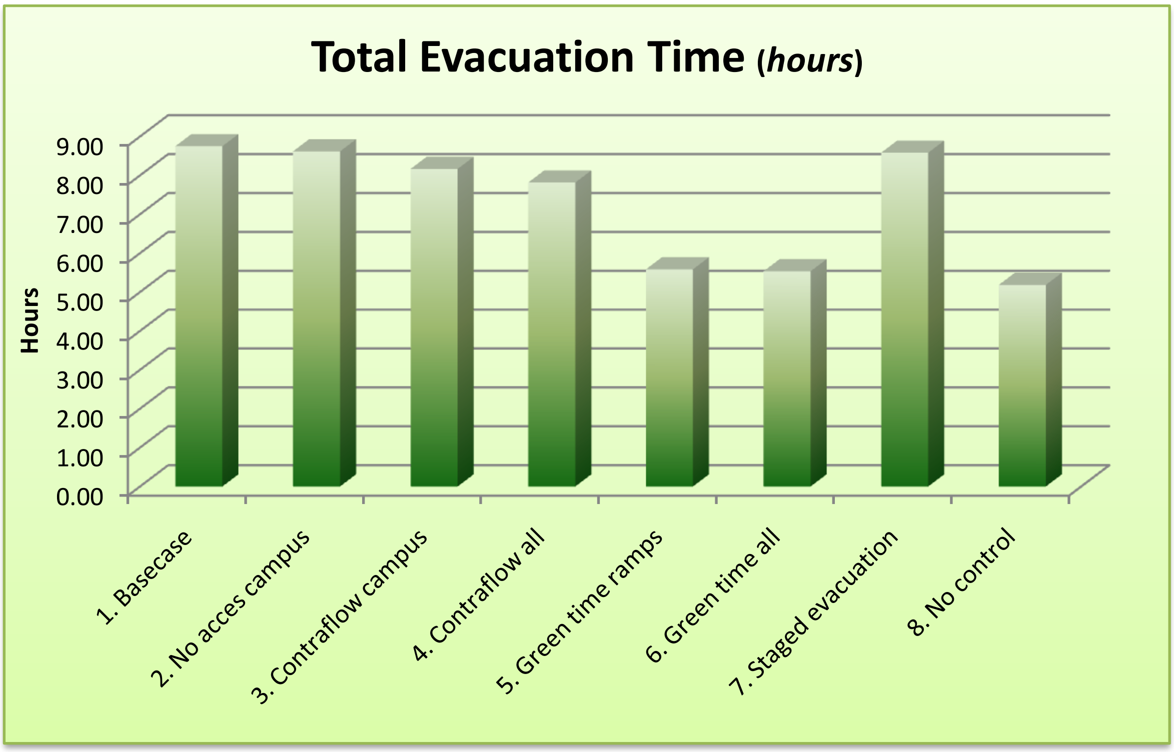


Figure18: Total evacuation time for the strategies in case 1. The lower the bar, the better the results

Conclusion
It has been observed that the strategy without any control results in the shortest evacuation time. Within the control strategies, increasing the green time in whole Gainesville results in the shortest evacuation time. Immediately behind this strategy is the increase in green time for only the directions that lead to the ramps for the interstate. Contraflow all over Gainesville positively influences the evacuation time. No access to and contraflow on the campus have a small impact. The base case is the worst case, with a resulting evacuation time of 8 hours and 45 minutes.

6.1.2 Percentage evacuated

Introduction

These are the results for the percentage of people evacuated after each time interval. The results indicate the speed of the evacuation for each strategy. It is another way to present the results of the total evacuation time. Each interval consists of one minute and the number of vehicles that had to be evacuated to reach the hundred percent lays at 34.783 vehicles.

Results

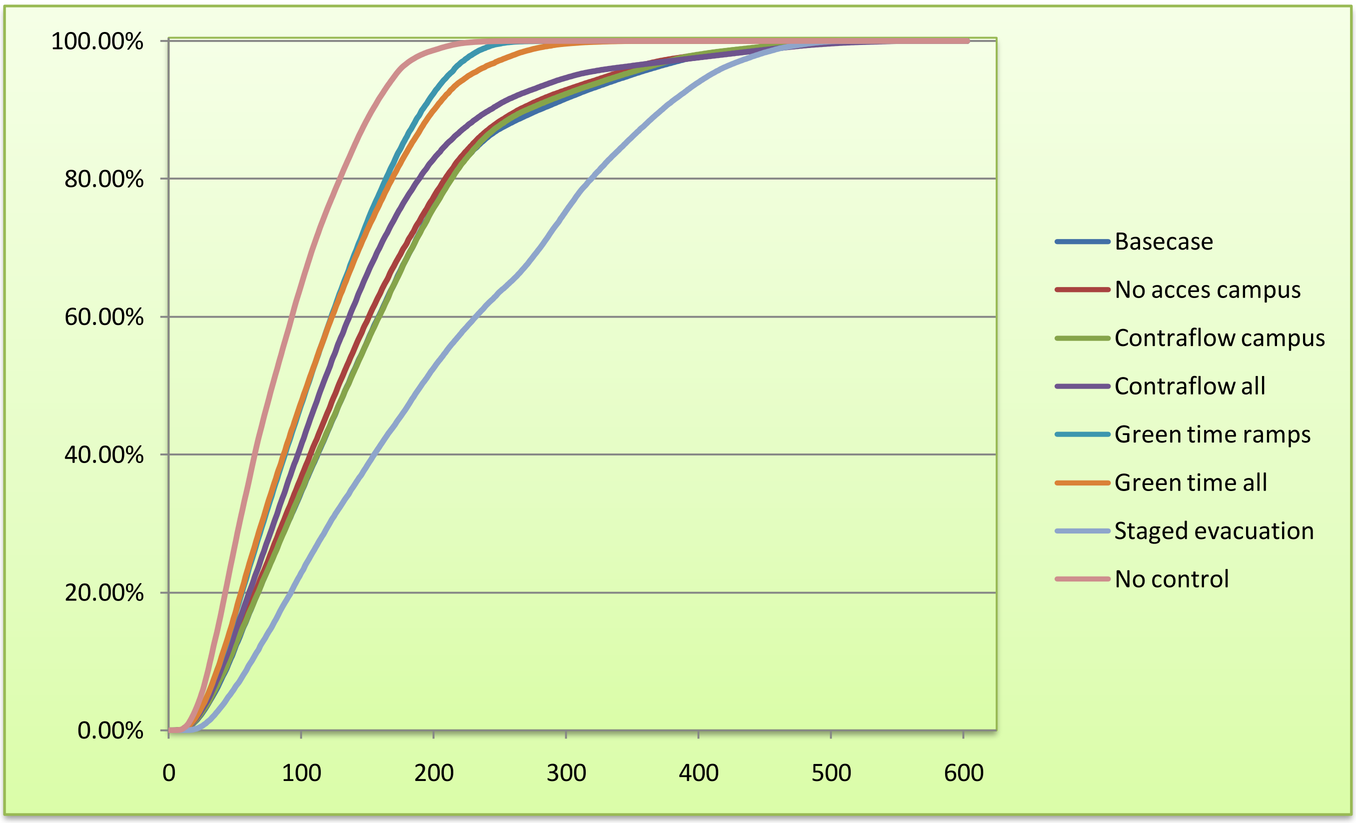


Figure 19: Percentage of cars that have left the network in case 1 after the start of the evacuation

Conclusion

This is a compilation of the results of the eight strategies. It is observed that the 'no control' strategy has the steepest graph and also reaches the hundred percent as first. It is followed by the strategies 'green time ramps' and 'green time all'. The base case, no access toward the campus and staged evacuation are relatively similar in the time they reach the 100 percent. It can be seen that the staged evacuation shows the most steady, almost linear line.

6.1.3 Total Travel Time

Introduction

The total travel time is an important assessment criteria that will be used in this research. If people need to travel for a longer time in the evacuation area, it will indicate that they are longer exposed to the threat. Since the total travel time can differ from the evacuation time, it is used to assess the effectiveness from the different strategies.

Results

Strategy	Description	Total Travel Time (hours)	Rank
1	Base case	58916	7
2	No access campus	57395	6
3	Contraflow campus	63459	8
4	Contraflow all	53778	5
5	Green time ramps	36734	3
6	Green time all	38204	4
7	Staged Evacuation	34291	2
8	No control	25187	1

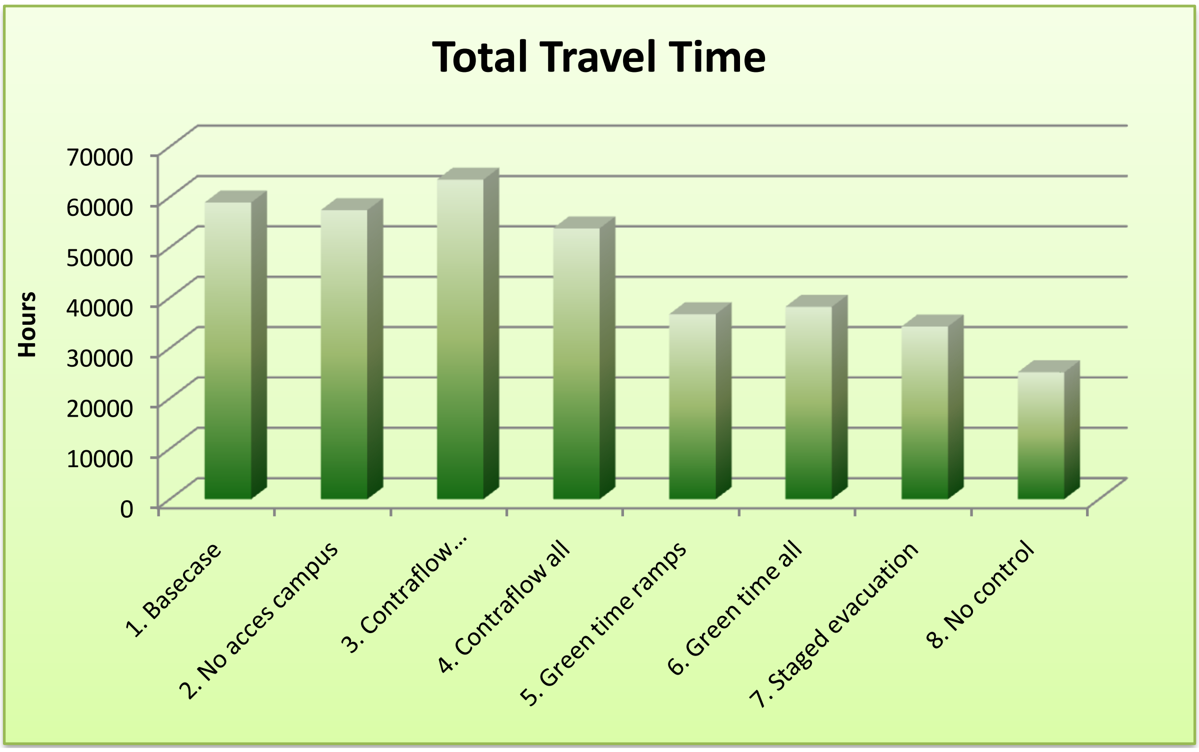


Figure 20: Total Travel Time for all vehicles in the network per strategy. The lower the bar, the better the strategy

Conclusion

When the total travel time per vehicle is analyzed, it is observed that the no control strategy results in the shortest average travel time for the vehicles. The staged evacuation results in the shortest travel time within the control strategies followed by the two strategies which increase the green time. Contraflow in Gainesville and on the campus will reduce the travel time. When the incoming campus lanes are closed, the total travel time will be slightly decreased. The deployment of contraflow on campus only results in an increase of the total travel time.

6.1.4 Average Delay Ratio

Introduction

The delay time ratio is a factor that partly determines the quality of the traffic handling within the network. In order to draw conclusions about the effectiveness of the different strategies, the delay time needs to be considered. The results indicate the percentage of delay time within one travel hour.

Results

Strategy	Description	Delay Time Ratio(delay time per travel hour)	Rank
1	Base case	0.726	7
2	No access campus	0.724	6
3	Contraflow campus	0.744	8
4	Contraflow all	0.702	5
5	Green time ramps	0.574	3
6	Green time all	0.597	4
7	Staged Evacuation	0.552	2
8	No control	0.444	1

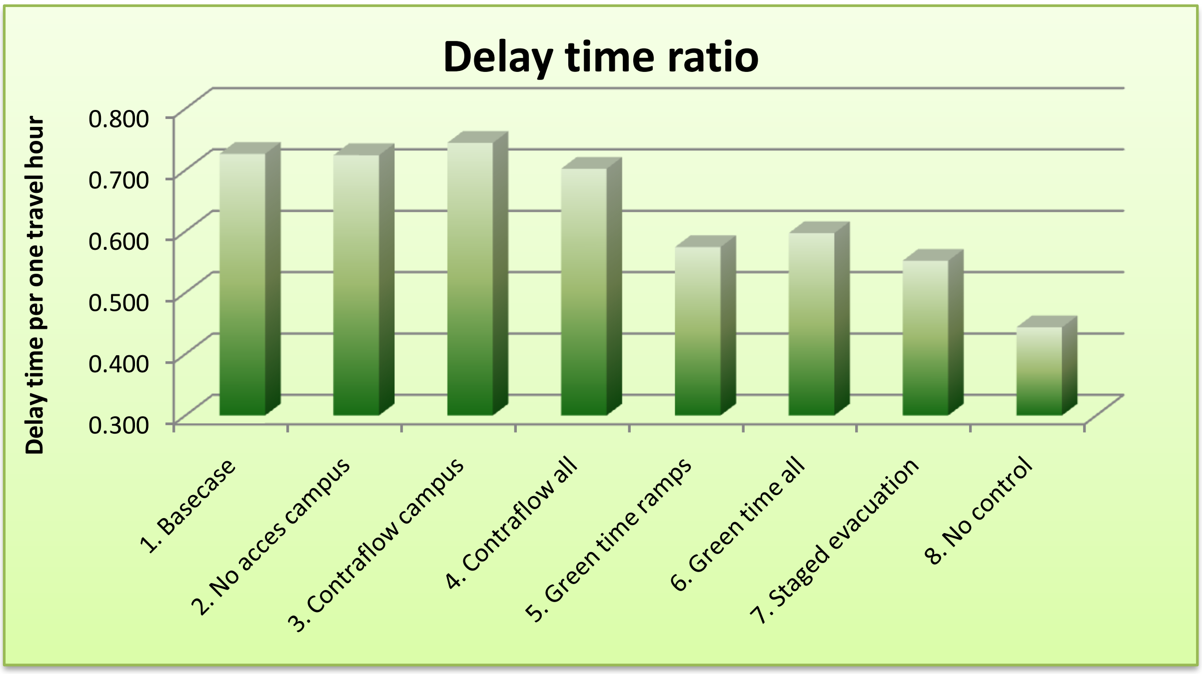


Figure 21: Delay time per travel hour for the strategies in the first case. The lower the bar, the better the strategy

Conclusion

Again, the 'no control' strategy gives the best results. This is the only strategy where the move time in one travel hour is larger than the delay time. The second best strategy is the staged evacuation. It is followed by the increase in green time for the ramps. If green time is increased all over Gainesville, the delay time ratio is higher than in strategy 5. Contraflow in whole Gainesville and blocking traffic from entering the campus cut back the delay by a small amount. Deploying contraflow on just the campus will even increase the delay time.

6.1.5 Total Travel Distance

Introduction

The Total Travel Distance is another factor that determines the quality of the traffic handling within the network. In order to draw conclusions about the effectiveness of the different strategies, the total travel time is considered. To compare the different strategies, the results are divided by the number of cars that have been discharged from the network.

Results

Strategy	Description	Total Travel Distance (miles per vehicle)	Rank
1	Base case	15.21	1
2	No access campus	15.22	2
3	Contraflow campus	19.01	8
4	Contraflow all	16.67	5
5	Green time ramps	16.52	3
6	Green time all	16.79	6
7	Staged Evacuation	16.6	4
8	No control	16.92	7

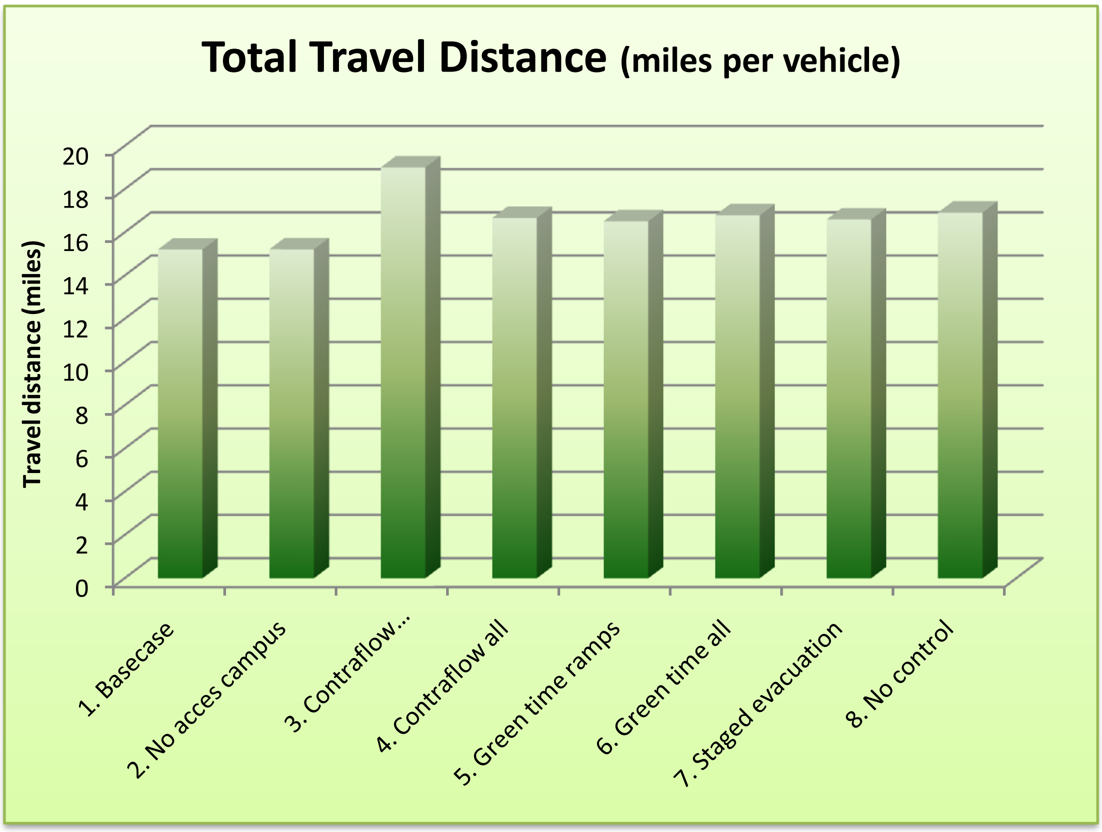


Figure 22: The average total travel distance for each strategy in case 1. The lower the bar, the better the strategy

Conclusion

The base case results in the shortest average travel distance for the evacuees. All of the other strategies lead to higher travel distances for the evacuees. The second best strategy is with minimal control, the closure of the campus inbound lanes. The worst strategy is the deployment of contraflow on the campus area, which results in an average travel distance over 19 miles.

6.1.6 Average Travel Speed

Introduction

The average travel speed is also a factor in the quality of the traffic handling within the network. The higher the average speed is, the better is the flow on the network. In order to draw conclusions about the effectiveness of the different strategies, the average travel speed needs to be considered.

Results

Strategy	Description	Average Travel Speed (miles per hour)	Rank
1	Base case	9.56	7
2	No access campus	9.64	6
3	Contraflow campus	8.79	8
4	Contraflow all	10.58	5
5	Green time ramps	15.74	3
6	Green time all	14.53	4
7	Staged Evacuation	16.04	2
8	No control	20.13	1

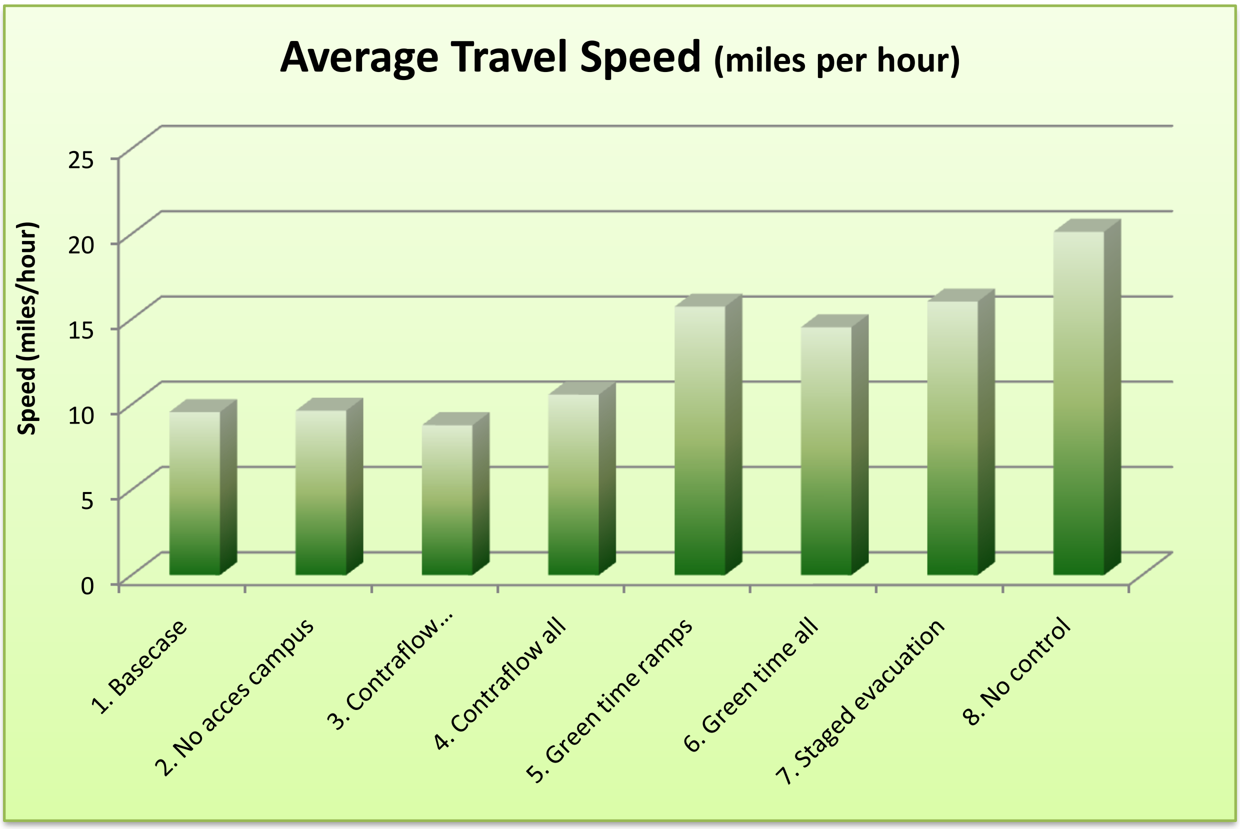


Figure 23: Average travel speed per vehicle per strategy in case 1. The higher the bar, the better the strategy

Conclusion

The drivers obtain the highest average travel speed in the no control strategy. The second best strategy is the staged evacuation, followed by the increase in green time for the ramp directions. The contraflow deployment on the campus results in the lowest average travel speed.

6.2 Case 2

6.2.1 Evacuated vehicles

Introduction

Due to time restrictions, it has not been possible to establish the evacuation time in the second case. It still is possible to say something about the evacuation speed of the strategies when background traffic is considered. All of the strategies have been analyzed for twelve hours. After these twelve hours, the simulation stopped and produced a number of vehicles that have exited the network. Therefore, the strategy which discharged the most vehicles after twelve hours is expected to be better than the others.

Results

Strategy	Description	Evacuated vehicles (number)	Rank
1	Base case	52800	6
2	No access campus	51857	7
3	Contraflow campus	51806	8
4	Contraflow all	62679	1
5	Green time ramps	59927	4
6	Green time all	59943	3
7	Staged Evacuation	59965	2
8	No control	52865	5

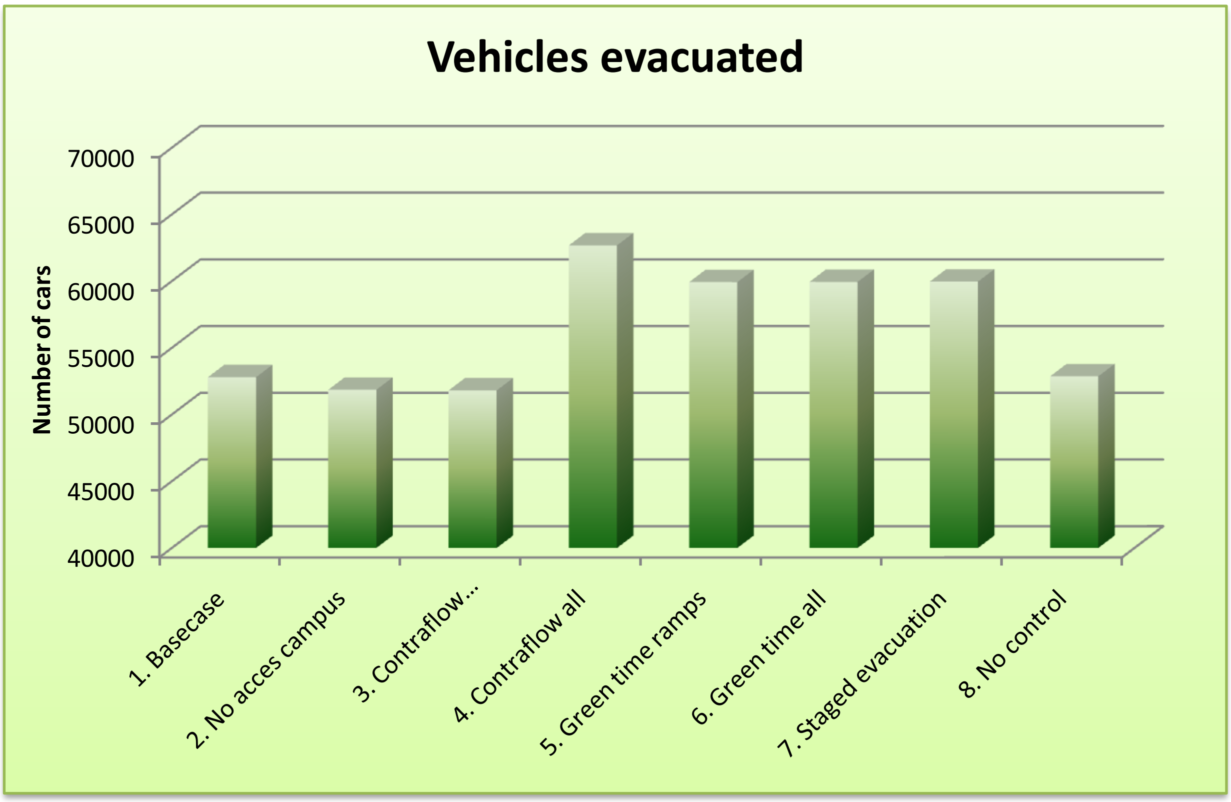


Figure 24: Evacuated vehicles per strategy after twelve hours, in case 2. The higher the bar, the better the strategy

Conclusion

The simulation with contraflow on the campus and in Gainesville evacuated the most cars. The second best strategy is the staged evacuation, shortly followed by the increase in green time. The deployment of contraflow on only the campus site resulted in lowest number of evacuated cars.

6.2.2 Percentage evacuated

Introduction

These are the results for the percentage of people evacuated after each time interval. The results indicate the speed of the evacuation over the intervals for each strategy. It is another way to present the results of the total evacuation time. Each interval consists of one minute and the number of vehicles that had to be evacuated to reach the hundred percent lays at 63.143 vehicles.

Results

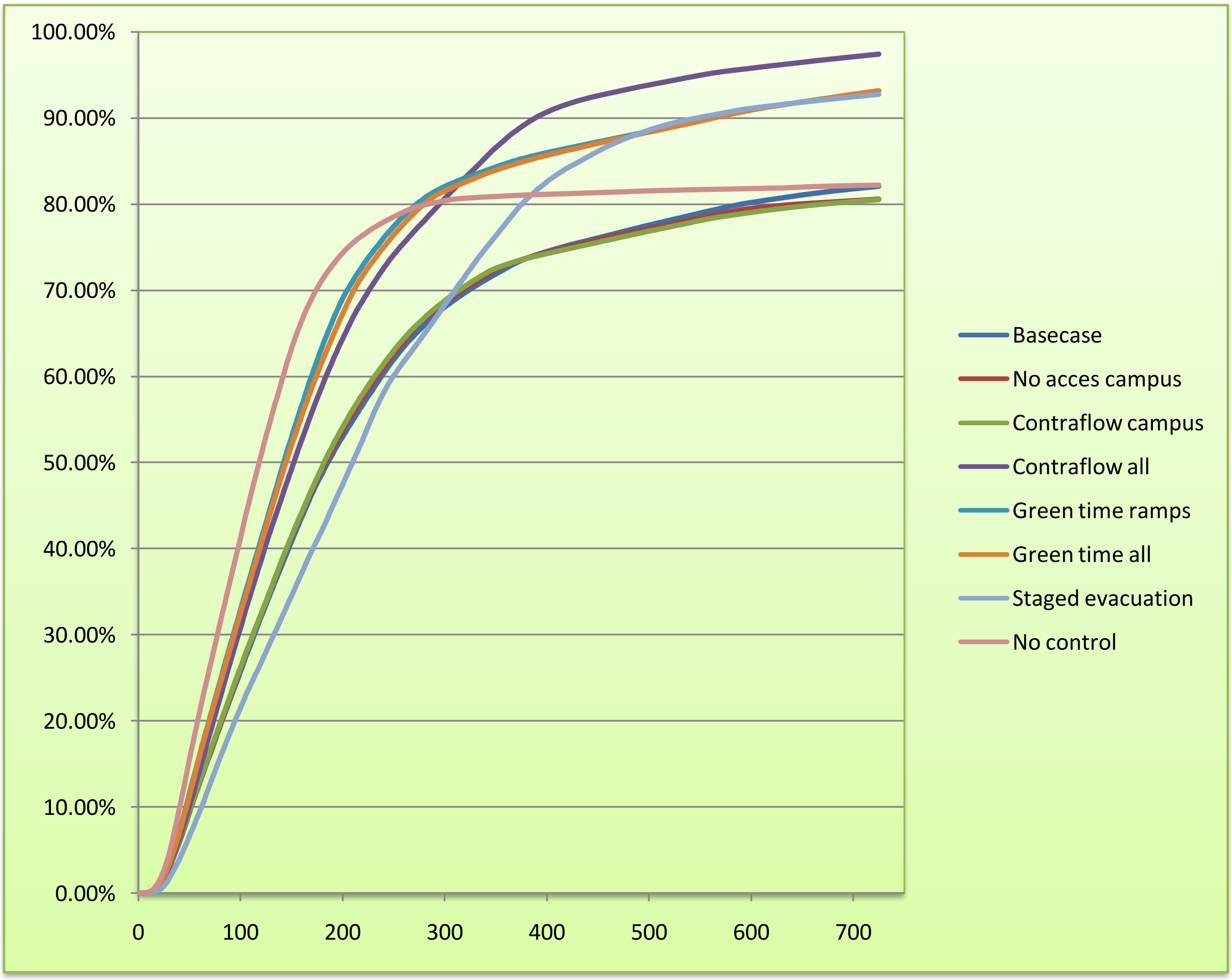


Figure 25: Percentage of cars that have left the network in case 2 after the start of the evacuation

Conclusion

The most cars are evacuated in the contraflow case. The 'No control' strategy produces the greatest slope in the first 150 minutes, but then radically turns horizontal. The staged evacuation shows a more linear line than any of the other strategies. Contraflow on the campus, no access to the campus and the base case result in an almost identical graph. The same goes for both of the green time strategies, they almost follow an identical path.

6.2.3 Total Travel Time

Introduction

The total travel time is an important assessment criteria that will be used in this research. If people need to travel for a longer time in the evacuation area, it will indicate that they are longer exposed to the threat. The values represent the total travel time in the network after twelve hours. If the travel time is lower within the network after twelve hours, this indicates a better performance for the traffic on the network.

Results

Strategy	Description	Total Travel Time (hours)	Rank
1	Base case	136944	7
2	No access campus	132708	6
3	Contraflow campus	138733	8
4	Contraflow all	131550	5
5	Green time ramps	130342	4
6	Green time all	128764	3
7	Staged Evacuation	127592	2
8	No control	96462	1

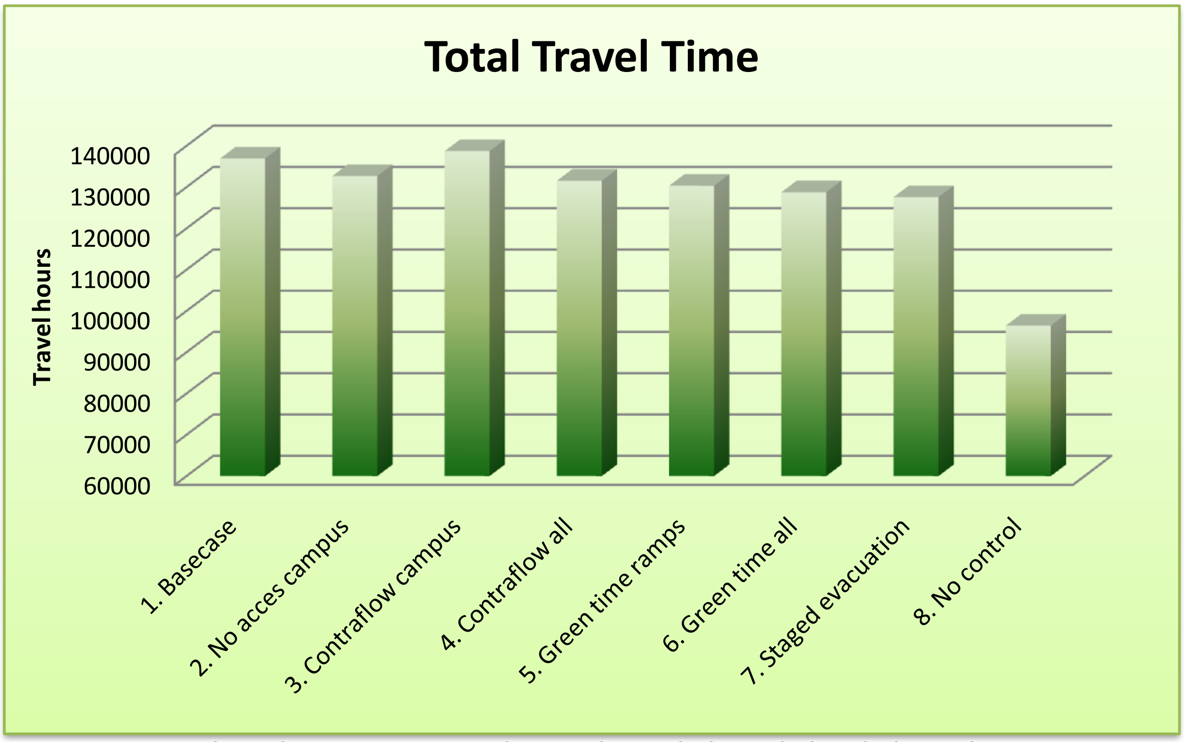


Figure 26: Total Travel Time per strategy in the second case. The lower the bar, the better the strategy

Conclusion

The results indicate that the 'No Control' strategy has the lowest total travel time. It can be seen that the staged evacuation and the green time strategies also result in a reduction in the total travel time. The contraflow in Gainesville and on the campus also positively influence the travel time. The "No access" strategy does also result in a small reduction of the total travel time. If contraflow is deployed just on the campus, the total travel time is increased.

6.2.3 Delay time ratio

Introduction

The delay time ratio gives information about the delay time as a percentage of the total travel time. The higher this number, the more delay time people experience on the network.

Results

Strategy	Description	Delay time (ratio per travel hour)	Rank
1	Base case	0.786	8
2	No access campus	0.774	5
3	Contraflow campus	0.785	7
4	Contraflow all	0.779	6
5	Green time ramps	0.760	3
6	Green time all	0.770	4
7	Staged Evacuation	0.747	2
8	No control	0.550	1

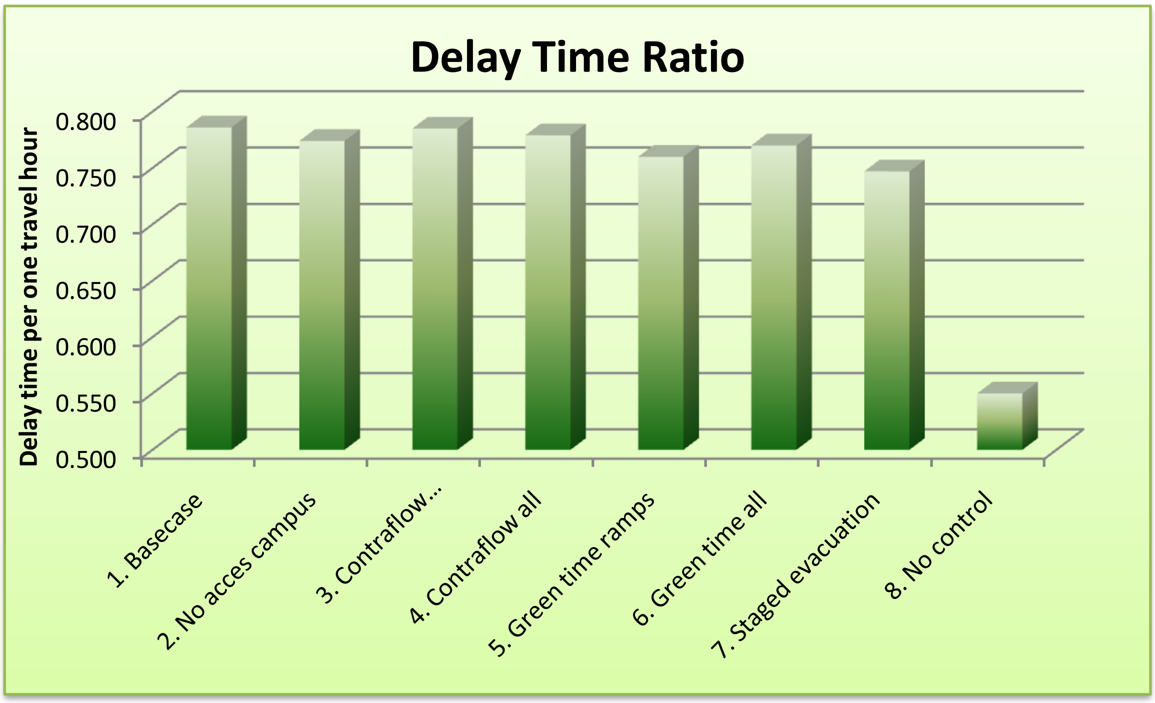


Figure 27: Delay time per travel hour for the strategies in case 2 . The lower the bar, the better the strategy

Conclusion

None of the strategies is able to get more move than delay time in one travel hour. The ‘No control’ strategy shows spectacular results when it is compared to the other strategies. Between the control strategies, the results do not differ very much. The staged evacuation results in the lowest ratio within the control strategies, followed by the green time strategies. The base case shows the most delay time per total travel time.

6.2.4 Average Travel Speed

Introduction

The average travel speed is also a factor in the quality of the traffic handling within the network. The higher the average speed is, the better is the flow on the network. In order to draw conclusions about the effectiveness of the different strategies, the average travel speed needs to be considered.

Results

Strategy	Description	Average Travel Speed (miles per hour)	Rank
1	Base case	7.92	8
2	No access campus	8.50	5
3	Contraflow campus	8.08	7
4	Contraflow all	8.41	6
5	Green time ramps	9.40	3
6	Green time all	8.97	4
7	Staged Evacuation	9.81	2
8	No control	17.08	1

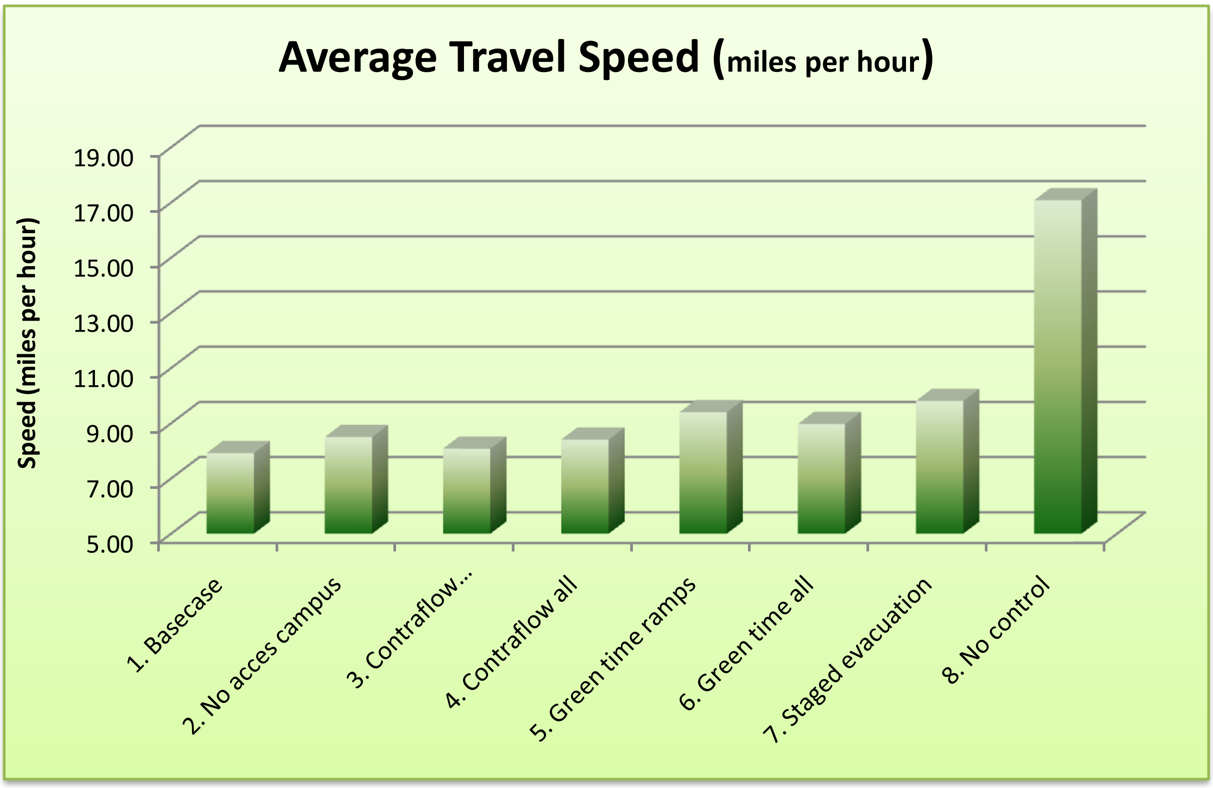


Figure 28: Average travel speed per vehicle per strategy in case 2. The higher the bar, the better the strategy

Conclusion

The 'No control' strategy produces the highest average travel speed. It is almost ten miles per hour higher than the average speed in the base case. Within the control strategies, the staged evacuation produces the highest average speed followed by the increased green time for the ramp directions. The other strategies have a minor impact on the average travel speed.

7. Discussion of results

This chapter will discuss of the results as shown in chapter six can be explained. It will present possible explanations for the large differences and tries to point out why some strategies have more effect than others. Conclusions about which strategy is more preferred over the others can be found in the next chapter.

7.1 Case 1

7.1.1 Total Evacuation Time

An important criteria is the time it takes to evacuate people out of Gainesville. The 'No control' strategy resulted in the lowest evacuation time for all strategies. Although this seems unlikely, there are some reasons that support this observation. One of the reasons why it is possible is because the traffic in this strategy does not experience any delay time due to signal controls or stop signs. In normal conditions, signal controls cause for a capacity reduction and thus delay time at intersections. They are designed to slow traffic down and regulate crossing flows. When these signal controls are not present, drivers do not experience this delay. In the first case it is also assumed that there is no background traffic on the network. This eliminates a lot of natural conflicts with crossing directions that would exist in normal conditions. The present flows are mainly headed towards the same directions causing a lower number of conflicting flows. In combination with the absence of signal controls, this leads to less interruptions and a more faster possible flow. This also explains why the vehicles that are evacuated per minute reaches such a high maximum (*see appendix 17*) The fact that there are almost now conflicts between traffic directions due to an empty network, people can drive in the beginning of the simulation almost at free flow speed towards their destination.

Within the control strategies, the strategy that increases green time for the ramp access gave spectacular results. By just giving the flows that want to access the I-75 more green time, cut the evacuation time back by more than three hours. An explanation can be found in the fact that a lot of traffic heads towards south Florida. This results in a great flow towards the interstate, resulting in a high demand for the ramps. Since most of the traffic will go south, it has to make a left turn to access these ramps (*see figure 29 and appendix 18*). The left turns are before all ramps regulated by signal controls. If the demand exceeds the capacity of this turning direction, it leads to queues. The demand largely exceeds the capacity as modeled in the base case, resulting in a large delay. The increase of green time for this turning direction leads to an increase in the capacity, resulting in a lower queue and less delay time.

The results also indicate that increasing green time all over Gainesville will result in the lowest evacuation time within the control strategies. However, there is not a major difference between the two strategies that deploy more green time for congested flows. Expending the increase in green time for all directions decreased the evacuation time by three more minutes. The difference between the two strategies can be explained when the flow on the exit links is considered. With more green time all over Gainesville, the flow of exiting traffic is higher in the first few hours (*see appendix 15*). But after a while, the results indicate a similar flow as in the previous strategy. This indicates that the traffic will reach some of the bottlenecks faster, but still gets stuck at these bottlenecks. In this case the bottlenecks are formed by the ramps. Although their green time is increased, it is observed that they still lead to congestion and still have a large influence on the evacuation time.

The contraflow strategies also result in lower evacuation times compared to the base case. When contraflow is deployed on only the campus site, the evacuation time is cut back by almost 35 minutes. Contraflow all over the city results in an evacuation time that lies about 55 minutes below the base case. So it is observed that the contraflow strategies have a positive impact on the evacuation time but do not give spectacular results. A reason can be found in the fact that traffic still gets stuck at the ramp access points. Contraflow results in an increase of capacity of the links, but will not result in a large increase of intersection capacity. This is also determined by the length of the green time the flows will experience.

So an explanation for the relatively small reduction is that the contraflow brings more evacuees faster to the bottlenecks, but is not able to solve the whole capacity reduction at the intersections. Although not included in this research, it has been observed that the campus network is cleared faster than in the other cases. This is the result of the capacity increase of the lanes exiting the campus area.
To a certain extend this is also the result when the campus inbound lanes are closed. However, the closure of the access lanes does not result in a significant reduction in the needed evacuation time.
The staged evacuation has not resulted in a large decrease of the evacuation time. There is a suitable explanation for this result. Since there is a time sequence when cars are allowed to leave, the flow gets more spread over time(*see figure 19 and appendix 16*) The chosen sequence can have a positive influence on other performance measures, but will not result in a large reduction of the evacuation time. What has been observed is that the campus area is cleared faster than in any other strategy.

7.1.2 Total Travel Time

The second assessment criteria treats the total travel time on the network. Within this criterion, the results differ from the total evacuation time. Still, the best strategy is the 'No control' strategy. But is has already been explained why this strategy is somewhat biased in its results.
If the control strategies are considered, the staged evacuation shows spectacular results when compared to the base case. It reduces the average travel time by more than one hour. This indicates a better flow of traffic in this strategy than in any of the others. People can travel faster to their destination and experience less travel delay time. An explanation can be the more spread flow of traffic originated by the staged evacuation. Figure 19 at page 46 and appendix 16 show graphs that are more linear than any other strategy, which supports the given explanation.
The strategy that increases the green time at the ramp intersections comes close to the results of the staged evacuation. People experience less delay time, which indicates an improvement in the traffic flows on the network. This is the result of the reduction in the delay time at the ramp intersections.
This travel time is less than in the strategy where more green time is deployed over whole Gainesville. This is somewhat remarkable since it was expected that this strategy should lead to more flows that experience less delay time than in the ramp strategy. An explanation can be that some directions experience a large increase in the cycle length of the signal scheme, without an increase in their green time. This will result in more delay time for these vehicles. Another explanation is that this strategy leads traffic faster to the bottlenecks at the interstate, the ramp intersections. This results in a larger demand of capacity. Since the capacity is the same as in the previous strategy, the ramp intersections get more congested. This can result in an increasing delay experience, which than results in a higher average travel time.
The 'Contraflow all' strategy also shows a reduction for the average total travel time. In this strategy people can travel faster to their destination than in the base case. This is the result of an increase in capacity for the outgoing flows. The extra lane makes it possible for more people to travel with less congestion to their destination.
When contraflow is deployed at the campus, there is an increase in the total travel time. This can result from the fact that drivers are faster evacuated from the campus network. However, the links outside the campus area are not suited for this increase, resulting in more congestion and thus more delay time.
There is not much difference between the total travel time in the base case and the case when campus access lanes are closed. The reduction in total travel time is very small, probably since the traffic gets less stuck on the campus site but still experience a lot of delay outside the campus area.

7.1.3 Performance of traffic handling

Besides the evacuation and travel time, the strategies differ in the quality of the traffic handling within the network. The delay time ratio is related to the traffic handling in the network. The more delay vehicles experience, the less the quality of the strategy. Again, the “no control” strategy shows the best results. This strategy is the only strategy in which the evacuees experience less delay than move time per one travel hour. This indicates a better flow of traffic in the network. Within the control strategies the staged evacuation results in the best quality of traffic handling. This can be explained by the more spread out flow of traffic over the evacuation time. There is less traffic on the network at certain intervals, resulting in a lower demand and thus less congestion. The green time strategies result also in lower ratios. Here goes the same explanation as is presented for the total travel time in chapter 7.1.2, since in these strategies one travel hour consists of more delay than move time. The contraflow on the campus results in the highest ratio, caused by a high demand and relatively low capacity of the network directly around the campus.
Another criteria that determines this quality, is the average travel distance for each vehicle. The quality will be better if people need to travel less miles to get to their destination. What has been observed is that none of the strategies will result in an average travel distance lower than the base case. People need to travel in all of the strategies further to follow the route which will result in their minimal costs. The ‘contraflow on campus’ strategy results in the largest travel distance. All of the other strategies result in almost the same distances. It is unclear why the travel distance with the campus contraflow is significant higher than in the other strategies. It can be that due to more congestion on the major roads directly around the campus, more people will reroute their route and take other routes that are less congested but result in larger travel distances. And since more routes are modeled directly around the campus, people have more alternatives which will result in an average larger travel distance.
Another factor that influences the quality is the average travel speed. Within this standard, the ‘No control’ strategy shows the best results. An explanation has been given in paragraph 7.1.1. When the control strategies are considered, the staged evacuation leads to the highest average travel speed. This will be the result of less congested roads since evacuating cars are more spread over time. The two strategies that increase the green time are resulting in much higher average travel speeds than the base case, due to the result of less delay time at the ramp controls. The contraflow strategies do not generate spectacular results. The deployment of contraflow on the campus site even reduces the average travel speed over the whole network.

7.2 Case 2

7.2.1 Evacuated vehicles

The second case differs from the first since background traffic is taken into account. As explained before, it has not been possible to establish evacuation times in this case. Therefore, the evacuated vehicles after twelve hours have been used to evaluate the effects of the strategies. These results are compared to the total evacuation results from the first case.

The deployment of contraflow all over Gainesville leads to the best results. The results of this strategy are more significant than in the first case where it ended up as the fourth best strategy. One explanation is that the increase of capacity, gained by contraflow, has a more significant impact than the increase in green time. This will be the result of more traffic on the network that is more sensitive to a capacity increase of the links then for an increase in green time. This is can be explained due to more traffic in the network, which results in a lower percentage of the total vehicles that need access to the I-75. This decreases the effect of the green time, but improves the more capacity of lanes in the network.

The two strategies that increased green time at the ramps and in Gainesville, still result in a major increase of evacuated vehicles. Green time in whole Gainesville leads to little more vehicles evacuated from the network. But a significant difference between these two strategies is not observed. Their effect can be less significant due to the more flows and directions in the network that result in more congestion of the directions that do not see an increase in their green time.

A major difference between its first and second case results can be found in the staged evacuation strategy. In the first case it was ranked as sixth best strategy. However, with background traffic, the strategy seems more effective than the others, resulting in the second most effective strategy. This spectacular difference can be the result from the less delay background traffic experiences than with the other strategies. In this strategy not every parking lot starts discharging vehicles at the beginning of the simulation. With this strategy, the flow of evacuation traffic is more spread causing a lower demand per interval and this gives the background and evacuation traffic more chance to flow out of the network. It probably is crucial that the incoming background flows are blocked after two hours. Otherwise the network would probably be more congested when the large parking lots are set free, decreasing the efficiency of staged evacuation.

The strategy without any form of control measures, is decreased in its efficiency. In the first case it had the lowest evacuation time, but in the second case it dropped to a fifth place. This can be explained by the flows created by the background traffic. In the first case the evacuation traffic had almost a free path towards their destinations. There were not a lot of conflicting routes. With the presence of background traffic, the number of crossing paths, and thus conflicts, are largely increased. Without any form of control, this can result in more waiting and thus delay time. This will probably be the cause of the decrease of evacuation efficiency for this strategy.

The closure of access roads on the campus did not result in a significant improvement of the evacuated vehicles. It even had a slight decrease of cars evacuated compared to the base case. Although this can be a biased result, it indicates that this strategy does not generate the expected effects. The same goes for the strategy in which contraflow is deployed on the campus site. Traffic still gets stuck outside the campus area. It is however observed that with these last two strategies, the vehicles on the campus area still faster discharged than in the base case.

7.2.2 Total Travel Time

Again, the “No control” strategy results in the lowest total travel time. Although strategy is not able to evacuate the most cars in twelve hours, the cars on the network experience the least travel time. The travel time can be low since the cars do not experience a lot of delay due to signal controls. However, they will experience more delay due to the conflicts with the background traffic. It is seen that this increase in conflicts does not result in a large increase of total travel time. A reason can be that the cars in the beginning of the time period can travel anywhere over the network at free flow speed. It takes a while before there are conflicts and it takes even longer to get queues as a result of these conflicts. This explains while the travel time is lower than in any of the other strategies.

The differences between the control strategies are not as large as in the first case. Staged evacuation still results in the lowest travel time. But the difference between the green time strategies and contraflow in whole Gainesville are less significant. Unlike the first case, the “green time all” strategy is better than the “Green time ramps” strategy. An explanation can be found in the fact that there are more vehicles present on the network so the congestion at the ramps becomes less important in determining the total travel time. So increasing the green time all over Gainesville will result in more effect, and this is observed in the results.

The contraflow on the campus area still results in an increasing total travel time. The same reason as in the first case can explain this result. The traffic is earlier discharged from the campus but gets stuck directly around the campus.

This is in contrast to the no access strategy, where the total travel time is reduced. This can be explained by the fact that there is less congestion on the campus area. The difference with the contraflow is that the traffic leaves the campus area more spread over time, resulting in a lower demand per interval and therewith less congestion around the campus.

7.2.3 Performance of traffic measures

An important standard to measure the quality of the traffic handling in the network is the delay time per travel hour. The delay time ratio states the average delay time per one travel hour on the network.

The strategy that scores best in this field is the ‘No control’ strategy. The results indicate that without any form of control, the vehicles experience the least delay time. An explanation can be that there is a lot of traffic that evacuates in the first few hours in this strategy. After most of these fast discharging cars have gone, the other directions that discharge slowly, remain. This can have a greater impact on the number of vehicles that are evacuated than it has on the average delay time ratio, resulting in the observed values.

Within the control strategies it is observed that all of the strategies are close to each other. The control strategy with the lowest delay time ratio is the staged evacuation. This strokes with the results found in the first case where this strategy also was the second best. Due to the more spread flow of vehicles, less congestion is experienced and thus less delay is observed than in the other control strategies.

The strategies that increased the green time for the outgoing evacuation flows, also saw a decrease in their delay time ratio. So despite the presence of background traffic, these strategies still decrease the delay time per travel hour. This indicates that although some directions experience an increase in their delay time due to a greater cycle length, the overall delay time for the network decreases. The strategy that increased the green time just for the ramp directions, reduced the overall delay time more than the strategy which increased green time all over Gainesville.

Both contraflow strategies decreased the delay time ratio compared to the base case but still have a larger ratio than the no campus access strategy. The reason lies probably in the fact that the contraflow strategies transport the evacuees faster to controlled intersections which increases the waiting time and thus the delay time per travel hour.
The quality is determined by many factors, another one of them is the average travel speed. The 'No control' strategy shows the highest average travel speed within the network. This is somewhat remarkable since it did not produce the highest number of evacuated vehicles. But as explained in the previous paragraph, this can be the result of a lot of cars that travel at high speeds during the first few hours, after which more to the end only the cars remain that experience large delays. It can be that when the strategies are analyzed over a greater period, the average speed drops since only slow traveling vehicles remain. Within the control strategies, the staged evacuation results in the highest average speed. This is the result of a more spread flow since the demand is more spread over time. The strategy that only gives more green time to ramp access directions allows a higher average speed than the strategy which deploys more green time all over Gainesville. The base case results in the lowest average speed, but the contraflow and no access strategy result within the same margin.

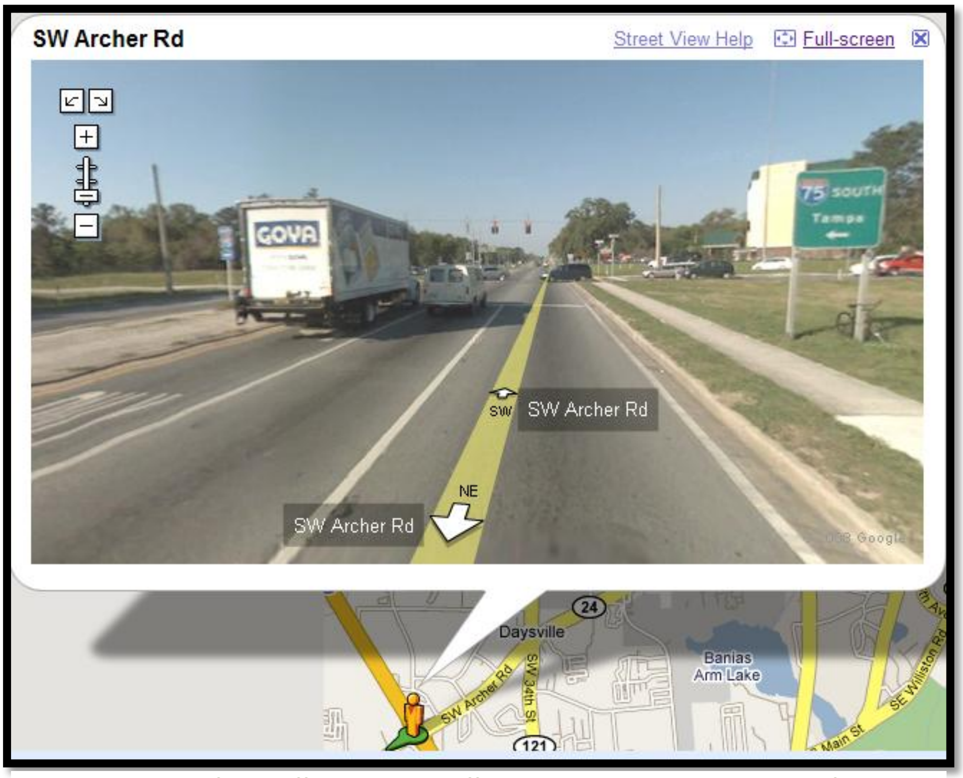


Figure 29: One of the traffic lights that traffic has to pass, in order to make a left turn towards the interstate

8. Conclusion

In this research, eight evacuation strategies have been tested to establish their effects on an evacuation in the city of Gainesville, Florida. The scenario that has been used to test these strategies, was build around the evacuation of the football stadium. This stadium, located on the campus of the University of Florida, accommodates about 90.000 people during game days. The scenario included the use of two transportation modes, the bus and private car. Within this scenario, two cases have been developed to test the sensitivity of the results. The first case did focus only on the traffic generated by the evacuating spectators. The second case added background traffic to the traffic generated by the evacuees. This chapter will discuss the conclusions that can be drawn from the results. It should be noticed that the results as presented before do not indicate actual evacuation times for the city of Gainesville. The network is used as a test network and there are differences with the real network, which would not make it valid to draw conclusions about the actual evacuation times for the city of Gainesville. It is suitable for the comparison of different strategies. Since the input values are kept the same for the strategies, their results can be compared to draw conclusions that will indicate which strategies are more and less promising.

When the first case is considered, the ‘No control’ strategy seems to create the largest reduction in the overall evacuation time. It also indicates that evacuees experience the lowest travel time when all forms of control are removed. However, the ‘No control’ strategy does not produce the same results in the second case. Although the total travel time, the delay time ratio and travel speed still show the best results, the number of cars that left the network under this strategy is lower than in four other strategies. This indicates that the results of a network without control will worsen when more traffic, with more directions is present on the network. The second problem with the ‘no control’ strategy is its feasibility. The ‘No control’ strategy does not mean ‘No rules’. In Corsim, the drivers still obey rules like first come, first serve at the intersections where the signal controls are shut off. If all controls are removed or turned off, conflicting flows will be allowed. This creates dangerous and probably chaotic situations, and will probably increase the chance of accidents within the network that is under evacuation conditions. If these accidents happen, the traffic will experience congestion that can lead to a sharp increase in the needed evacuation time. Although the results of the ‘No control’ strategy seem very promising, its feasibility is not likely.

Within the control strategies, both green time strategies seem very promising. In the first case these strategies reduced the evacuation time spectacular by more than three hours. They even discharged the evacuation traffic two hours earlier than in the contraflow strategy. In the second case they evacuated over ten percent more cars than the base case did. Although the contraflow strategy seemed more effective in this case, the difference is not large enough to prefer contraflow over the green time. If both green time strategies are compared to each other, it can be concluded that they almost lead to the same results. The evacuation time for the strategy that increases green time all over Gainesville, is slightly less than in the ramp strategy. The second case shows opposite results, the ramp strategy evacuates more vehicles. Over both cases the quality of the traffic service is better when only the green time for the ramp directions are increased. It will also take more effort to increase the green times over the whole network than just at the ramps. So it can be concluded that it is the most efficient control strategy is to increase the green time just at the ramps.

Besides the two strategies that increase the green time, staged evacuation came up as a very promising strategy. The evacuation time did not reduce much in the first case, indicating that there must be enough time available to evacuate the population. If this is the case, then the second case showed staged evacuation as the second best strategy. The most vehicles were evacuated after twelve hours. The total travel times do show that staged evacuation is an effective way to evacuate people out of an urban area. Also the criteria that have been used to analyze the quality of the traffic service, indicate promising results. In both cases, the staged evacuation showed a reduction in the delay time and an improvement in the average travel speed. The results indicate that staged evacuation is a serious strategy that should be considered when an evacuation plan is designed.

The contraflow results are partially disappointing. There is a difference between the two contraflow strategies. When contraflow is deployed at the campus, traffic will be able to leave this area faster. This improvement is not seen in the overall results. In the first case it did reduce the evacuation time, but in the second case its efficiency dropped and the results were even worse than in the base case. So it can be concluded that the deployment of contraflow on the campus site directs traffic faster away from the direct vicinity of the threat but does not have a significant, positive impact in the evacuation results for the whole network.

The results of the other contraflow strategy, where also lanes in Gainesville are reversed, are better. In the second case it is observed that the contraflow is effective in handling larger flows of traffic, it even evacuated the most cars from all strategies. However, these results do not come back in the results that handle the quality of the traffic service. In the first case this strategy did result in a lower evacuation time on the network and did also improve the quality of the traffic service. The results suggest that contraflow will reduce needed evacuation time, but that it is vital where and how the contraflow is deployed.

The closure of incoming lanes towards the campus show not very promising results. It did reduce the congestion on the campus area, but was not able to solve it. In the first case traffic was able to evacuate just a little bit faster than in the base case. In the second case the number of vehicles evacuated was lower than the base case. The quality measures showed some better results. The travel time is decreased and the average speed lays higher than in the base case. Although this strategy improves the quality of the traffic handling, it will not solve any of the congestion problems during an evacuation. So even though it makes sense that inbound lanes towards the threat are closed to prevent traffic from entering dangerous areas, it is not a profitable strategy in these cases.

The conclusions per strategy are:

- The base case provided good reference results and helped by pointing out which strategies are more promising than others. It can also helped by discovering bottlenecks in the network.

- The ‘no access’ strategy is not effective in improving the overall evacuation time and the quality of the network. However, it has been observed that the traffic on the campus site experience less congestion and is evacuated faster than in the base case.

- The deployment of contraflow on the campus area gave a small reduction in evacuation time, but did not score good results within the total travel time and the network performance measures. The strategy is able to evacuate vehicles faster from the campus area but moves the congestion outwards the campus area.

- The deployment of contraflow on the campus area and in Gainesville, resulted in more promising results. The evacuation and travel time is reduced and it resulted in the highest number of evacuated vehicles. Although the performance measures did not always indicate the same results, this strategy is definitely worth considering.

- With increasing the green time at the signal controls, a significant reduction in evacuation time is obtained. The network performance measures show good results and this strategy is relatively easy to implement. Therefore this strategy should be considered as the most promising strategy.

- The evacuation time is even more reduced, if the previous strategy is expended with an increase of green time on the main streets. However, some of the network performance measures show results that are not as good as the previous strategy. To implement this strategy will also take more effort and therefore this strategy is not preferred over the increase in green time just at the ramps.

- The staged evacuation showed good results. Although the evacuation time did not reduce a lot in the first case, the second case showed a significant improvement between this strategy and the base case. The average travel time did support the idea behind this strategy that people experience less congestion and thus less delay time which improves their average speed and travel time. The strategy did also indicate a shorter evacuation time for the traffic on the campus area. The traffic will experience less delay outside the direct vicinity of the campus and is able to flow faster out of the endangered area.

- The no control strategy did result in great results. The evacuation time in the first case was cut back by more than three hours and it resulted in the lowest average travel time. The network wide performance measures did improve significant. However, it is expected that the results will not be the same in the real world. There will be more chaos and people will be more confused about the rules in the network. Therefore, it is unknown what the results will be during an evacuation in the real world.

9. Recommendations

This chapter will focus on the recommendations that were found during the analysis of the strategies and should be considered for future research.

Corsim is not a designed micro simulator that can cope with all the specific circumstances of an evacuation. The largest disadvantage was found during the second case. Corsim was not able to change the lane characteristics during the simulation. The purpose of the second case was to analyze how the strategies would behave when they are deployed on a network with background traffic. In order to approach the reality, the first few hours of the simulation should be used to create a situation where the background traffic is flowing on the network. After these first hours, the evacuation of the stadium would occur resulting in a large increase of demand. For the strategies that increased green time this would be possible to implement. Corsim allows other signal schemes at different intervals. The staged evacuation would also be no problem to implement. However, the strategies that required changes in the lane characteristics where not able to implement. Corsim requires these characteristics to be steady over time, which makes it impossible to change the direction of lanes during different time intervals. This made it impossible to use this approach to compare the results. But it is recommended that in other studies with simulators, the background traffic is considered. The results can be different and sometimes even unexpected when compared to analysis that just consider evacuation flows. It is thought that these results will come closer to the reality when background flows are present and significant.

For this research it was not necessary to model the network as in reality. To obtain results that are closer to the reality, original signal schemes should be modeled into the network. If this is used in the base case, it can be analyzed whether or not the green time strategies still have the large impact on the evacuation time in Gainesville. It is recommended to test the sensitivity of the results by using other, real signal schemes. Another option is to analyze the results with the use of actuated control systems. Corsim is not able to work with actuated control systems when the traffic assignment function is used. Other simulation programs that can cope with this problem, should be used to analyze the effects of actuated signal controls on the evacuation time in the base case.

It is also expected that Corsim would calculate more real results if actual observed flows are used. In this research flows have been generated by matching the known attraction values to estimated production values. In future research, more information could be gathered to predict actual flows after a game. This will give more information about the actual flows after a game.

Due to time restrictions it has not been able to establish evacuation times in the second case. Although the number of evacuated cars can be used as an alternative, it would be better to run the simulation longer to find the actual evacuation times for the test network. Although unlikely, it is possible that some strategies have a large increase in their efficiency after the analyzed time period. To find out if this actually happens, the simulation time should be increased till all cars have left the network.

The 'No control' strategy showed some striking results. Although its efficiency dropped when background traffic was considered, it still increased the network wide performance measures. It is recommended to do more research why this no control strategy is so efficient in Corsim and how it could be applied in the real world. It probably will have to do with the elimination of conflicts in the network. In the real world people will be more confused and it is expected that there will be more chaos on the network. But if there is a way to approach the situation in Corsim, the results can be spectacular.

During the analysis of the staged evacuation strategy, it was observed that after 250 minutes a jump in the number of exit trips occurs (*see appendix 16*). It is recommended to play with the sequence and time between the evacuation order. In that case it should be possible to find a more optimal solution that could result in even better results. It is also recommended to find the most optimal solution by considering the link capacities on the network. If the sequence of the evacuation is adjusted towards this number, than an even more optimal solution can be found. It is expected that the results of Arulselvan's methodology can be used to improve the sequence of the staged evacuation.

Another recommendation is to analyze a combination of different strategies. The combination of promising strategies can result in an even shorter evacuation times and better network performance results. So it is recommended to analyze the results when green time at the ramps is increased combined with the deployment of contraflow in Gainesville. Another interesting option is to analyze the results of staged evacuation, combined with contraflow and green time strategies. It should be even possible to use staged contraflow in which the lanes that undergo contraflow change over time to find the most optimal solution. So there is a lot of research that can be done to analyze the results when strategies are simultaneously deployed.

This research did not consider the flows of pedestrians. However, after the game ends it was observed that a lot of people walk towards the parking lots and bus station. This leads to a large flow of pedestrians that influence the traffic flows. Future researches should look at the effects of the pedestrian flows, and how they influence the evacuation results. The same goes for the use of Recreational Vehicles during game days. They are used a lot but have been let out of consideration. However, these vehicles can have a significant negative impact in the total evacuation time.

Figure 30: A large number of pedestrians, just after the game

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Appendix 1: OD-matrix “Evacuation traffic”

The first OD-matrix is used to distribute the trips generated and attracted by each zone. The first OD-table will distribute trips to destinations outside Gainesville. For destinations in Gainesville, only origins at the campus site are used. This distribution can be found in the next table within this appendix.

			estination outside Gnv												
Origin [illegible] Gainesville	**Percentage of total**	**O/D**	8002	8003	8005	8006	8007	8008	8009	8010	8011	8013	8015	8004	**Equals**
Conference Center	5.00%	8012	80	28	9	36	21	82	29	77	241	45	256	778	1681
Performing Arts	4.00%	8029	64	22	7	29	17	65	23	62	193	36	205	622	1345
Golf Course	2.00%	8030	32	11	3	14	9	33	11	31	97	18	102	311	672
Fraternity Row I	2.00%	8025	32	11	3	14	9	33	11	31	97	18	102	311	672
Fraternity Row II	2.50%	8023	40	14	4	18	11	41	14	39	121	23	128	389	840
Woodlawn Street	4.00%	8022	64	22	7	29	17	65	23	62	193	36	205	622	1345
O'connell center I	3.00%	8019	48	17	5	22	13	49	17	46	145	27	154	467	1008
O'connell center II	3.00%	8017	48	17	5	22	13	49	17	46	145	27	154	467	1008
Pressly Soccer Stadium	1.50%	8021	24	8	3	11	6	24	9	23	72	14	77	233	504
Ben Hill Griffin Stadium	1.25%	8020	20	7	2	9	5	20	7	19	60	11	64	194	420
Fletcher Drive	0.75%	8035	12	4	1	5	3	12	4	12	36	7	38	117	252
Buckman Drive	1.00%	8034	16	6	2	7	4	16	6	15	48	9	51	156	336
Plaza of the Americas	1.25%	8031	20	7	2	9	5	20	7	19	60	11	64	194	420
Newell drive I	1.00%	8032	16	6	2	7	4	16	6	15	48	9	51	156	336
Newell drive II	1.50%	8026	24	8	3	11	6	24	9	23	72	14	77	233	504
Museum Road	2.00%	8024	32	11	3	14	9	33	11	31	97	18	102	311	672
Shuttle place I	2.00%	8027	32	11	3	14	9	33	11	31	97	18	102	311	672
Shuttle place II	4.00%	8028	64	22	7	29	17	65	23	62	193	36	205	622	1345
VA Hospital I	5.00%	8033	80	28	9	36	21	82	29	77	241	45	256	778	1681
VA Hospital II	5.00%	8037	80	28	9	36	21	82	29	77	241	45	256	778	1681
Origin within Gainesville		**O/D**													
Oaks Mall I	10.00%	8038	165	57	18	74	44	169	59	160	500	94	530	1609	3477
Oaks Mall II	8.00%	8014	132	46	14	59	35	135	48	128	400	75	424	1287	2782
Oaks Mall III	5.25%	8059	86	30	9	39	23	89	31	84	262	49	278	845	1826
Downtown Garage	8.00%	8039	132	46	14	59	35	135	48	128	400	75	424	1287	2782
Tioga Town Center	7.00%	8040	115	40	12	52	31	118	42	112	350	65	371	1126	2434
Haile Plantation	5.00%	8041	82	28	9	37	22	84	30	80	250	47	265	804	1739
Butler Plaza	5.00%	8042	82	28	9	37	22	84	30	80	250	47	265	804	1739
	Equals		1617	560	175	730	435	1658	584	1570	4909	919	5204	15811	34172

This table presents the distribution of trips between origins on the campus area and destinations inside Gainesville. These numbers are relatively low since it is assumed that 10.000 people who have their destination within Gainesville use the bus as their transportation mode.

			Destination inside Gnv																
Origin Gainesville	Percentage of total	O/D	8043	8044	8045	8046	8047	8048	8049	8050	8051	8052	8053	8054	8055	8056	8057	8058	Equals
Conference Center	5.00%	8012	0	0	0	0	1	1	1	1	1	2	2	6	9	9	12	12	59
Performing Arts	4.00%	8029	0	0	0	0	1	1	1	1	1	1	1	5	7	7	10	10	47
Golf Course	2.00%	8030	0	0	0	0	0	0	0	0	1	1	1	3	4	4	5	5	24
Fraternity Row I	2.00%	8025	0	0	0	0	0	0	0	0	1	1	1	3	4	4	5	5	24
Fraternity Row II	2.50%	8023	0	0	0	0	0	0	0	1	1	1	1	3	5	5	6	6	29
Woodlawn Street	4.00%	8022	0	0	0	0	1	1	1	1	1	1	1	5	7	7	10	10	47
O'connell center I	3.00%	8019	0	0	0	0	0	1	1	1	1	1	1	4	6	6	7	7	35
O'connell center II	3.00%	8017	0	0	0	0	0	1	1	1	1	1	1	4	6	6	7	7	35
Pressly Soccer Stadium	1.50%	8021	0	0	0	0	0	0	0	0	0	1	1	2	3	3	4	4	18
Ben Hill Griffin Stadium	1.25%	8020	0	0	0	0	0	0	0	0	0	0	0	2	2	2	3	3	15
Fletcher Drive	0.75%	8035	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	9
Buckman Drive	1.00%	8034	0	0	0	0	0	0	0	0	0	0	0	1	2	2	2	2	12
Plaza of the Americas	1.25%	8031	0	0	0	0	0	0	0	0	0	0	0	2	2	2	3	3	15
Newell drive I	1.00%	8032	0	0	0	0	0	0	0	0	0	0	0	1	2	2	2	2	12
Newell drive II	1.50%	8026	0	0	0	0	0	0	0	0	0	1	1	2	3	3	4	4	18
Museum Road	2.00%	8024	0	0	0	0	0	0	0	0	1	1	1	3	4	4	5	5	24
Shuttle place I	2.00%	8027	0	0	0	0	0	0	0	0	1	1	1	3	4	4	5	5	24
Shuttle place II	4.00%	8028	0	0	0	0	1	1	1	1	1	1	1	5	7	7	10	10	47
VA Hospital I	5.00%	8033	0	0	0	0	1	1	1	1	1	2	2	6	9	9	12	12	59
VA Hospital II	5.00%	8037	0	0	0	0	1	1	1	1	1	2	2	6	9	9	12	12	59
	Equals		1	2	4	5	8	9	10	12	13	19	19	66	95	97	123	127	610

Appendix 2: OD-matrix "Background traffic"

This table presents the distribution of traffic as used to analyze the strategies while background traffic is flowing on the network. The base for these numbers is the transportation data provided by the Florida Department of Transportation *(Florida Department of Transportation, 2007)*.

Origin outside Gainesville	**O/D**	**8011**	**8004**	**8009**	**8005**	**8003**	**8002**	**8010**	**8008**	**8015**	**8060**	**8006**	**8007**	**8013**	**Total**
I75 North	**8001**		1897	154	129	148	139	153	166	291	232	233	280	115	3938
I75 South	**8018**	1883		163	136	156	147	162	175	307	245	245	295	122	4036
Newberry	**8009**	152	162		11	13	12	13	14	25	20	20	24	10	475
Archer	**8005**	127	135	11		11	10	11	12	21	17	17	20	8	399
Williston	**8003**	146	155	13	11		11	13	14	24	19	19	23	9	455
Micanopy	**8002**	137	146	12	10	11		12	13	22	18	18	21	9	429
Hawthorne	**8010**	176	187	15	13	15	14		16	29	23	23	28	11	549
Melrose	**8008**	148	157	13	11	12	12	13		24	19	19	23	10	460
Waldo	**8015**	271	288	23	20	22	21	23	25		35	35	42	18	824
NE 39th Str	**8060**	224	238	19	16	19	17	19	21	37		29	35	14	688
Brooker	**8006**	236	251	20	17	20	18	20	22	39	31		37	15	726
Worthington Springs	**8007**	276	293	24	20	23	22	24	26	45	36	36		18	842
Alachua	**8013**	114	121	10	8	9	9	10	11	19	15	15	18		359
	Total	3889	4030	478	401	458	432	473	514	882	710	709	846	359	**14180**

Appendix 3 : Adjusted parameters driver behavior

These are the parameters that have been adjusted. They are adjusted to a way that the drivers will be more aggressive in their decision a driving behavior.

Near-Side Cross-Street Acceptable Gap Distribution

Driver Type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Standard (*in seconds*)	5.6	5.0	4.6	4.2	3.9	3.7	3.4	3.0	2.6	2.0
Adjusted to (*in seconds*)	4.8	4.5	4.2	3.9	3.6	3.4	3.1	2.8	2.2	1.8

Far-Side Cross-Street Additional Time Distribution

Total number of lanes to clear intersection	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Standard (*in seconds*)	1.2	2.1	2.6	3.1	3.5	3.9	4.2	4.6	4.9	5.1
Adjusted to (*in seconds*)	1.0	1.8	2.3	2.8	3.1	3.4	3.8	4.1	4.3	4.5

Spillback Probabilities (*blocking traffic at intersection*)

Resulting spillback position	**1**	**2**	**3**	**4+**
Standard (*probability joining upwards queue)*)	80%	40%	10%	0%
Adjusted to (*probability joining upwards queue*)	90%	50%	25%	10%

Maximum Allowable Turning Speeds

Turning direction	**Standard** (*in feet per second*)	**Adjusted to** (*in feet per second*)
Right turn	13 ft/s (=14 km/h)	16 ft/s (=24 km/h)
Left turn	22 ft/s (= 17.5 km/h)	25 ft/s (= 27.5 km/h)

Acceptable Gap in Oncoming Traffic (left turn **)**

Driver Type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Standard (*in seconds*)	7.8	6.6	6.0	5.4	4.8	4.5	4.2	3.9	3.6	2.7
Adjusted to (*in seconds*)	6.6	6.0	5.4	4.9	4.5	4.1	3.8	3.6	3.3	2.5

Acceptable Gap in Oncoming Traffic (right turn **)**

Driver Type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Standard (*in seconds*)	10	8.8	8.0	7.2	6.4	6.0	5.6	5.2	4.8	3.6
Adjusted to (*in seconds*)	8.5	7.3	6.8	6.4	6.0	5.7	5.3	4.9	4.4	3.1

Lane Changes

Description	**Standard**	**Adjusted**
Duration of lane change maneuver	3sec.	2sec.
Min. deceleration for a lane change	5 ft/sec^2	4 ft/sec^2
Deceleration rate of lead vehicle	12 ft/sec^2	15 ft/sec^2
Deceleration rate of follower vehicle	12 ft/sec^2	15 ft/sec^2
Mandatory lane change acceptable deceleration	10 ft/sec^2	13 ft/sec^2
Discretionary lane change acceptable deceleration	5 ft/sec^2	8 ft/sec^2

Lane Changes (driver behavior)

Description	**Standard**	**Adjusted**
Time to react to sudden deceleration of lead vehicle	1sec.	0.8sec
Driver type factor (factor used to compute motivation of a drive to change lanes **)**	25	20
Safety factor (higher will lead to a greater risk acceptation)	0.8	1.0
Percentage of drivers who will cooperate with a lane changer (let him merge)	50%	40%
Headway at which all drivers will attempt a lane change	2.0sec	1.6sec
Headway at which no drivers will attempt a lane change	5.0sec	7.0sec

Left turn jumpers and laggers

Description	**Standard**	**Adjusted**	
Probability of first driver in queue who turns left in front of opposing traffic	38%	45%	
Number of seconds after start of No Go (driver goes left during NO GO phase)	2	4	5
First value is standard percentage, second one is the adjusted value	50 → 60	15 → 20	0 → 5

Appendix 4: Additional information "No Access Campus"

The incoming lanes at the campus area are blocked to prevent traffic from entering the campus area. It has not been possible to close all lanes since some lanes are used by buses to access the campus. In this appendix can be seen which lanes are blocked and which are used by buses to enter the campus. It can also be seen how the campus area looks in Corsim. The bus lanes are colored.

Figure 31: Map with blocked entries and bus lanes

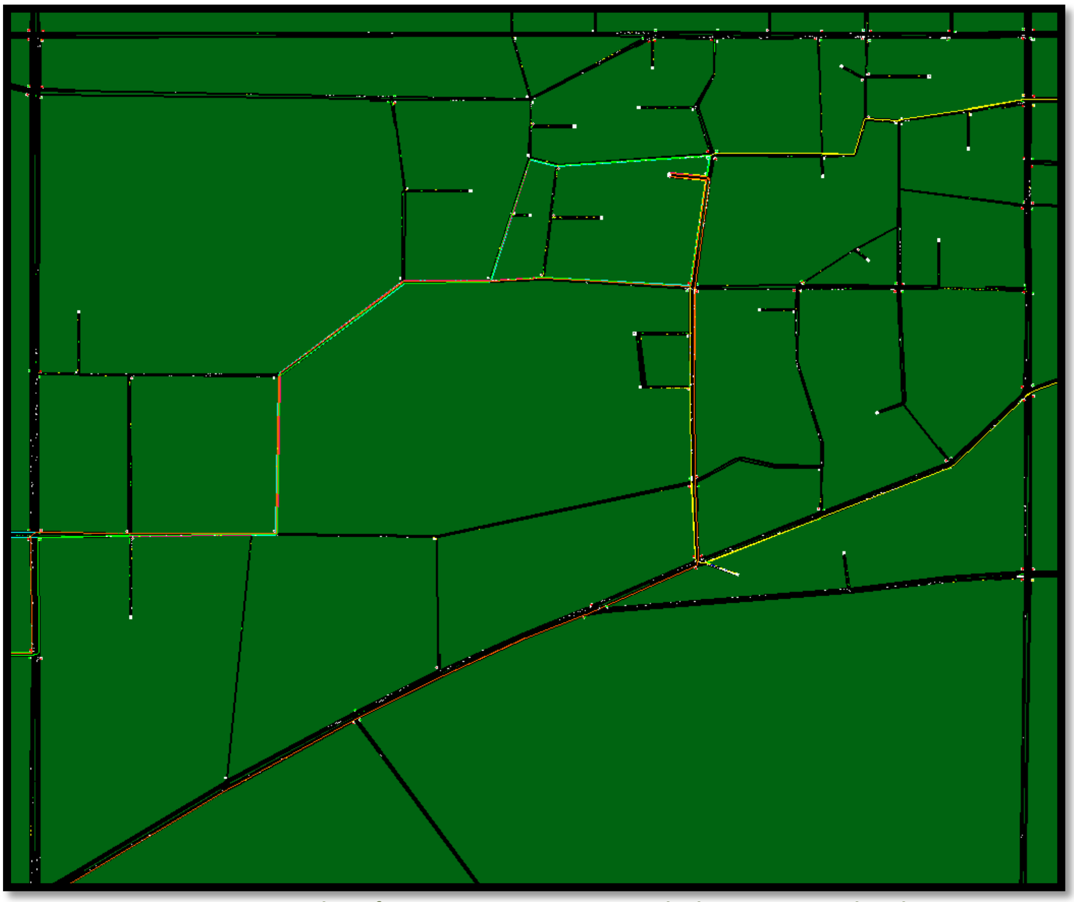


Figure 32: Screenshot of campus area in strategy 2. The bus Lines are colored.

Appendix 5: Additional information "contraflow on campus"

This figure shows where contraflow is deployed on the campus area and what directions gained an extra lane. Not all lanes could be reversed, since there would still be the need for buses to enter the campus area.

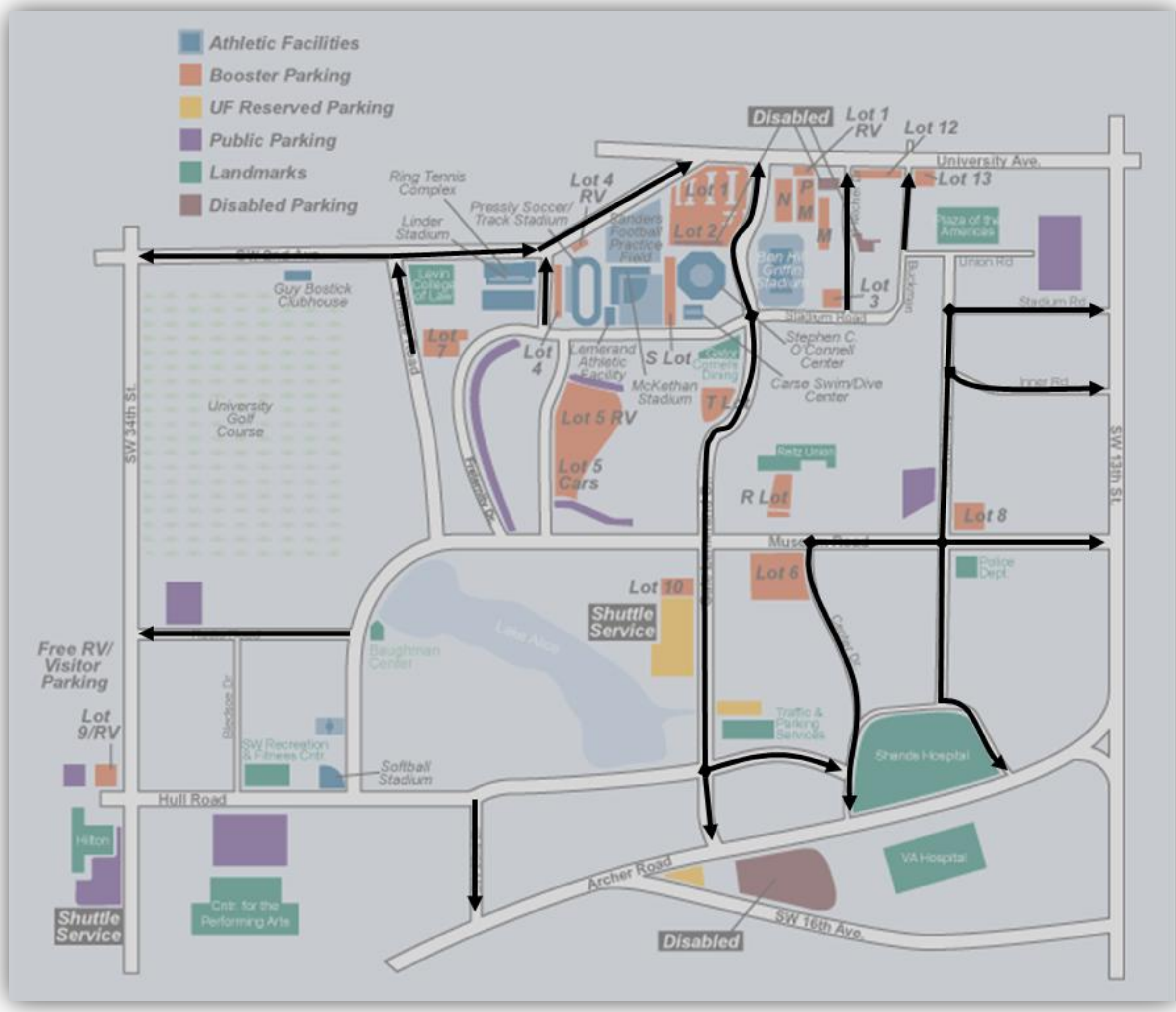


Figure 32: Map of the campus area including the contraflow lanes and their directions

Appendix 6: Additional information "Contraflow campus and Gainesville"

These are the lanes that have been reversed in Gainesville. Each direction gained one more lane, towards the direction pointed by the arrow. At the bullets, the direction of the contraflow changed. The lanes have been chosen by looking at the base case and identifying the most congested lanes.

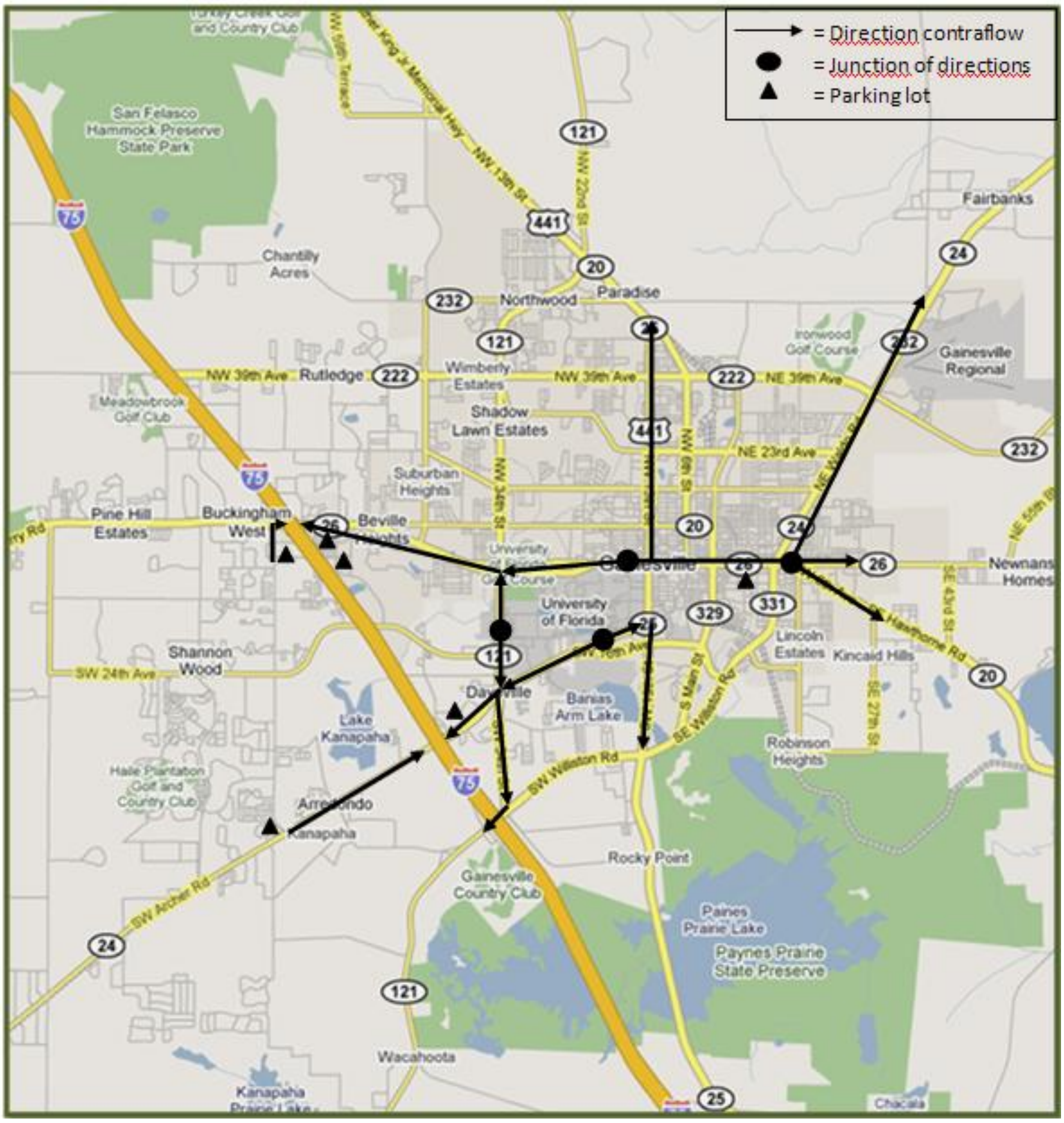
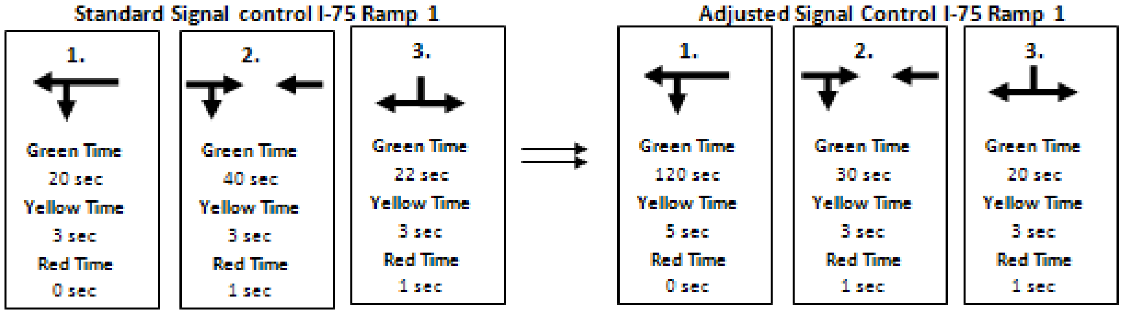
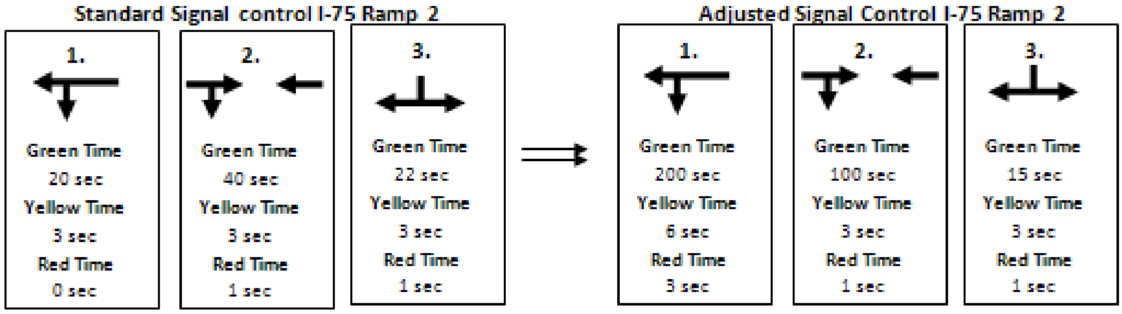


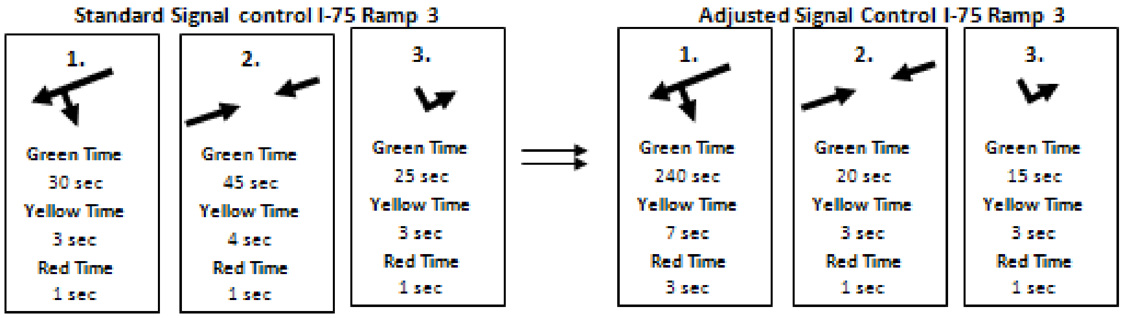
Figure 33: Contraflow lanes and their directions within the Gainesville network

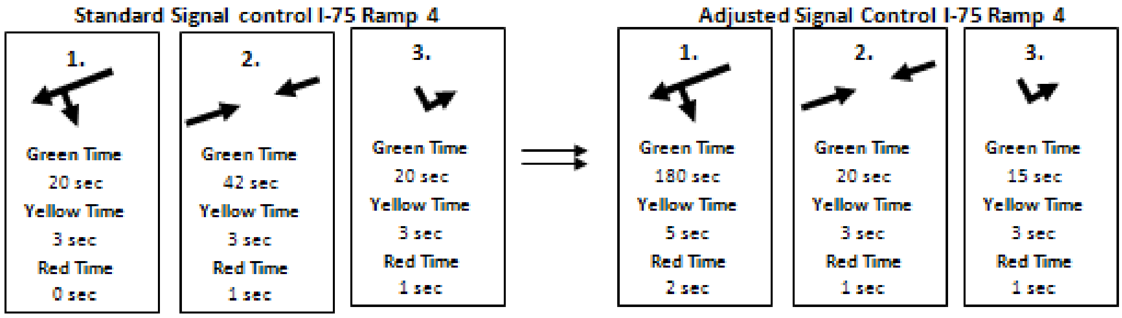
Appendix 7: Additional information "Increasing green time ramps"

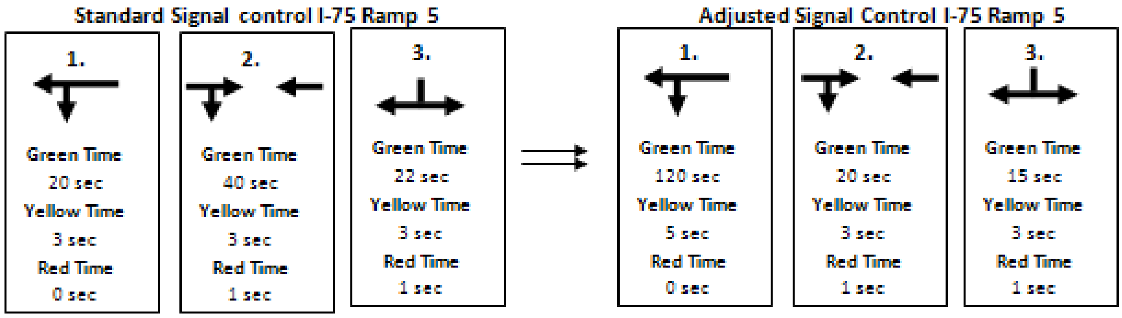
The figures underneath represent the values in the base case and their adjusted value. The controls are all located directly at one of the ramps and control the access of traffic to the I-75.











Appendix 8: Additional information “Increasing green time all”

This attachment shows which intersections, represented by node numbers, have been adjusted. The directions that carried the evacuation traffic saw their green time being doubled. This strategy includes the increase in green time for the ramps as stated in the fourth strategy.

Campus

Adjusted nodes: 40, 39, 41, 42, 25

Gainesville

1. SW 34th Street: Turning point is node nr. 55: More green time for incoming links; more green time for north-south traffic.

Adjusted nodes: Turning point: 55
Southbound adjusted nodes: 56; 58
Northbound adjusted nodes: 54; 66; 53; 16; 151

2. Western University Avenue: Turning point is node nr. 1 and 64: More green time for incoming links at nodes 1 and 64; After these nodes more green time for the west and east directions.

Adjusted nodes: Turning points: 1 and 64
Westbound adjusted nodes: 53; 148
Eastbound adjusted nodes: 27; 15; 6; 3; 119; 120; 124; 113; 101; 100; 201

3. SW Archer Road: Turning point is node nr. 37: More green time for the incoming link at this node number. Past this node, more green time for the Southwest- and Northeast links.

Adjusted Nodes: Turning point: 37
South-Westbound adjusted nodes: 63; 58; 278; 290
North- Eastbound adjusted nodes: 36; 35; 34

4. Martin Luther: Turning point is node 33: More green time for the incoming link at this node. After this node, the South and North directions gain more green time.

Adjusted nodes: Turning point: 33
Northbound adjusted nodes: 32; 31; 30; 3; 19; 166; 155; 159; 157; 207
Southbound adjusted nodes: 34; 84; 86

5. NW 8th Avenue: Turning point is node nr. 16: After this node more green time for the west and east directions.

Adjusted nodes: Turning points: 16
Westbound adjusted nodes: 149; 244; 259; 246; 248; 267; 301
Eastbound adjusted nodes: 27; 15; 6; 3; 119; 120; 124; 113; 101; 100; 201

6. SW 20th Avenue: One turning point where traffic enters SW 20th avenue. They see an increase in their available green time. It is node 272

7. NW Waldo Road: Turning point at node 100. After this point the North-eastbound gets more green time.

Adjusted nodes: Turning points: 100
North-eastbound adjusted nodes: 18; 188; 189; 216; 329

8. NE 53rd Avenue: Two nodes 204, and 203, leading toward exit points gain more green time for these directions.

The figure underneath shows where the adjusted intersections are placed.

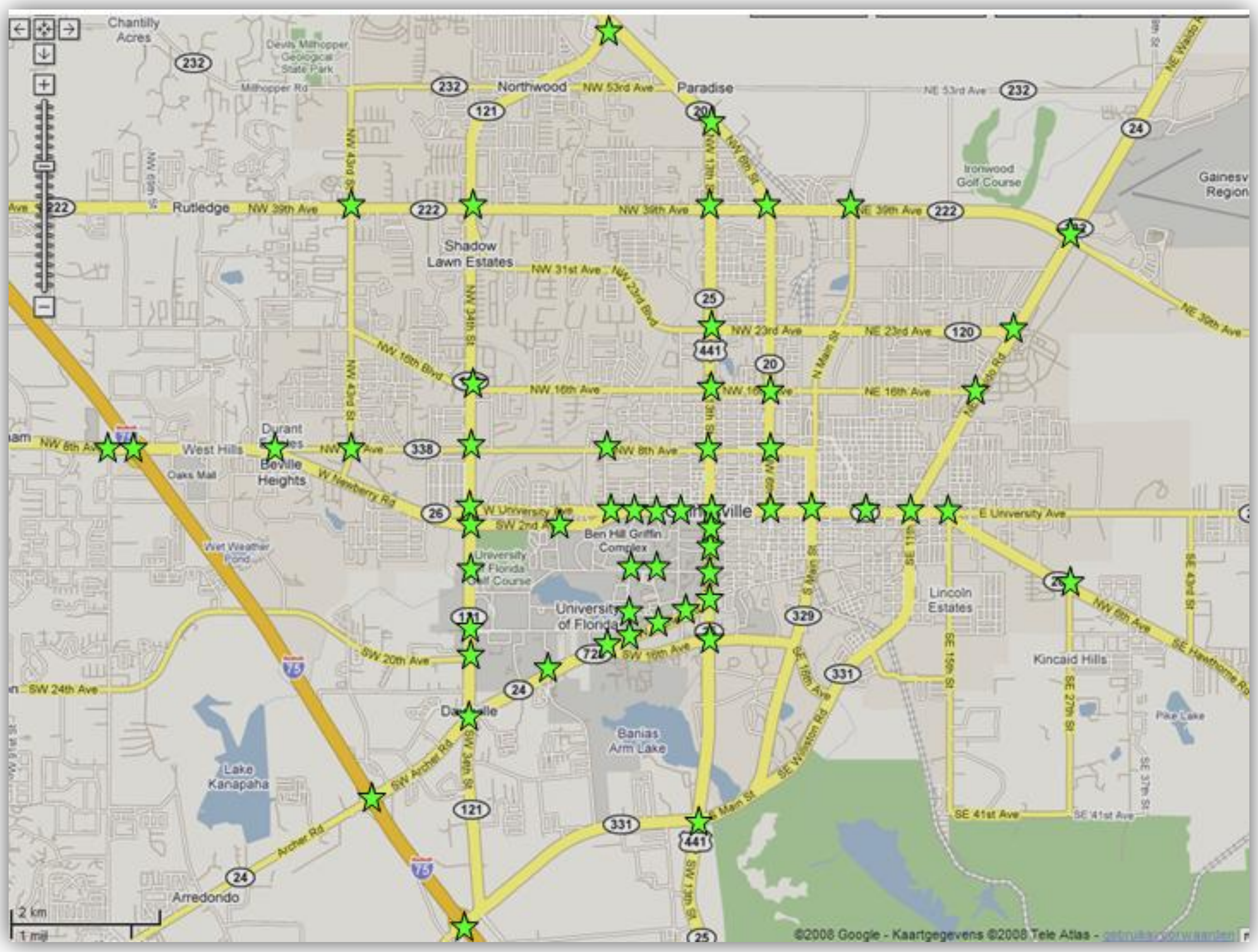


Figure 33: Locations where the green time for congested directions has been increased

Appendix 9: Additional information "Staged evacuation"

One vital part within this strategy is the determination of the sequence. In the study that Chin and Zhan (2006) carried out in the field of staged evacuation, they assumed four specific evacuation zones. Every person within each zone is informed at the same time and all vehicles enter the queue of evacuating vehicles at the same time. They used 25 different sequences but did not provide a basis for their decisions. Teo (2001) did provide a sequence order for staged evacuation under emergency conditions. She pointed out that occupants who are in immediate danger are evacuated first, followed by the other occupants. The benefits of this system are that the occupants that are in immediate danger can evacuate faster with less stress. Also, the occupants who are in greater danger are evacuated first, so the potential number of casualties may be reduced *(Teo, 2001)*. A same approach will be used in this study. The scenario includes a threat at the football stadium. Therefore, the parking lots in the vicinity of the stadium will be evacuated first working outwards towards the parking lots located further away from the stadium. The time between the evacuations is arbitrary but will provide results that approach a spontaneously organized staged evacuation.

1st interval (0 - 1920sec.)

Parking lots: The lots located in the direct vicinity of the stadium:

Node	Node
8019	8017
8021	8025
8034	8023
8022	8020
8035	8031

2nd interval (1920 - 3840sec.)

Parking lots: Further away from the stadium, but still in sight of the campus area

Node	Node
8032	8026
8024	8027
8028	8030
8029	

3rd interval (3840 - 7560sec.)

Parking lots: Lots located around the boundary of the campus area

Node	Node
8012	8033
8037	

4th interval (7680 - 14880sec.)

Parking lots: Biggest parking lot present in Gainesville, the Oaks Mall parking lot.

Node	Node
8038	8014
8059	

5th interval (14880 - end)

Parking lots: The last four parking areas located in Gainesville

Node	Node
8040	8041
8039	8042

Appendix 10: Results "Base case"

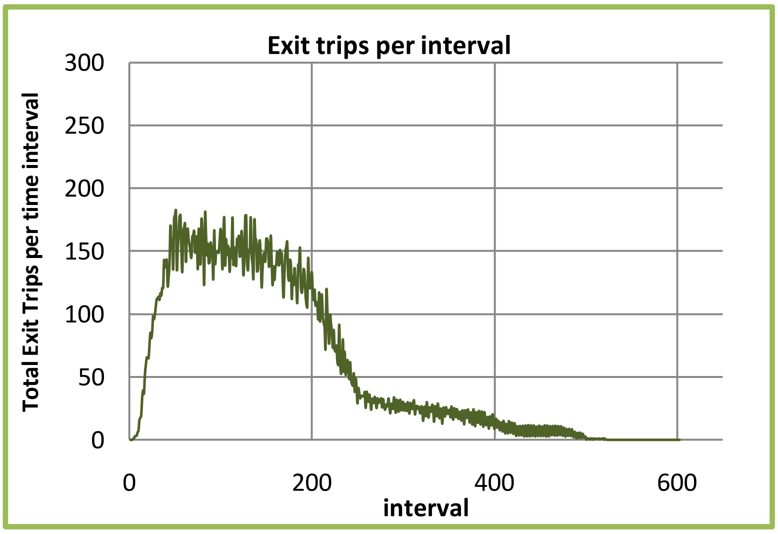
Introduction

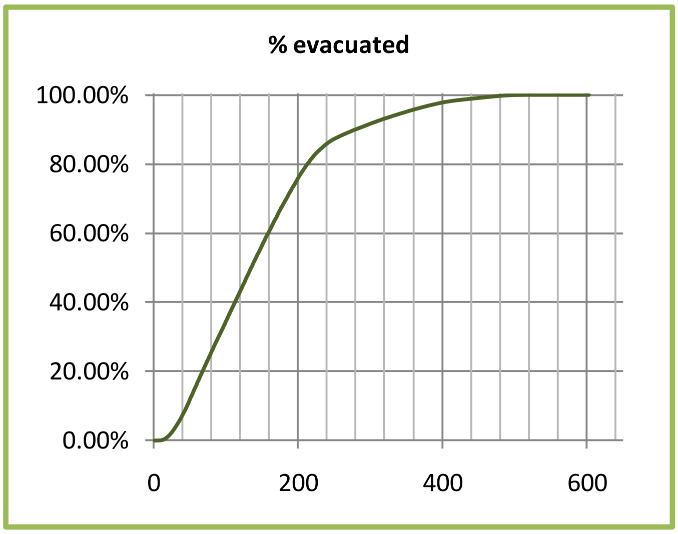
The first scenario that has been analyzed is the so called 'Base Case'. This scenario will be used as a reference to analyze the results from the several strategies. In the base case, no special traffic operations are employed.

5.1.1 Strategy 1.1: Evacuation traffic

In the first sub-scenario, OD-matrix number one has been used to deploy traffic flows onto the network. The results are obtained by averaging the results of 15 different runs:

- Total Evacuation Time: **8** hours and **45** minutes
- Total Average Travel Time: **1** hour ; **42** minutes ; **55** seconds per vehicle

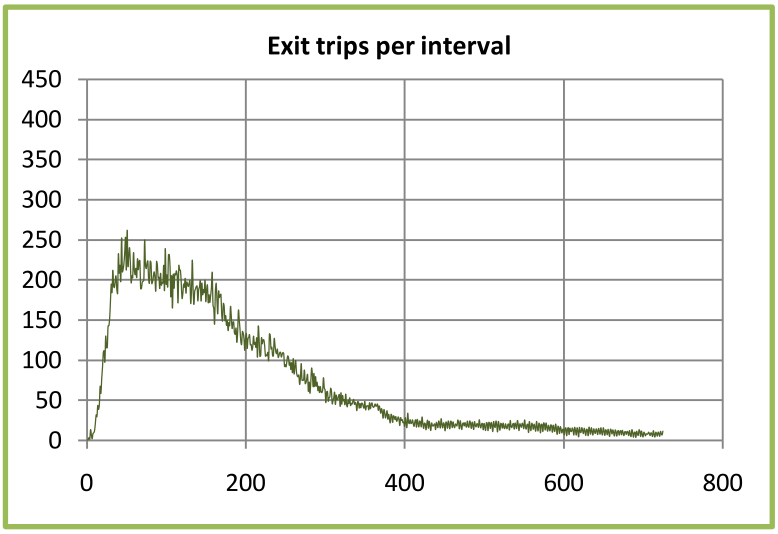


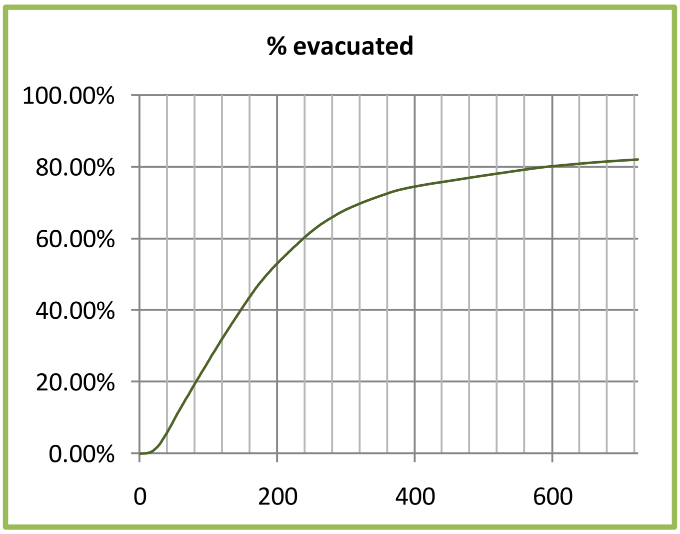


5.1.2 Strategy 1.2: Evacuation and background traffic

In the second sub-scenario, OD-matrix number one and two have been used to deploy traffic flows onto the network. The results are obtained by averaging the results of 10 different runs:

- Total vehicles evacuated: **82 percent** (52.800 out of 64.324)





Appendix 11: Results "No Access Campus"

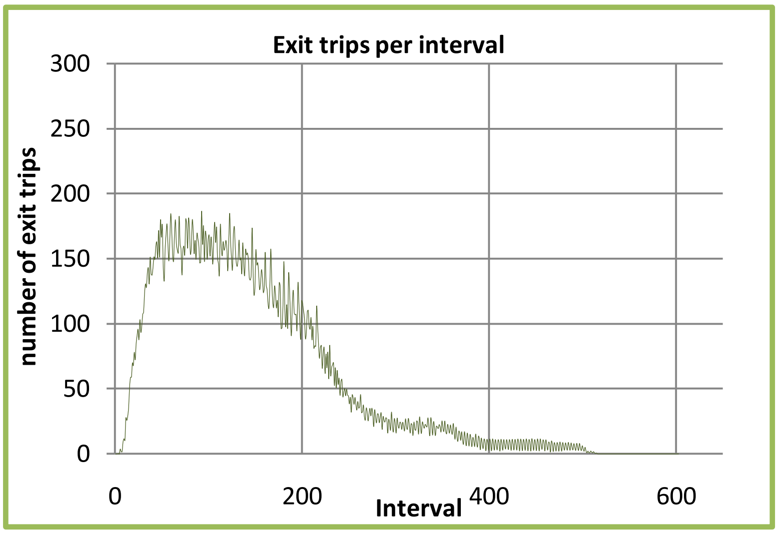
Introduction

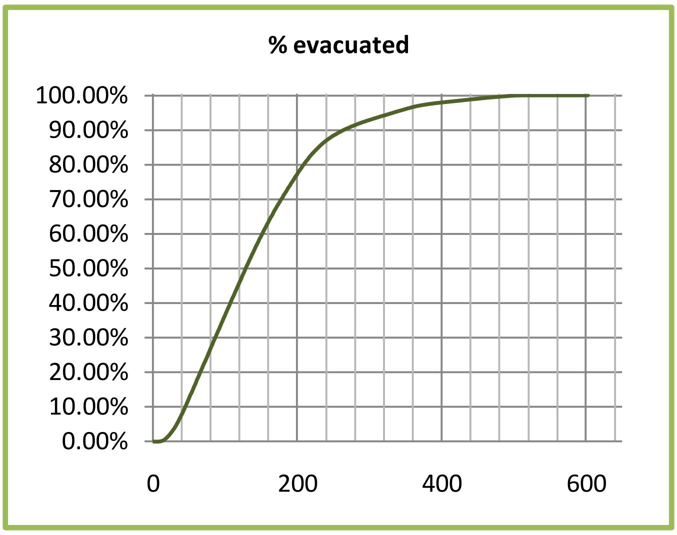
In this scenario, no traffic is allowed to enter the campus area. From the base case scenario, information was retrieved that traffic got stuck on the campus area. The cause of these traffic jams were cars who entered the campus area, in order to take short cuts towards their destinations. To analyze the effects from this scenario, inbound lanes are blocked to prevent traffic from entering the network. In real life, the lanes can be blocked by police or traffic officers.

5.2.1 Strategy 2.1: Evacuation traffic

In the first sub-scenario, OD-matrix number one has been used to deploy traffic flows onto the network. The results are obtained by averaging the results of 15 different runs:

- Total Evacuation Time: **8** hours and **37** minutes
- Total Average Travel Time: **1** hour ; **41** minutes ; **30** seconds per vehicle

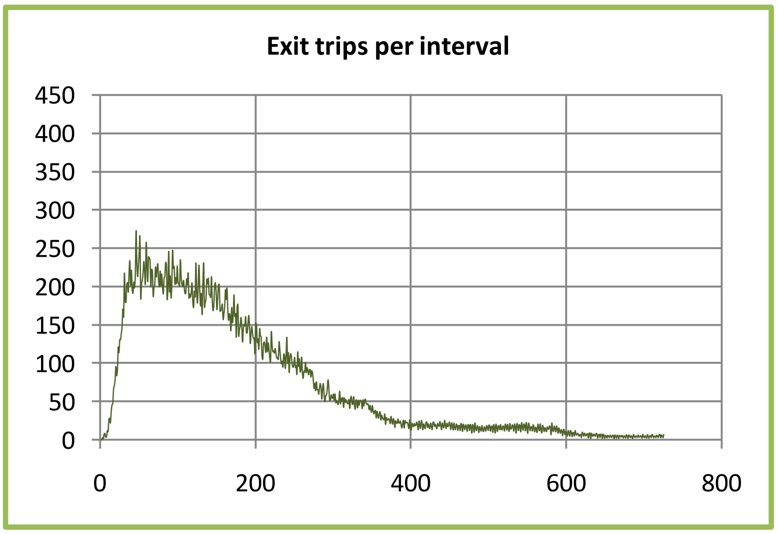


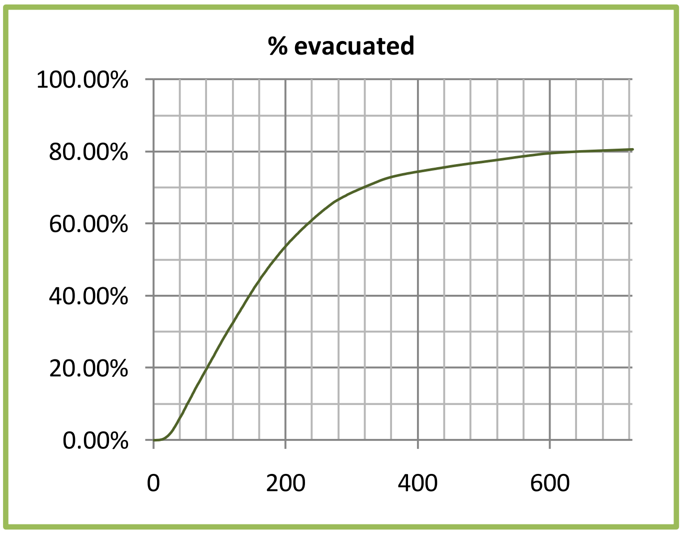


5.2.2 Strategy 2.2: Evacuation and background traffic

In the second sub-scenario, OD-matrix number one and two have been used to deploy traffic flows onto the network. The results are obtained by averaging the results of 10 different runs:

- Total vehicles evacuated: **81 percent** (51.857 out of 64.324)





Appendix 12: Results "Contraflow Campus"

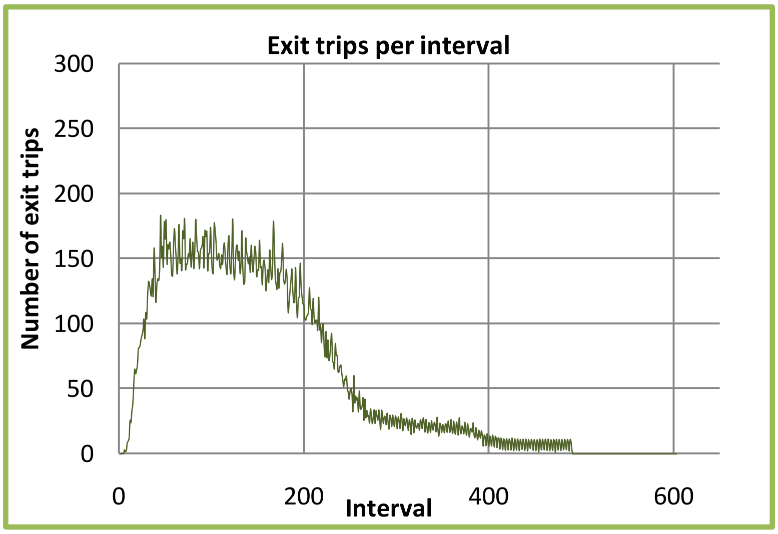
Introduction

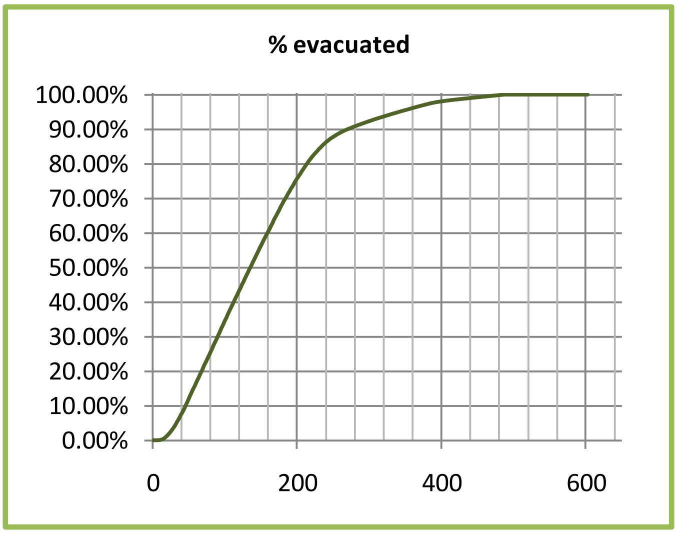
When the results of the base case were examined, it was noticed that traffic got stuck on the campus site. It is expected that with the use of contraflow, the travel time for drivers on the campus will be reduced. Therefore, the inbound links to the campus area are being transformed into outbound links. This result in a blocking of traffic like in scenario 2, but now the inbound lanes of the campus area are used for outgoing traffic. In the literature, Wolshon et al (2003) found that the capacity will increase by 70 percent. In order to model this assumption, the speed on the extra outgoing link has been reduced. It should be noticed that not all lanes could be transformed into contraflow routes. Some lanes already were one-way and other lanes are in use by buses that still needs to get to their destination on the campus site.

5.3.1 Strategy 3.1: Evacuation traffic

In the first sub-scenario, OD-matrix number one has been used to deploy traffic flows onto the network. The results are obtained by averaging the results of 15 different runs:

- Total Evacuation Time: **8** hours and **10** minutes
- Total Average Travel Time: **1** hour ; **48** minutes ; **31** seconds per vehicle

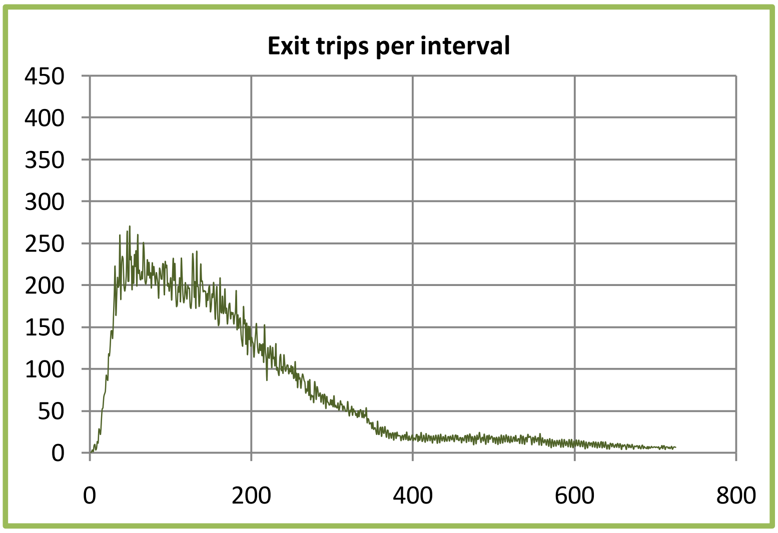


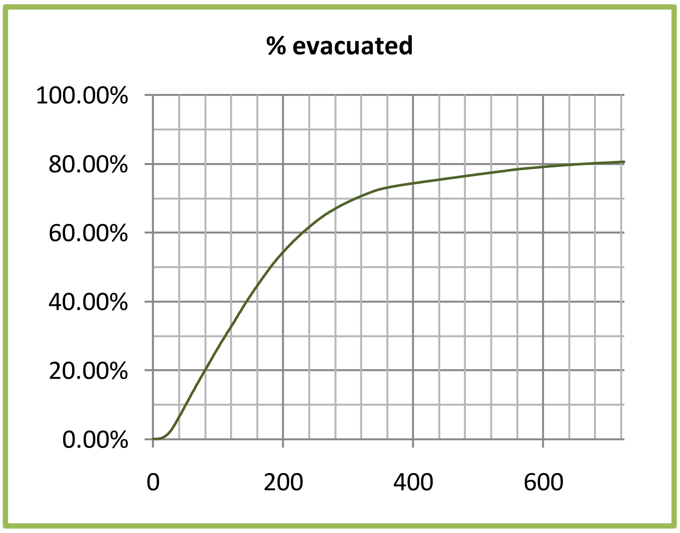


5.3.2 Strategy 3.2: Evacuation and background traffic

In the second sub-scenario, OD-matrix number one and two have been used to deploy traffic flows onto the network. The results are obtained by averaging the results of 10 different runs:

- Total vehicles evacuated: **81 percent** (51.806 out of 64.324)





Appendix 13: Results "Contraflow Campus and Gainesville"

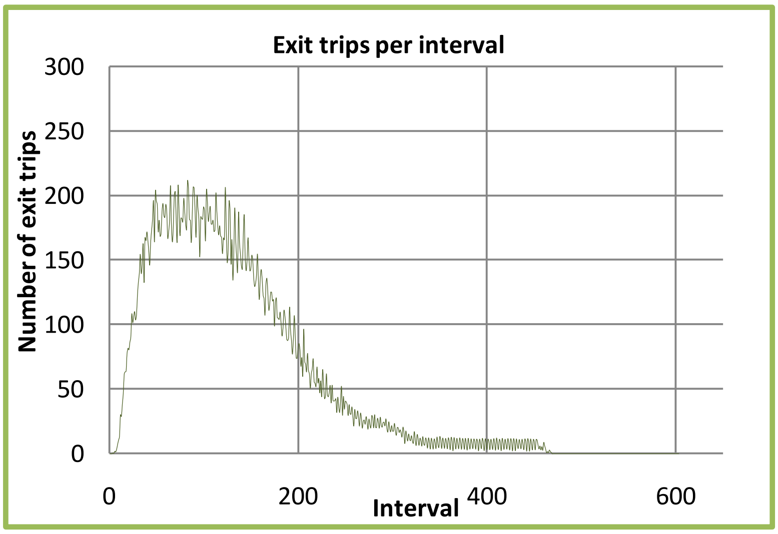
Introduction

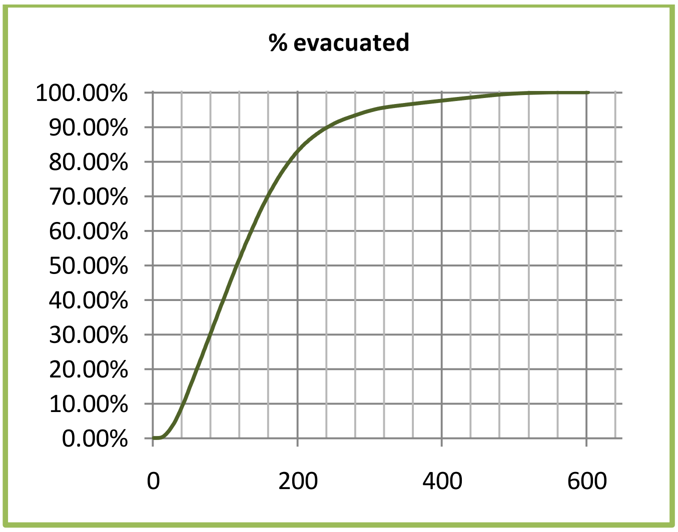
The results from scenario 3 indicate a small decrease in the total evacuation time for the network. It is expected that the use of contraflow on some of the main arteries will further decrease the total evacuation time. Scenario 4 tries to address the effects of the usage of contraflow on the campus site and within some arteries in Gainesville. In the model eleven main arteries were transformed into contraflow lanes, by increasing the number of lanes for the main outgoing flow by one and removing one lane of the contrary flow. In order to cope with the 70 percent capacity increase (*see page 16*), the speed on the added link has been decreased. The links on which contraflow has been applied can be found in appendix 6.

Strategy 4.1: Evacuation traffic

In the first sub-scenario, OD-matrix number one has been used to deploy traffic flows onto the network. The results are obtained by averaging the results of 15 different runs:

- Total Evacuation Time: **7** hours and **49** minutes
- Total Average Travel Time: **1** hour ; **35** minutes ; **02** seconds per vehicle

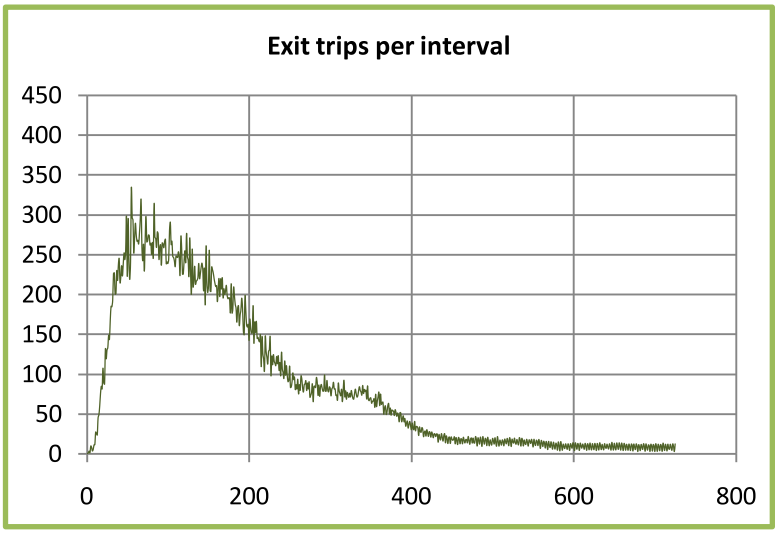


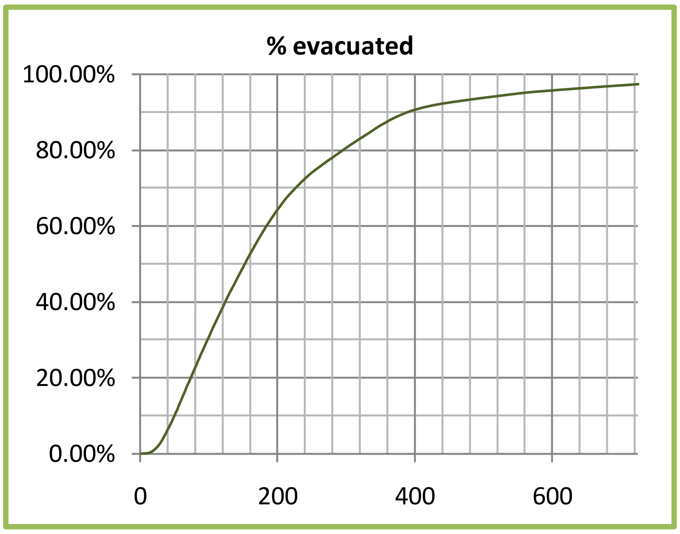


Strategy 4.2: Evacuation and background traffic

In the second sub-scenario, OD-matrix number one and two have been used to deploy traffic flows onto the network. The results are obtained by averaging the results of 10 different runs:

- Total vehicles evacuated: **97 percent** (62.679 out of 64.324)





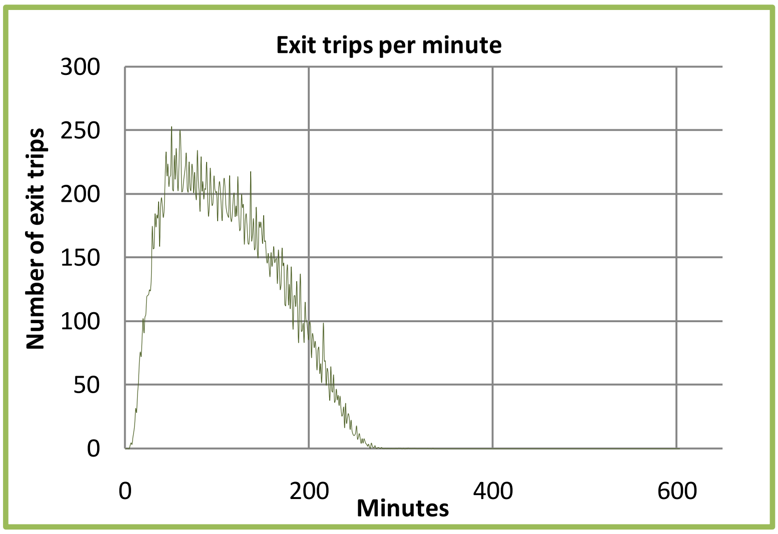
Appendix 14: Results "Increasing Green Time Ramps"

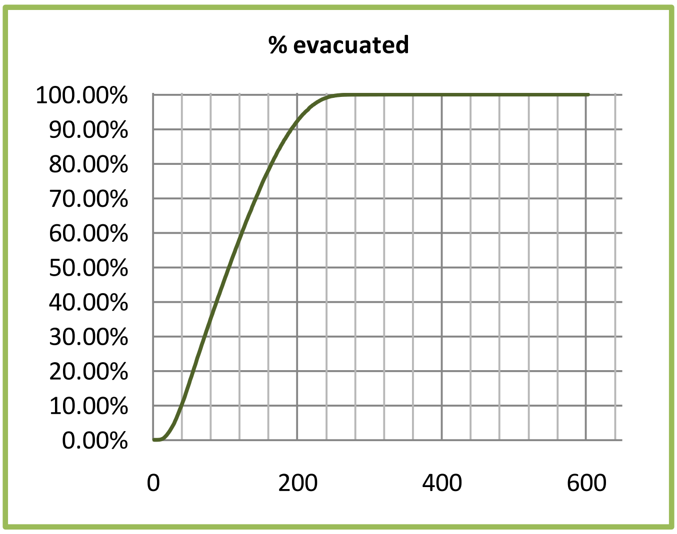
It is observed that the contraflow lanes will increase the capacity of the outgoing links. The reduction in evacuation time is relatively small. When the simulation file was further analyzed, it was discovered that a lot of traffic got stuck at the intersections that control the access to the I-75. Therefore it is decided to test a scenario were the signal controls towards these ramps gain more green time than in the base case. All other signal controls have been set at their normal scheme.

Scenario 5.1: Evacuation traffic

In the first sub-scenario, OD-matrix number one has been used to deploy traffic flows onto the network. The results are obtained by averaging the results of 15 different runs:

- Total Evacuation Time: **5** hours and **35** minutes
- Total Average Travel Time: **1** hour ; **03** minutes ; **56** seconds per vehicle

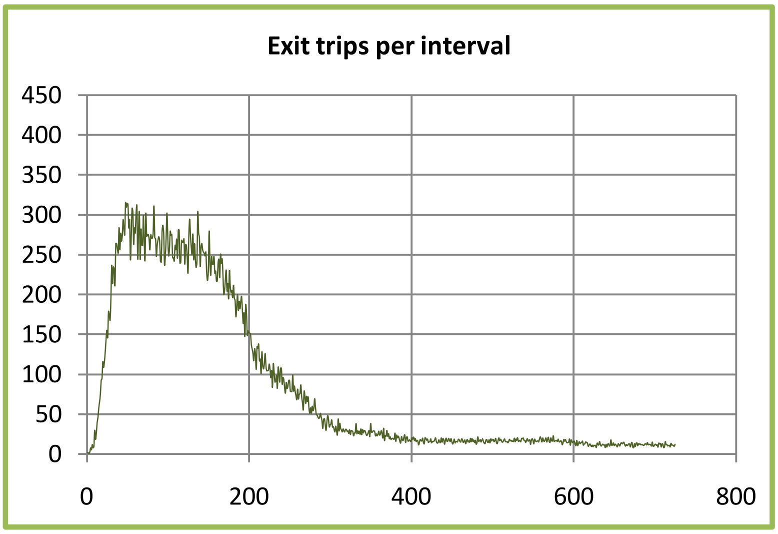


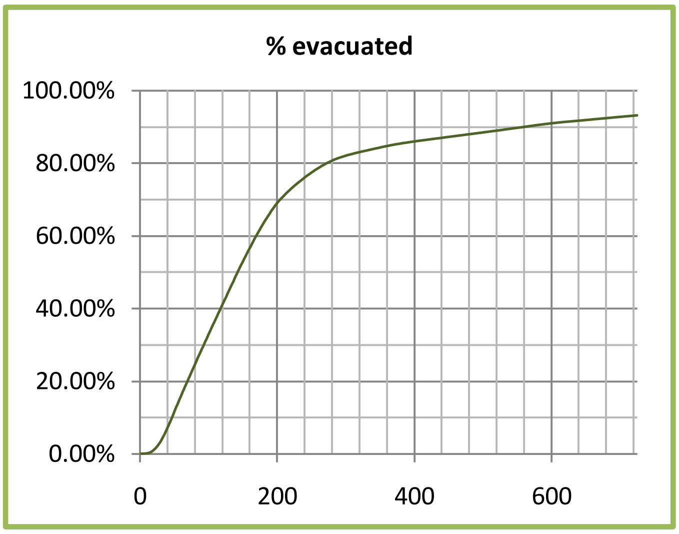


Strategy 5.2: Evacuation and background traffic

In the second sub-scenario, OD-matrix number one and two have been used to deploy traffic flows onto the network. The results are obtained by averaging the results of 10 different runs:

- Total vehicles evacuated: **93 percent** (59.927 out of 64.324)





Appendix 15: Results “Increasing green time ramps and main streets”

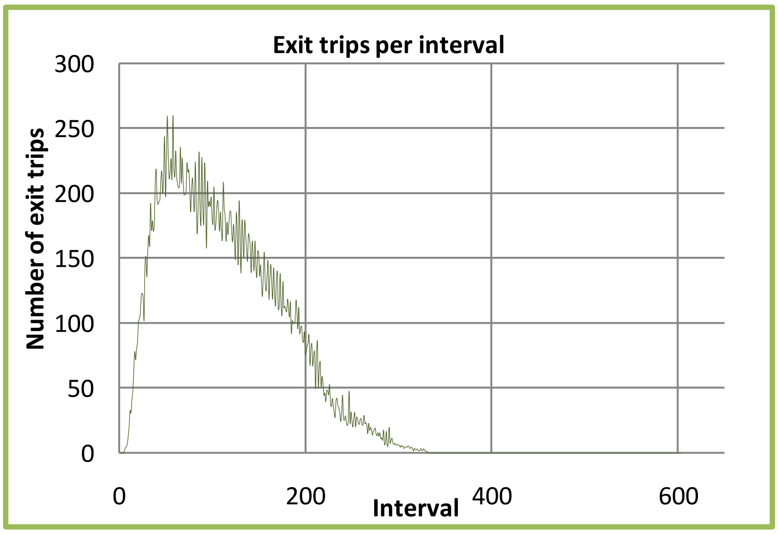
Introduction

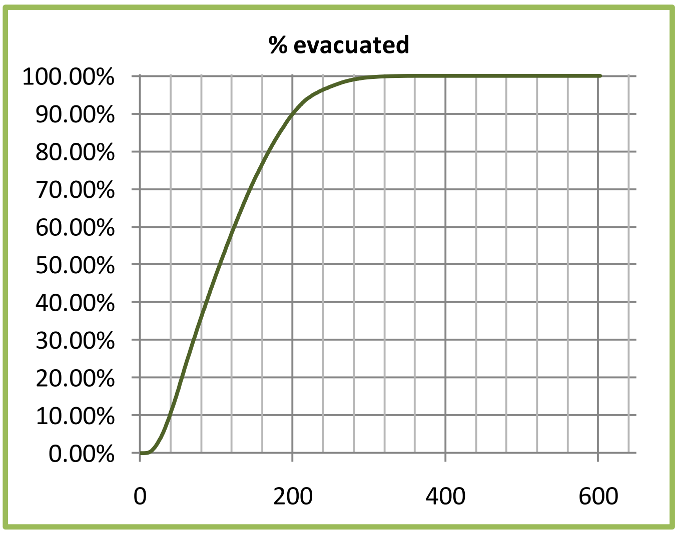
In the base case it came clear that besides at the ramp signals, also the signal controls in the main road network caused queues and thus delays. Therefore, a scenario is analyzed where the green time is increased for outgoing flows at the main streets.

Strategy 6.1: Evacuation traffic

In the first sub-scenario, OD-matrix number one has been used to deploy traffic flows onto the network. The results are obtained by averaging the results of 15 different runs:

- Total Evacuation Time: **5** hours and **32** minutes
- Total Average Travel Time: **1** hour ; **8** minutes ; **01** seconds per vehicle

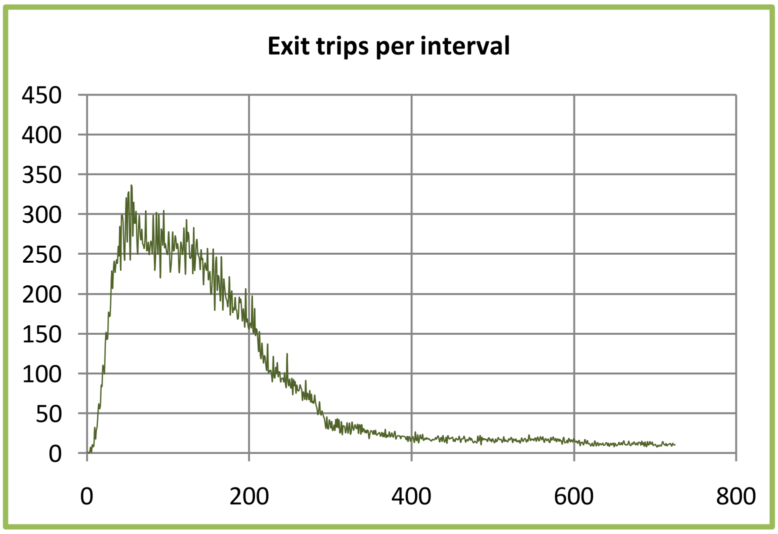


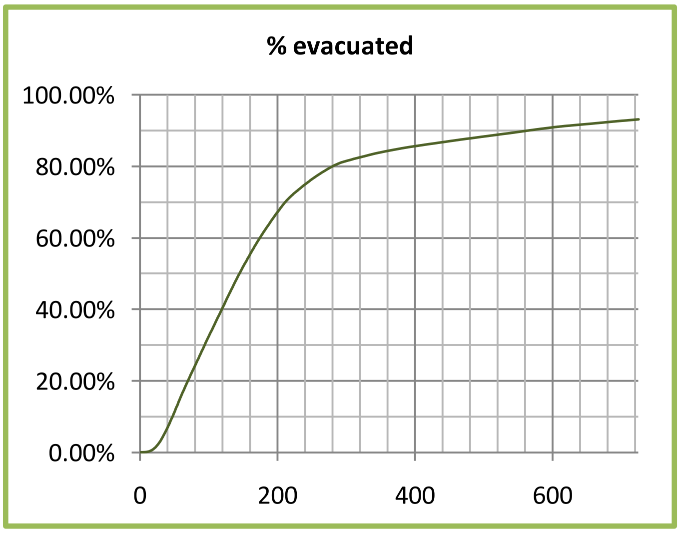


Strategy 6.2: Evacuation and background traffic

In the second sub-scenario, OD-matrix number one and two have been used to deploy traffic flows onto the network. The results are obtained by averaging the results of 10 different runs:

- Total vehicles evacuated: **93 percent** (59.943 out of 64.324)





Appendix 16: Results “Staged evacuation”

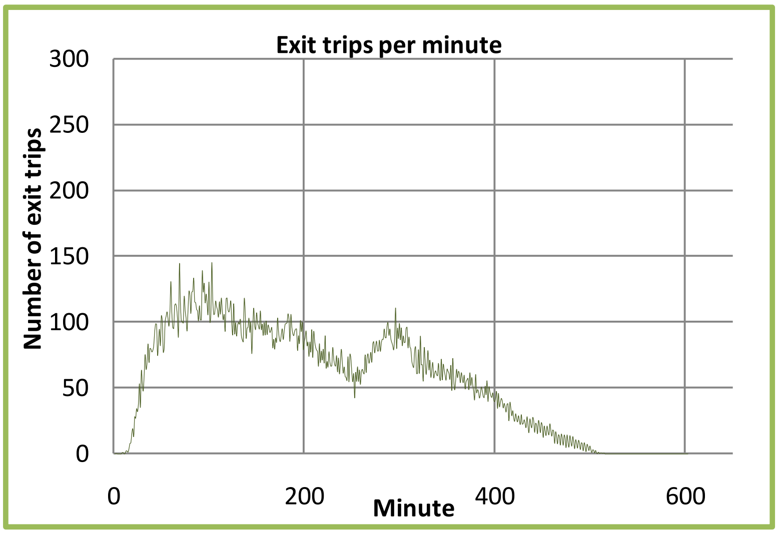
Introduction

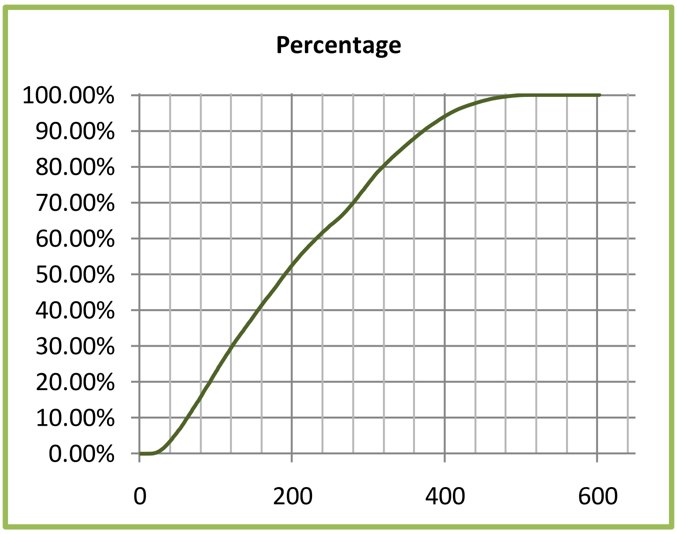
In the literature, staged evacuation is presented as an alternative strategy to reduce congestion and the evacuation time. Therefore, the effects of staged evacuation on the network are analyzed. The areas most close to the stadium will be evacuated first, since these parking lots are most vulnerable towards the threat. The evacuation of the parking lots will be executed in order of their distance towards the stadium.

Scenario 7.1: Evacuation traffic

In the first sub-scenario, OD-matrix number one has been used to deploy traffic flows onto the network. The results are obtained by averaging the results of 15 different runs:

- Total Evacuation Time: **8** hours and **35** minutes
- Total Average Travel Time: **1** hour ; **2** minutes ; **10** seconds per vehicle

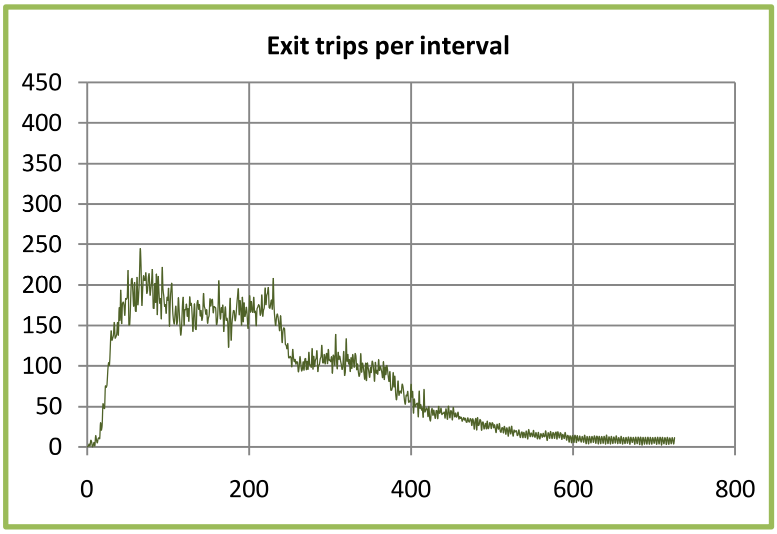


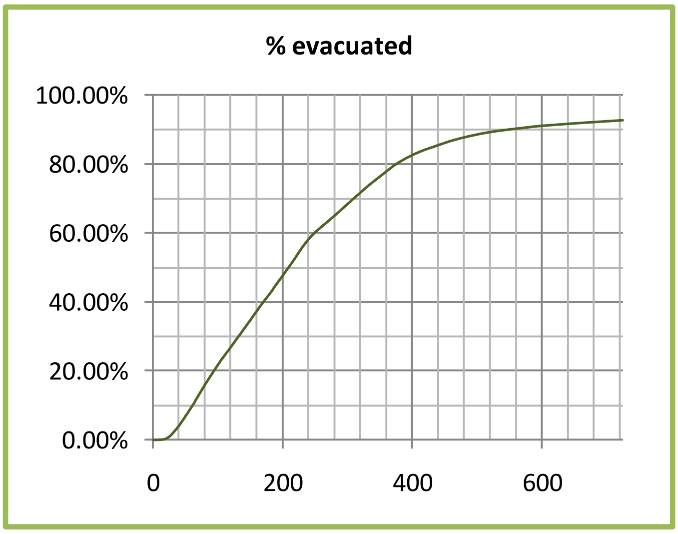


Strategy 7.2: Evacuation and background traffic

In the second sub-scenario, OD-matrix number one and two have been used to deploy traffic flows onto the network. The results are obtained by averaging the results of 10 different runs:

- Total vehicles evacuated: **92 percent** (59.665 out of 64.324)





Appendix 17: Results "No control"

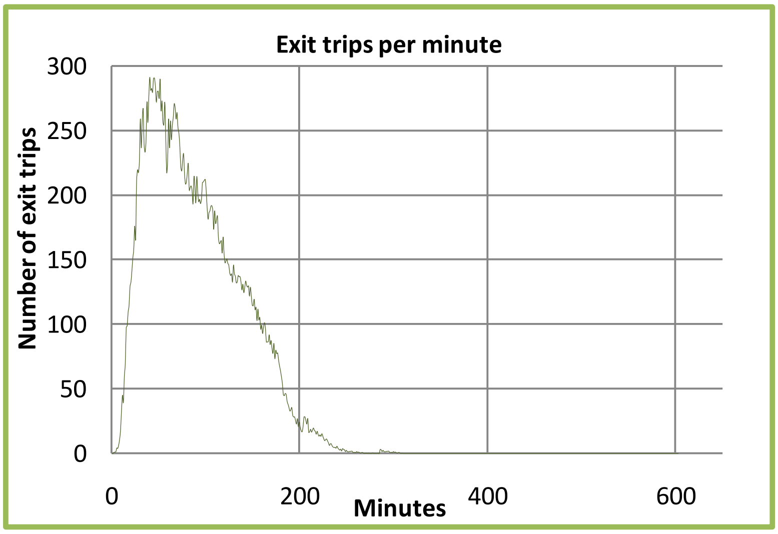
Introduction

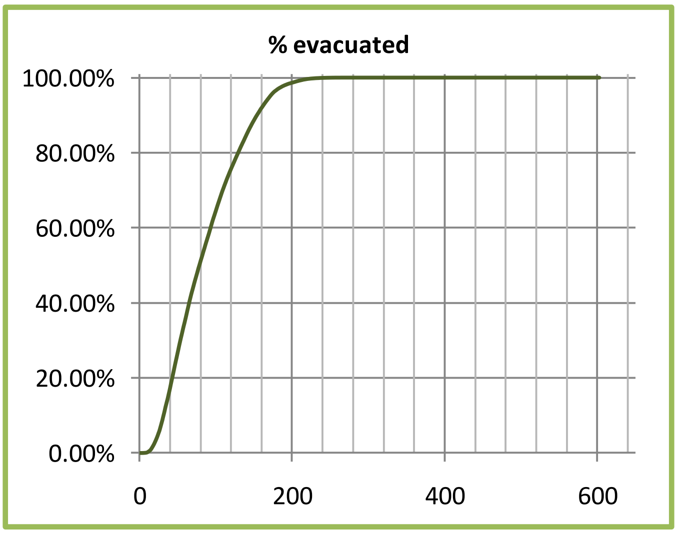
When testing the model, it was observed that without any form of control the traffic acts in a more natural way. To see what the results of just this 'natural' behavior will be, a scenario is analyzed without any control measures in the network.

Strategy 8.1: Evacuation traffic

In the first sub-scenario, OD-matrix number one has been used to deploy traffic flows onto the network. The results are obtained by averaging the results of 15 different runs:

- Total Evacuation Time: **5** hours and **11** minutes
- Total Average Travel Time: **0** hours ; **50** minutes ; **27** seconds per vehicle

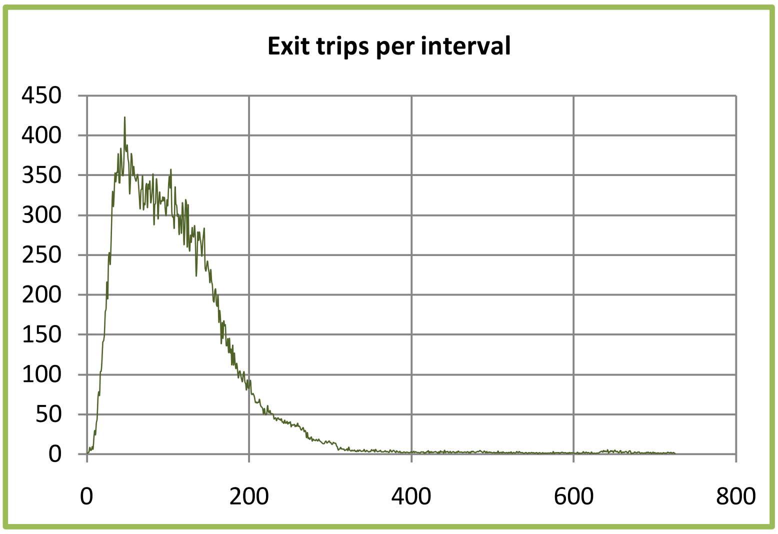


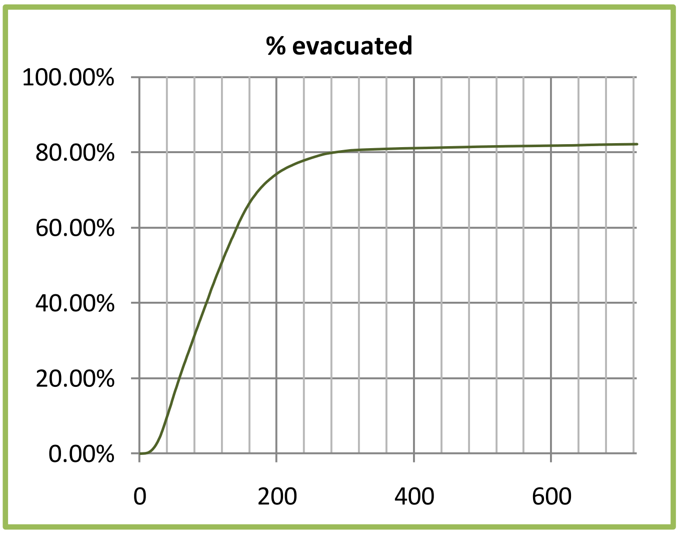


Strategy 8.2: Evacuation and background traffic

In the second sub-scenario, OD-matrix number one and two have been used to deploy traffic flows onto the network. The results are obtained by averaging the results of 10 different runs:

- Total vehicles evacuated: **96 percent** (61.865 out of 64.324)





Appendix 18: Captures from the network in Corsim

These are screenshots taken from the modeled network in Corsim.

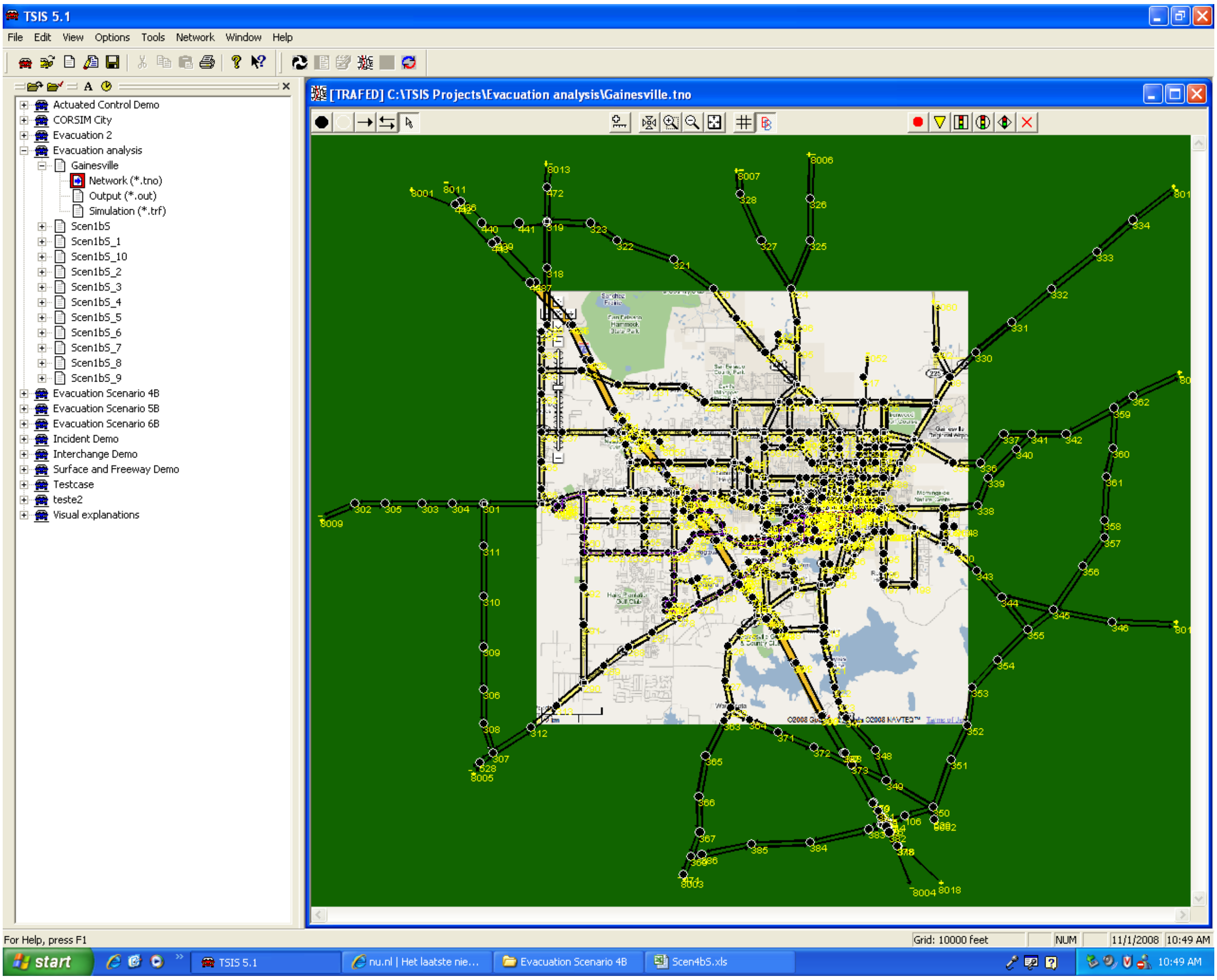


Figure 35: Interface of Corsim including the modeled network

The figure above presents what the model interface of Corsim looks like. The network is modeled with the use of a bitmap background. This makes it easier to model the Gainesville network, on scale, into Corsim. The first step included just a detailed picture of the campus area. After this was modeled into Corsim, a second picture was used to model the direct vicinity of the area. The third picture that has been used is the picture as can be seen in the figure above. Although it is important to implement the background at the right position and with the right scale into Corsim, it simplifies the modeling of the road network.

Modeled network details	
Number of modeled nodes	529
Modeled signal control schemes	*106*
Number of exit and entry nodes	59
Number of links	1249
Represented street miles	*665.5*

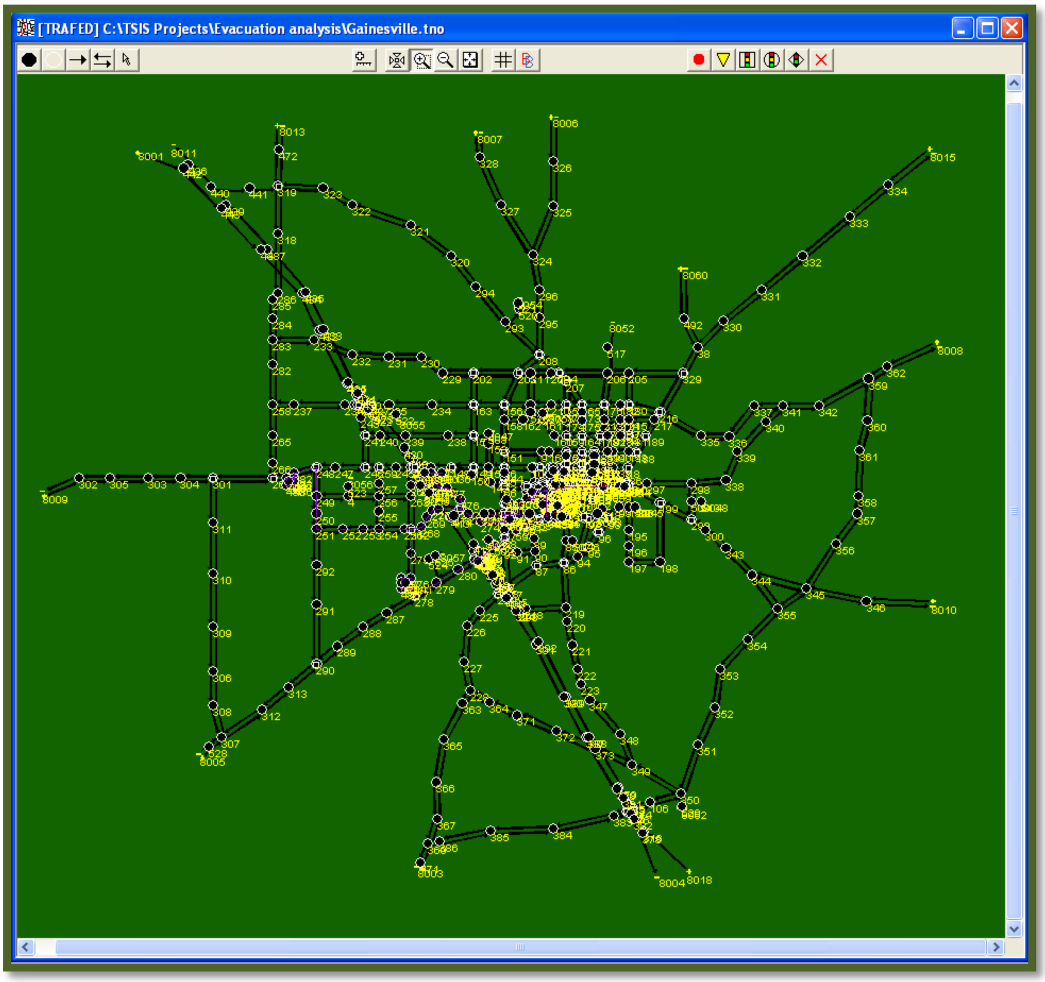


Figure 36: Screenshot of the modeled network without background

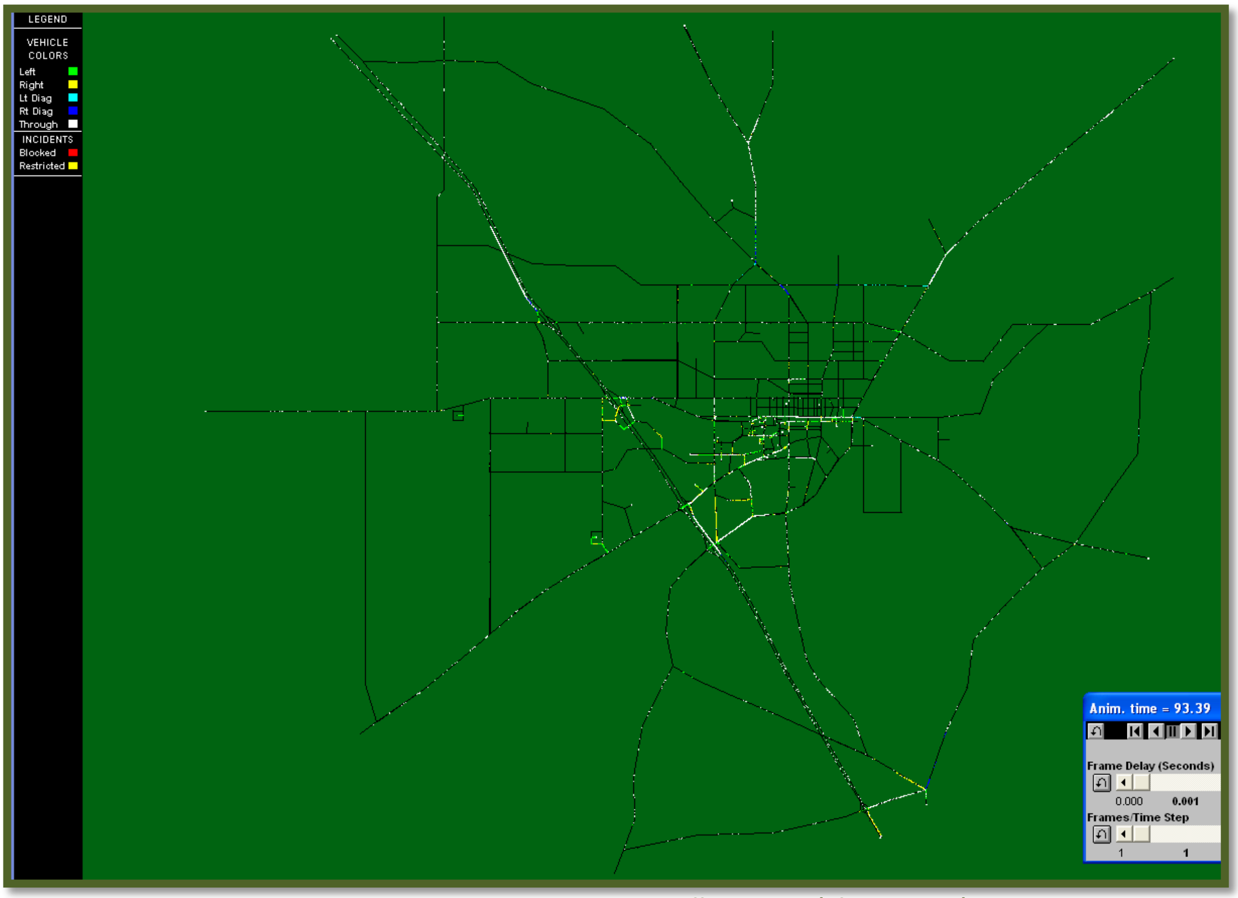


Figure 37: The base network loaded with traffic in case 2 (after 1.5 hour)

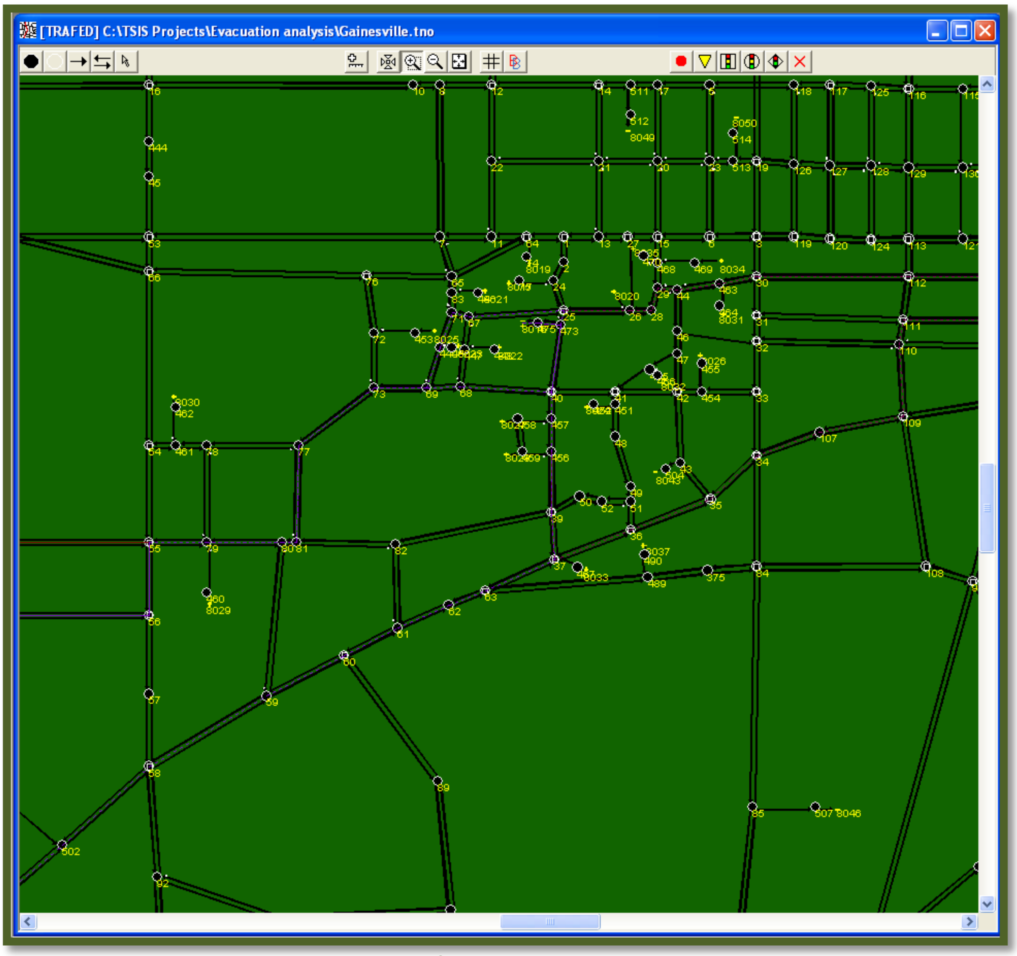


Figure 38: Screenshot of the detailed modeled campus area

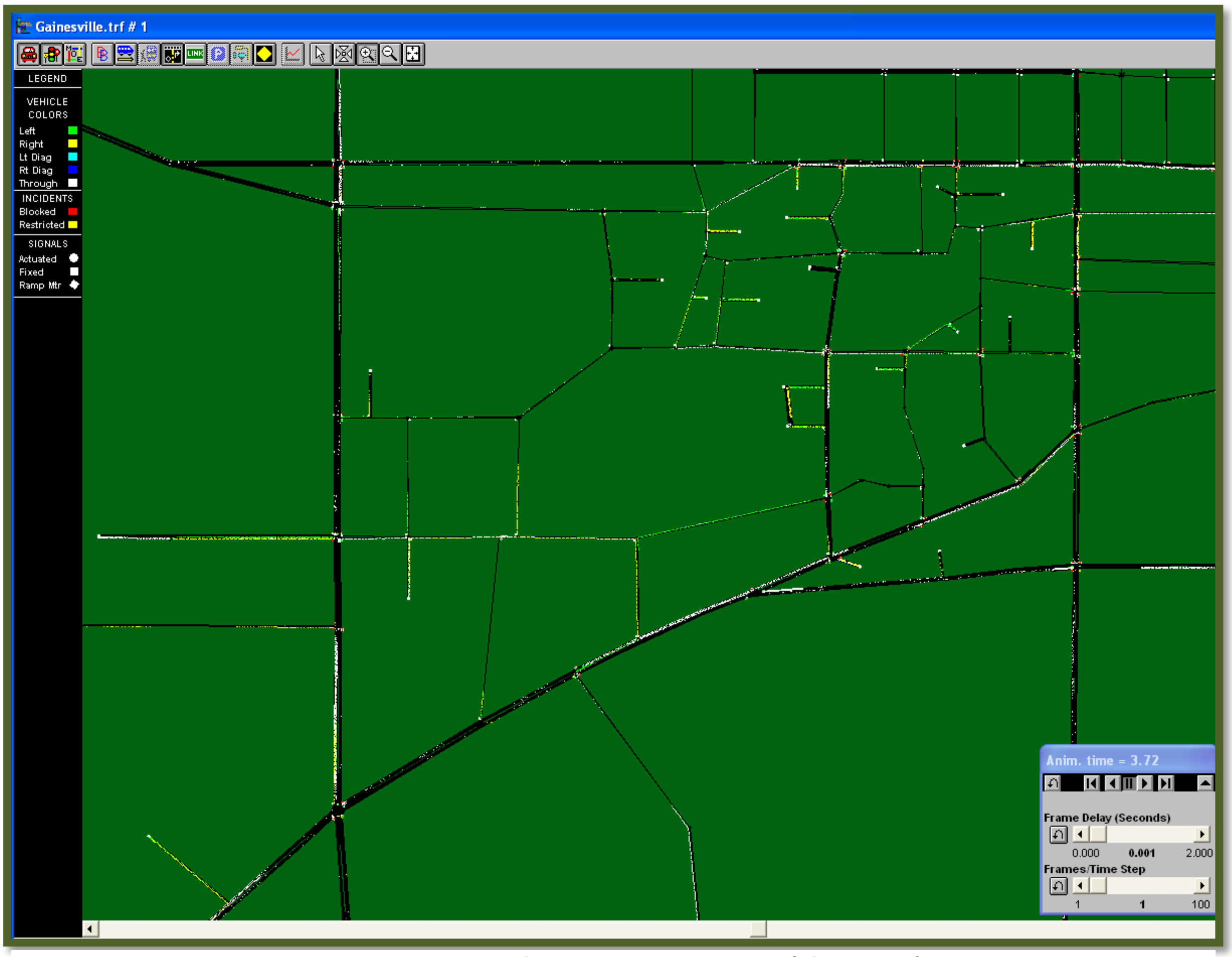


Figure 39: Screenshot of campus area in base case (after 1 hour)

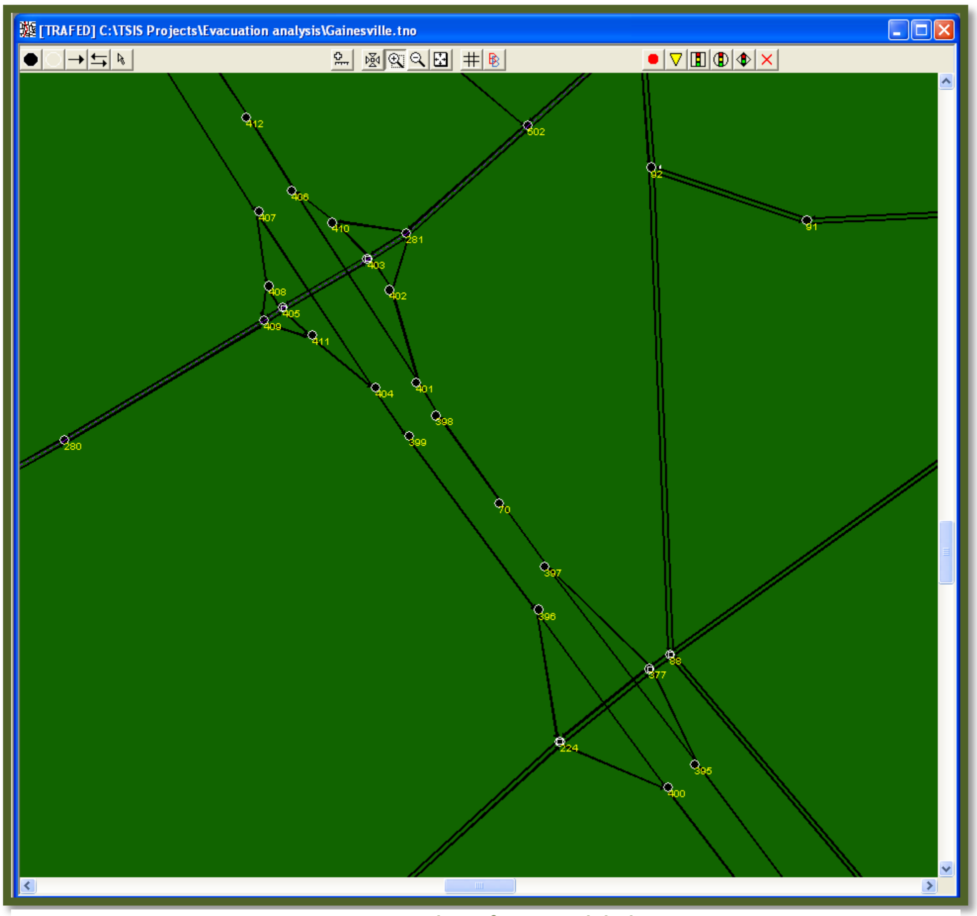


Figure 40: Screenshot of two modeled ramps

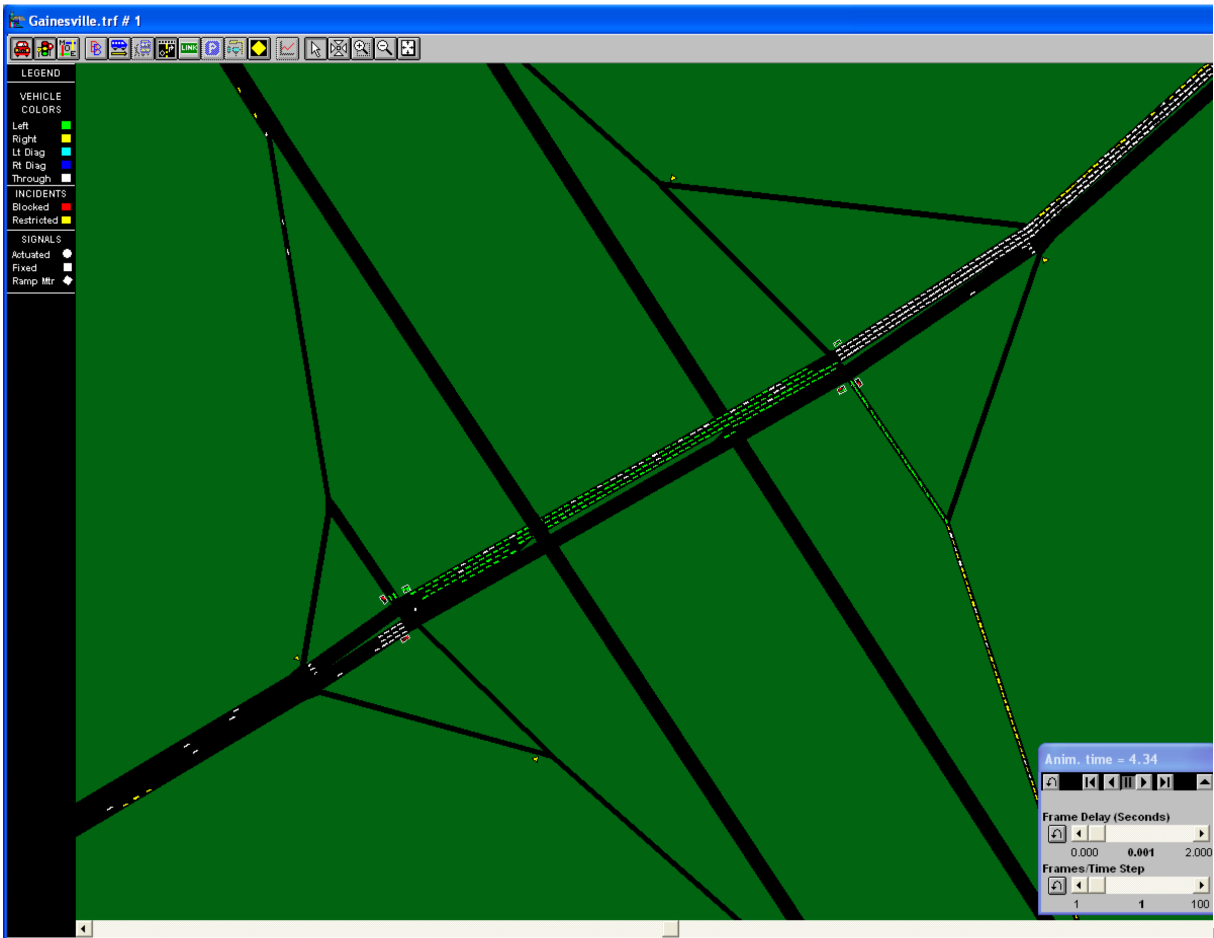
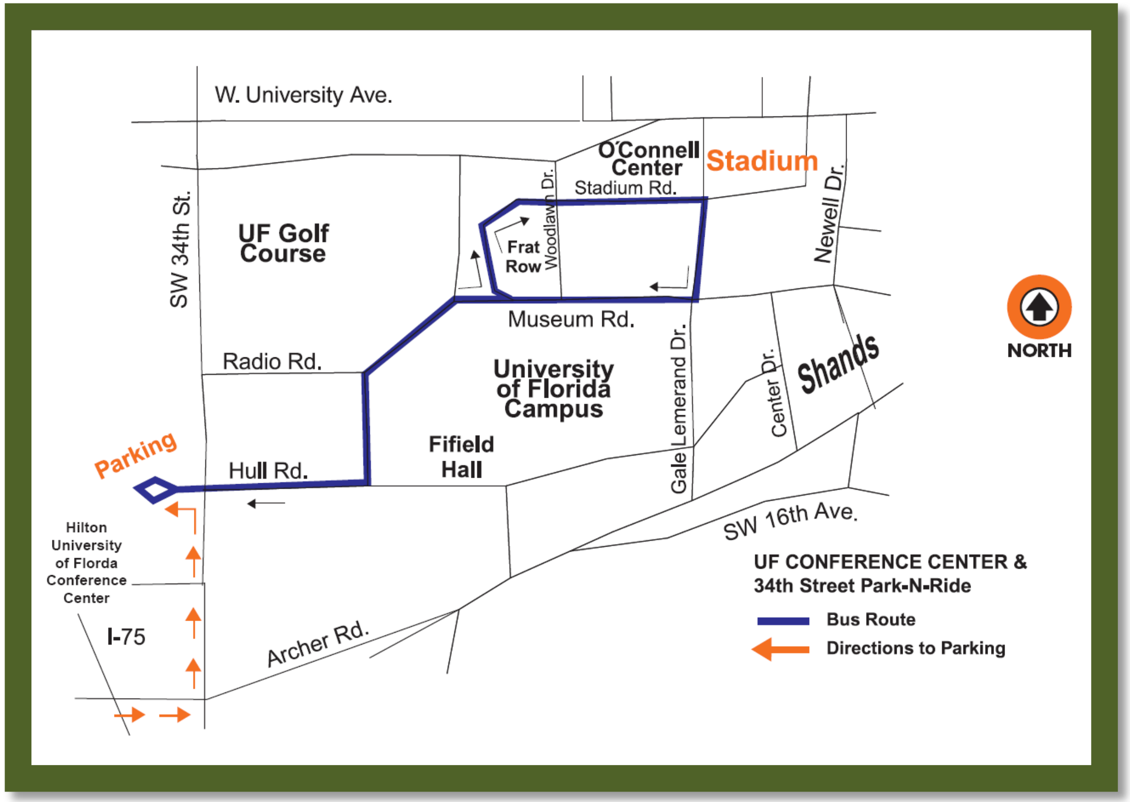


Figure 41: Heavy congestion at one intersection with ramp access

Appendix 19: Detailed information modeled bus routes

Line 1



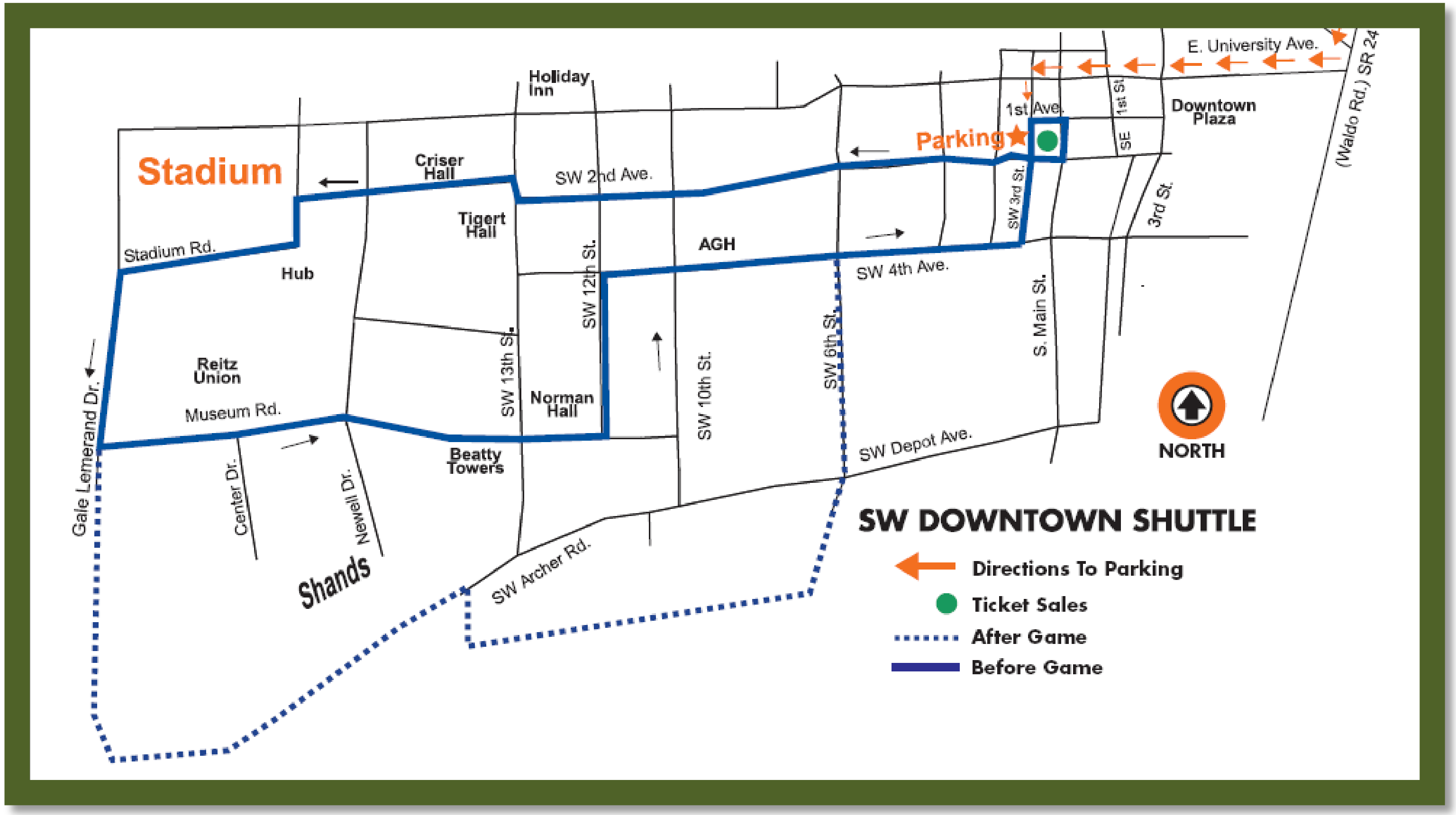
Origin: Stadium

Destination: University of Florida Conference Center

Frequency: every 10 minutes

Nodes: 8016-475-473--40-68-69-73-77-81-80-79-55-445-55-79-80-81-77-73-69-449-71-67-25-473-475-8016

Line 2



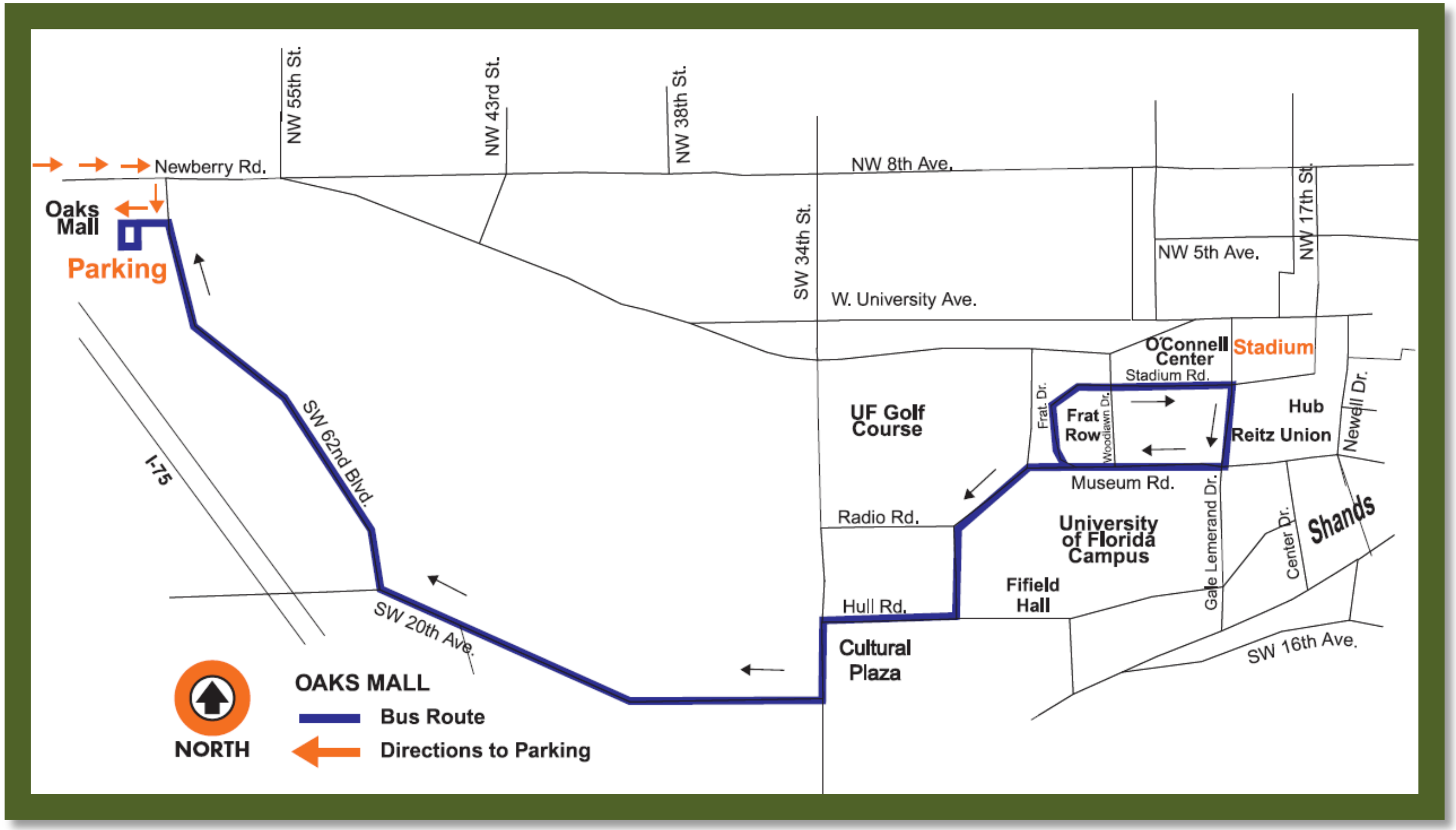
Origin: Stadium

Destination: Downtown Station

Frequency: every 10 minutes

Nodes: 8016-475-473-40-457-456-39-37-36-35-34-107-109-110-111-104-103-497-493-495-496-497-103-112-30-463-44-29-28-26-25-473-475-8016

Line 3



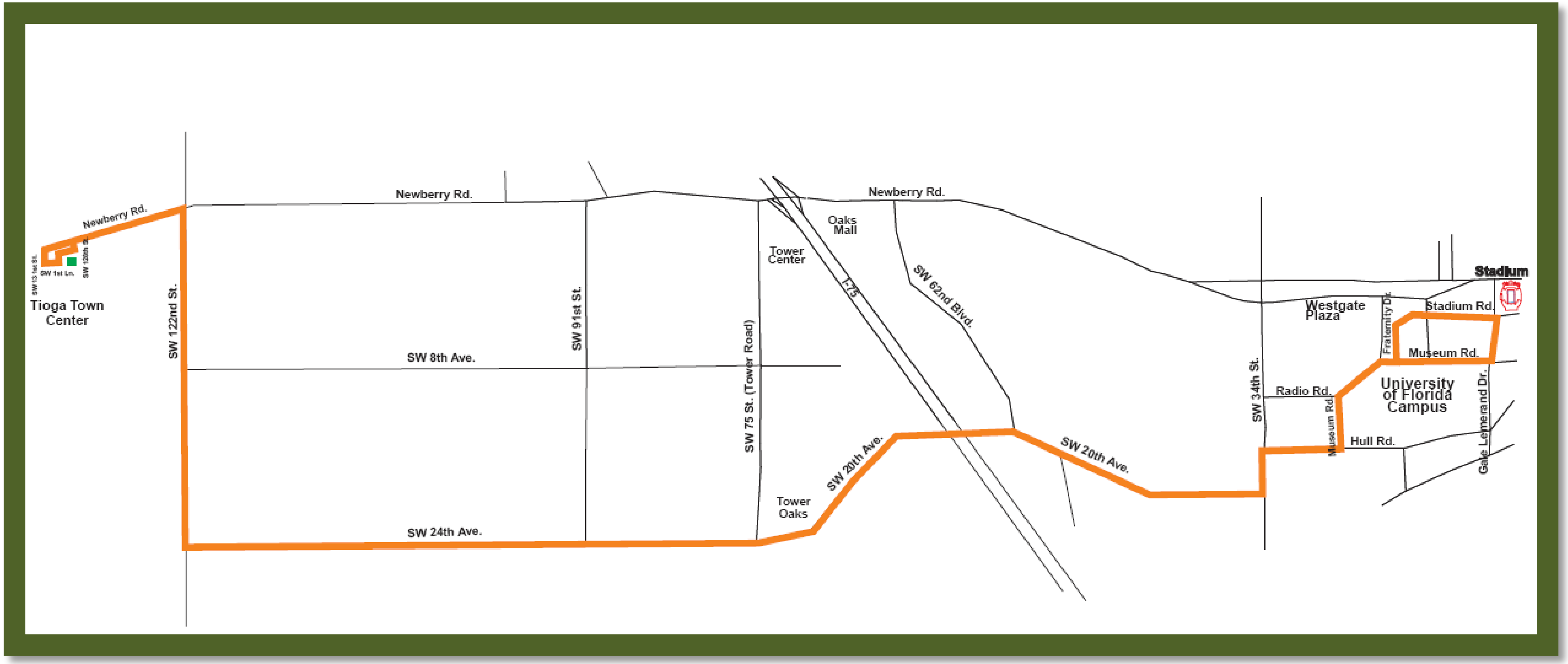
Origin: Stadium

Destination: Oaks Mall

Frequency: every 5 minutes

Nodes: 8016-475-473-40-68-69-73-77-81-80-79-55-56-274-273-272-476-477-478-480-481-480-478-477-476-272-273-274-56-55-79-80-81-77-73-69-449-71-67-25-473-475-8016

Line 4



Origin: Stadium

Destination: Tioga Town Center

Frequency: every 20 minutes

Nodes: 8016-475-473-40-68-69-73-77-81-80-79-55-56-274-273-272-271-270-269-268-262-261-254-253-252-251-250-249-248-482-483-484-485-486-498-483-482-248-249-250-251-252-253-254-261-262-268-269-270-271-272-273-274-56-55-79-80-81-77-73-69-449-71-67-25-473-475-8016

Line 5

Origin: Stadium

Destination: Haile Planatation

Frequency: every 20 minutes

Nodes: 8016-475-473-40-68-69-73-77-81-80-79-55-56-274-273-272-271-270-269-268-262-275-276-487-500-488-277-278-279-280-409-405-403-281-502-58-59-60-61-62-63-37-39-456-457-40-473-475-8016