

A NO-NOTICE EVACUATION PLAN FOR THE UW-MADISON CAMPUS:  
Developing a Plan to Evacuate a University Campus using Microscopic Simulation and Traffic  
Demand Modeling

Hannah R. Silber

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## ABSTRACT

In the past twenty years the United States population has grown from just under 267 million to an appalling 320 million residents, a growth trend that is only expected to continue. The United States Census Bureau estimates that the country has a net gain of one person every fourteen seconds. At this startling rate of population increase the threat of a widespread evacuation caused by a manmade disaster looms, an even more daunting task than ever before. Unfortunately the University of Wisconsin-Madison is already too familiar with the regrettable existence of a manmade disaster. In 1970, UW-Madison's Sterling Hall was attacked using a bomb planted in a van parked outside of the building. UW-Madison covers 936 acres in the city of Madison, Wisconsin and is home to over 43,000 students and over 21,000 faculty and staff. Currently, the university does not set guidelines or procedures for a no-notice evacuation. This statement is in no way meant to be a criticism, as most disasters necessitating an evacuation are highly unlikely to occur in Madison, Wisconsin such as a hurricane, wildfire, or massive flood.

Considering these facts, one scenario on the UW-Madison campus that would require a no-notice evacuation if it occurred, is an imminent explosion such as the act of terrorism that took place at Sterling Hall in 1970. This study aims to find the best practice in a worst-case scenario in order to create an evacuation plan for UW-Madison's campus area using three main methodologies: logistics analysis, a microscopic traffic simulation using VISSIM, and a traffic demand model. The VISSIM simulation will provide a descriptive simulation of the evacuation movements that will help identify major points of congestion in the network. Clearance times out of the evacuation perimeter will be evaluated utilizing different routes and optimal routes and volumes will be determined. The traffic demand model will provide an analysis of traffic generation, trip departure times, destination selection, and route assignment. These steps will create a model that will allow the completion of the final step of generating a specific plan, analyzing this plan, and making any necessary revisions.

Through this analysis, major points of congestion and optimal routes will be identified in order to develop an evacuation plan for the UW-Madison campus. A detailed logistics analysis will be conducted considering class times, class enrollments, daytime populations of campus building and facilities, the percentage of personal vehicles available for use, alternative modes of transportation available for use, acceptable shelter locations and their capacities, and optimal routes among other factors. Additionally, some best practices will be suggested regarding communications, technical support, and resources to be included in an emergency management plan.

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## 1 INTRODUCTION

In the past twenty years the United States population has grown from just under 267 million to an astonishing 320 million residents. This growth trend is only expected to increase as time goes on (1). The United States Census Bureau estimates that the country has a net gain of one person every fourteen seconds. At this startling rate of population increase the threat of a widespread evacuation caused by a manmade disaster looms, an even more daunting task than ever before. After the events of September 11<sup>th</sup>, 2001 it became clear how challenging a no-notice mass evacuation of such a densely populated urban area is. This already trying task was made all the more difficult by the violent implications of the attack as well as resident panic and disorder. Having a thorough and intuitive understanding of the area being evacuated is vital in this scenario in order to safely and efficiently move all residents out of the perimeter and to safety. In addition to the rising populations, the prevalence of disasters has also seen an overall increase since 1960 (27).

Unfortunately the University of Wisconsin's Madison campus is already too familiar with this type of manmade crisis. In the early fall of 1970, four men bombed UW-Madison's Sterling Hall, which at that point in time housed the University's physics department and the Army Mathematics Research Center. At the time this was the worst incident of domestic terrorism recorded (3). A memo put out by the Federal Bureau of Investigation (FBI) warned of the possibility of the attack triggering similar incidents in the future, which begs the question, what if it happened today? Having a set of guidelines and best practices in place is a necessity for any emergency management operation to run as smoothly as possible during a disaster.

Madison, Wisconsin is the capital city of the state of Wisconsin and has an estimated population of 243,344 people and an estimated population density of 3,037 people/square mile according to the United States Census Bureau (1). The city covers just over 94 square miles, 17 of which are water. Within Wisconsin, the University of Wisconsin system contains 13 4-year universities that are spread throughout the state. The original land-grant university of the system is the University of Wisconsin-Madison located in the state's capital city (25).

The University of Wisconsin-Madison was founded in 1848 and the first class was held on February 5th, 1849 (25). The location of the UW-Madison campus provides some unique evacuation challenges that most residents experience daily during their commutes to or through the campus area. One such barrier is the isthmus, a narrow piece of land between Lake Mendota and Lake Monona that connects Madison's northeast and south central sides. The isthmus acts as a distinctive terrain barrier during the city's normal peak hour traffic and would provide complications during an evacuation. Figure 1 below shows the city limits of Madison outlined in red. The isthmus can be seen in the center of the map and the campus is located near the area labeled as Shorewood Hills.



Figure 1: Map of Madison, Wisconsin

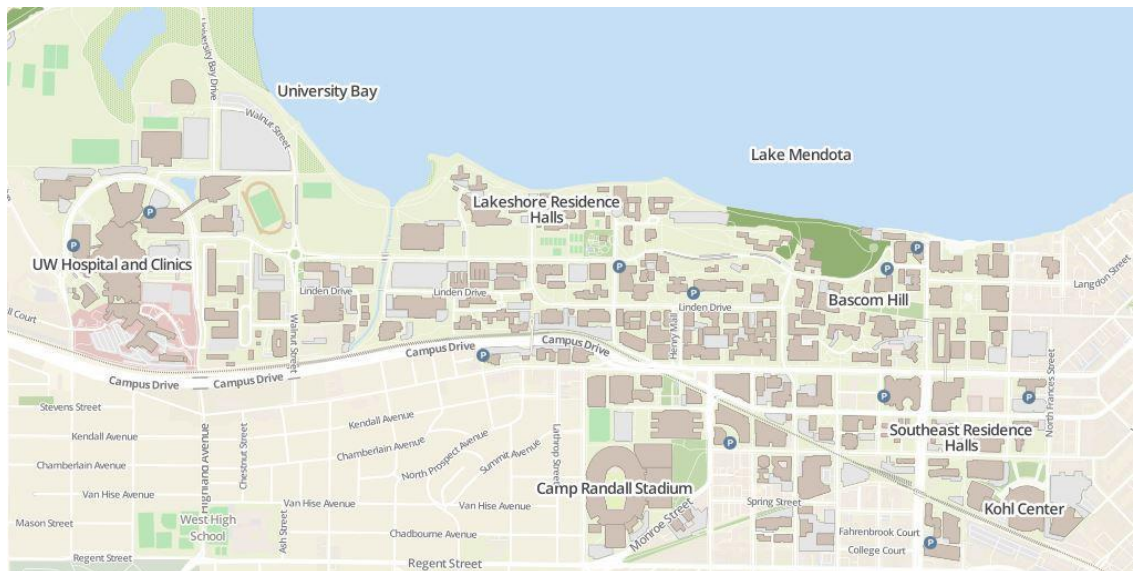


Figure 2: University of Wisconsin-Madison Campus

UW-Madison's extensive campus covers a total of 936 acres. On its western most boundaries, the medical science buildings and the hospital are located in the University Bay neighborhood. On its easternmost boundaries the Southeast Residence Halls and the Memorial Library meet State Street. Many students live off-campus in houses between the eastern campus and the Capitol Square as well as in apartments and houses around south campus near Camp Randall Stadium. In the fall of 2014 over 30,000 students applied to attend the university and the

enrollment for the fall of 2014 was reported as a total of 43,193 students including 29,302 undergraduate students, 9,445 graduate students, 1,987 special students, and 2,459 professional students (25).

The UW-Madison campus contains two main unidirectional roads that run through it. Campus Drive, which becomes West Johnson Street after crossing North Randall Avenue, is an eastbound route toward the Capitol and the isthmus. West Gorham Street, which becomes University Avenue after crossing North Bassett Street, is a westbound route toward the UW Hospital and Madison's west side. As is true for many universities, few UW-Madison students have cars, especially those living in university residence halls as the school prohibits cars on campus. A U.S. News & World Report article on UW-Madison reported that using 2013 data, 75% of students live off campus while 25% live on campus. Of those 25% living on campus, 0% is reported as having cars on campus (8). This distribution considers only undergraduate students. The lack of personal vehicles can both aid and hinder in an evacuation. On one hand, the fewer vehicles on a given route, the less congestion, however, without the use of personal vehicles the problem of evacuating all of the students without access to transportation still exists.

Another factor that adds to the complexity of evacuating a campus community is that upon notice of an evacuation, many people in the community will require directions and assistance to evacuate. In contrast, in a city-wide or mega region evacuation each individual household is considered responsible for their own evacuation movements. While certain routes may be established by emergency management planners as evacuation routes, the time, mode, and routes used for evacuation will vary depending on each household's assessment of risk and the time required for adequate preparation for an evacuation.

While Dane County provides some emergency management guidelines related to evacuation of Dane County by geographical area, it uses Census data from the year 2000 and the population estimates for the campus area does not include the thousands of students living there. Additionally, these guidelines do not solve the transportation issue for the campus population.

## **1.1 Objectives**

The objective of this study is to examine a no-notice evacuation of the UW-Madison campus in the event of a man made crisis such as an act of terrorism as occurred in August of 1970 at Sterling Hall. Currently, the UW-Madison campus is not well prepared for a no-notice evacuation. This statement is in no way meant to be a criticism, as most disasters necessitating an evacuation are highly unlikely to occur in Madison, Wisconsin such as a hurricane, wildfire, or massive flood. While the campus is vulnerable to a tornado such as the storm that destroyed multiple buildings on the University of Wisconsin-Platteville campus on June 16, 2014, this type of disaster requires sheltering in place upon notification of the incident as opposed to an evacuation. Considering these facts, a scenario on the UW-Madison campus that would require a

no-notice evacuation is an imminent explosion such as the act of terrorism that took place at Sterling Hall in 1970.

For the purpose of this study, it is assumed that a bomb will be located on the UW-Madison campus requiring an evacuation from multiple source locations to any of nine different safe spots or shelters. A traffic demand model will be created specific to UW-Madison's campus evacuation in order to ultimately assign trips. Using VISSIM, a traffic simulation will be created to determine where extreme traffic congestion occurs during the evacuation. Finally an optimal set of routes will be determined by analyzing the VISSIM simulation results for delays and travel times using various available routes. This study aims to find the best practice in a worst-case scenario in order to create an evacuation plan for UW-Madison's campus area. The plan will optimally utilize all reasonable routes to nine locations, or shelters, located to the southeast and the northeast of the campus area. Due to Lake Mendota and University Bay, the north of campus is not an acceptable placement for a safe node. Additionally, though shelters to the west of campus were examined, none supplied adequate capacities and thus were not chosen for this plan.

## **1.2 Organization**

For organization purposes, this thesis is divided into seven chapters. Chapter 1 includes an introduction, the objectives to be achieved through this project, and some basic assumptions being made. Chapter 2 contains a literature review. Chapter 3, which is broken into three main subsections, contains research methodologies regarding logistics, the traffic demand model, and the VISSIM simulation. Chapter 4 contains an analysis of the results obtained from the simulation and the demand model, particularly how the proposed methodologies in Chapter 3 affect clearance times. Chapter 5 includes a summary of findings, conclusions, and recommendations for future research. Chapter 6 contains all references used during this project and Chapter 7 is the appendix section containing any data tables too large to be included in the main body of the paper.

## **1.3 Basic Assumptions**

A more in depth discussion of these assumptions will be included later in relevant sections of the paper, but for the purposes of clarity some basic presumptions will be explained here. In order to create a plan that accommodates as many people as possible, it will be assumed that the entire campus population of students, faculty, and staff will be present during the evacuation. Estimates on how many people are located in which areas of campus during the evacuation will be made using data obtained from University of Wisconsin resources and any assumptions will be made conservatively as not to under represent the population being evacuated.

Another major assumption being made in this project is that traffic in the rest of the city will be made to clear the evacuation routes and that only UW-Madison campus vehicles involved

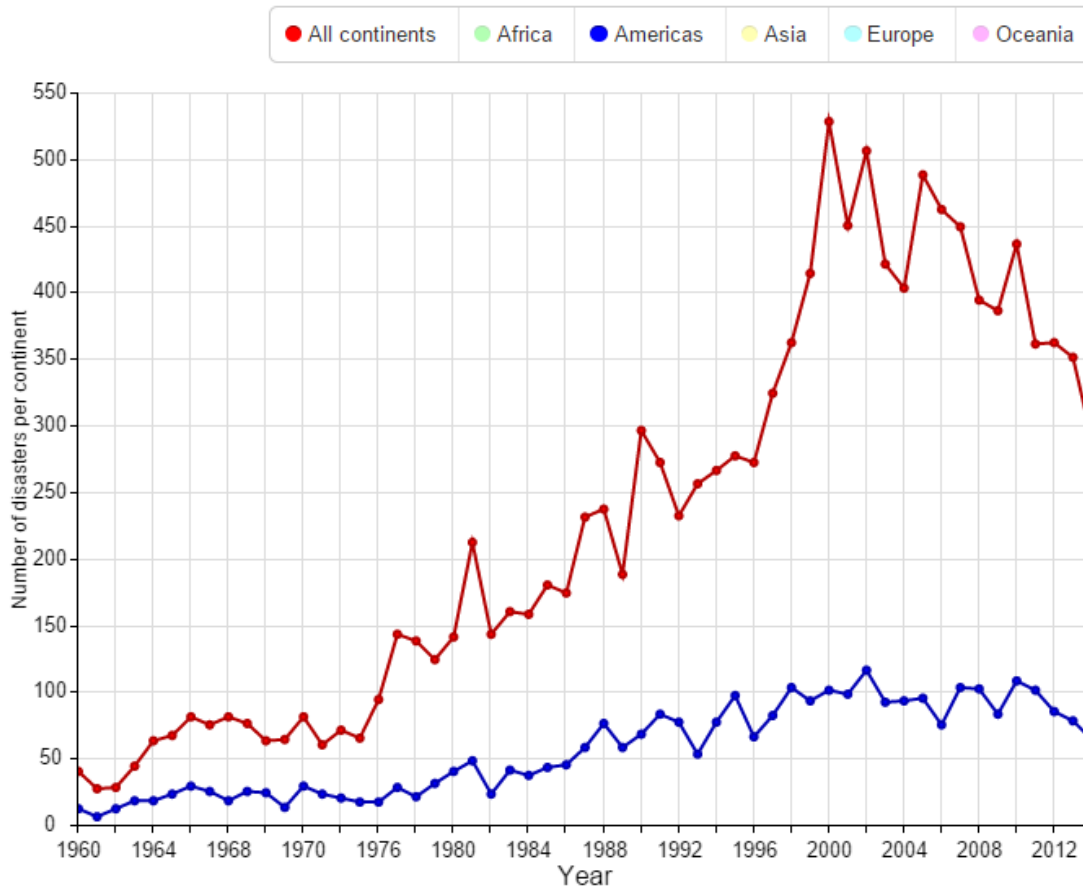
in the evacuation will be on the routes during the simulation. This will provide a clearer picture of where bottlenecks and major congestion will occur due to campus traffic alone. It is assumed that the hot zone as well as the perimeter around the routes being used will be shut down similar to during 9/11 when the entire island of Manhattan was shut down. This also helps ensure safety of Madison residents, as it will keep them out of the hot zone and out of the way of evacuation operations.

## **2 LITERATURE REVIEW**

### **2.1 Emergency Management & Evacuation Modeling**

The September 11<sup>th</sup>, 2001 attacks on the World Trade Centers brought increasing attention to evacuation modeling, particularly in the event of a man made crisis as opposed to a natural disaster. While a lot of evacuation modeling techniques focus on the event of a hurricane in susceptible regions, it is beneficial to analyze other situations. This helps when considering regions where events such as hurricanes are not likely such as in Madison, Wisconsin. In the case of New York City and 9/11, the city's Office of Emergency Management (OEM) required accurate geographical information such as terrain, neighborhood organization, population, subway and transit routes, established hurricane evacuation routes, and other roadway information (2). During a natural or manmade incident causing widespread evacuation traffic congestion is inevitable.

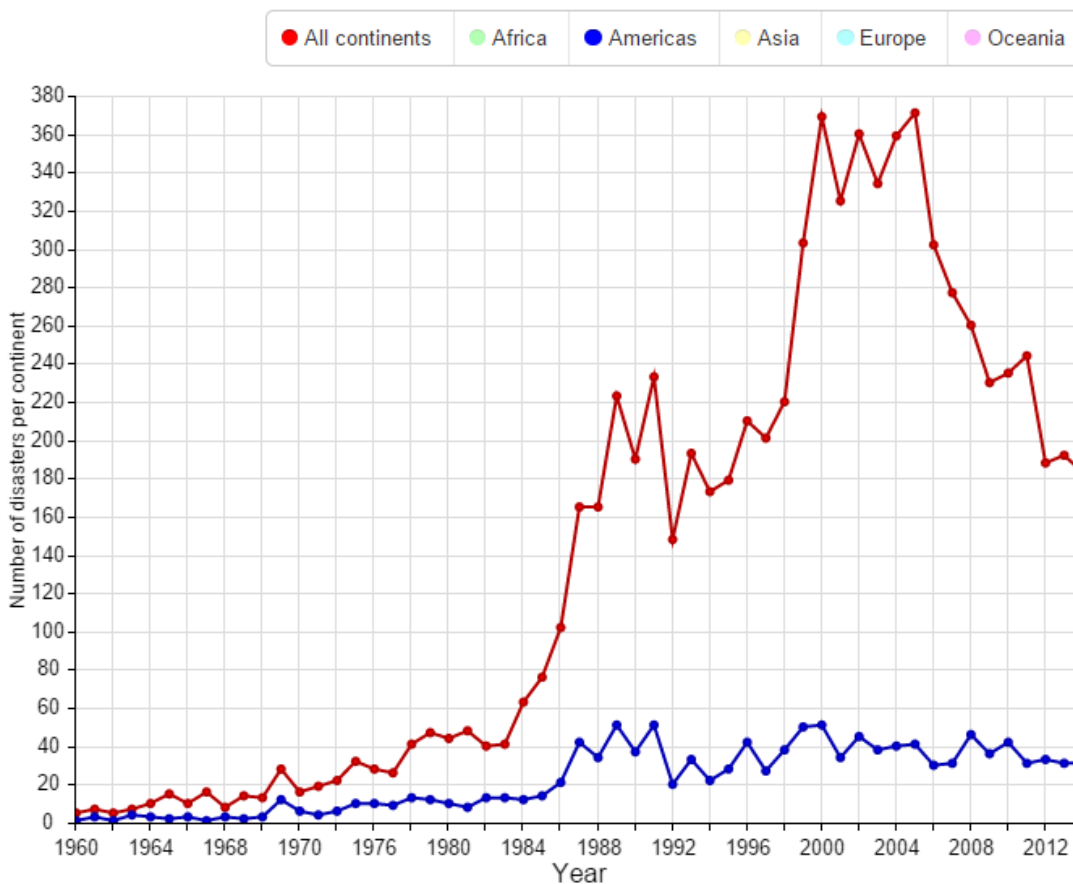
Since the year 1960, the trend in disaster occurrence both natural and technological has shown an increase as reported by the Centre for Research on the Epidemiology of Disasters International Disaster Database. The United Nations Office for Disaster Risk Reduction presented data regarding the trends of disasters per year. Here a natural disaster may include an animal accident, a drought, an earthquake, an epidemic, an extreme temperature situation, a flood, an insect infestation, a mass movement, a storm, volcanic activity, or a wildfire (27). A figure showing the total number of natural disasters from the year 1960 to the year 2014 for the Americas as compared to all continents is presented below.



EM-DAT: The OFDA/CRED International Disaster Database - [www.emdat.be](http://www.emdat.be) - Universite Catholique de Louvain, Brussels - Belgium

Figure 3: Total Number of Natural Disasters between 1960 and 2014 (27).

A technological disaster may include an industrial, transportation, or miscellaneous accident (27). A figure showing the total number of technological disasters from the year 1960 to the year 2014 for the Americas as compared to all continents is presented below.



EM-DAT: The OFDA/CRED International Disaster Database - [www.emdat.be](http://www.emdat.be) - Universite Catholique de Louvain, Brussels - Belgium

Figure 4: Total Number of Technological Disasters between 1960 and 2014 (27).

As can be seen from Figures 3 and 4 above, the overall trend in the occurrence of disasters both in the Americas and across all continents is increasing since the year 1960. Many factors contribute to this; in terms of the technological disasters, the prevalence of technology itself has dramatically increased since 1960. Despite the fact that technology may be more advanced and safer now than it was in 1960, the increase in population and the increase in the prevalence of technology both make it more likely that a technological accident may occur (27). In terms of the increasing prevalence of natural disasters, many researchers believe this trend has much to do with climate change, resource consumption, population increases, and waste byproducts (27). These trends combined with the increase in population add to the importance of proper emergency management and planning efforts so that when a disaster does occur, people can be moved to safety and large losses of life do not occur.

Focusing specifically on the University of Wisconsin-Madison, UW-Madison's campus is located in the city of Madison in Dane County, Wisconsin. Dane County has developed a multi-jurisdictional emergency management plan to assist in the orderly and coordinated evacuation of parts or the entirety of Dane County (9). While the plan is extensive, it is stated

that the plan is meant to provide guidance for responding to large-scale evacuations and therefore it mainly highlights key routes to be used and the locations and capacities of shelters. Madison's metropolitan area was divided into sixteen subdivisions in order to create the plan. Subdivisions were divided up based on multiple factors such as geographical features, Census Block Group boundaries, or major roadways (9). These subdivisions are listed below.

1. Waunakee
2. Middleton
3. North West
4. South West
5. Verona
6. Near West
7. Fitchburg
8. Campus
9. Isthmus
10. South
11. South East
12. McFarland/Stoughton
13. Near East
14. North East
15. North
16. Sun Prairie/Cottage Grove

Dane County's evacuation plan takes into account a detailed combination of land use, the demographics of the residents in the subdivisions, and any special needs facilities, which the documents classify as anywhere that houses or serves people who are unable to independently take care of themselves during an evacuation (9). As can be seen from the list above the campus area is grouped into one subdivision, however the data shown in the guidelines for the campus subdivision only contains the 2000 Census data and does not include the enrolled students living on campus. The guidelines provide some evacuation routes by functional classification for the campus area, which will be considered when choosing routes in this project. Figure 5 below shows the primary evacuation routes highlighted by Dane County in their evacuation guidelines.

<b>Primary Evacuation Routes</b>	
<b>Collectors</b>	
<b>North-South Routes</b>	
	Highland Avenue
	Breese Terrace
	N Randall Ave
	S Mills Street
	N Park Street
	N Lake Street
<b>East-West Routes</b>	
	Langdon Street
	W Dayton Street
<b>Minor Arterials</b>	
<b>North-South Routes</b>	
	Randall Avenue
	Monroe Street
<b>East-West Routes</b>	
	University Avenue
<b>Principle Arterials</b>	
<b>North-South Routes</b>	
	North Park Street
	Midvale Boulevard
<b>East-West Routes</b>	
	University Avenue/Campus Drive
	W Johnson Street

Figure 5: Primary Evacuation Routes for Campus Subdivision (9).

During a short or no-notice evacuation, a perimeter is established around the area impacted by the incident. This area can be referred to as the hot zone, namely the area that people are evacuating from (6). A hot zone can be dependent on time or time invariant depending on the nature of the incident. Floods, hurricanes, or airborne toxins are considered to have a dynamic hot zone perimeter as the perimeter may expand, decrease, or shift spatially over time (6). A hot zone perimeter may also be defined by an emergency management agency during an event, such as was true during 9/11; during the events of September 11<sup>th</sup> the hot zone was considered to be the Manhattan area in its entirety (6). When the perimeter of the hot zone is known or can be reasonably obtained, this information can then be used as input when modeling.

In a traffic simulation modeling and analysis of the Gulf Coast mega region completed by the Louisiana State University, a five-step process exists for modeling regional evacuations (5). This process, developed by Frank Southworth, involves some of the classic four-step traffic demand model features such as trip generation and route choice (5). The first step of

Southworth's process involves understanding the network routes, connectivity, signalization, and other features that will become important during an evacuation event. Next the traffic demand must be forecasted using the region's population data both spatially and temporally in an effort to predict how residents will respond during the evacuation, namely what routes they will take and when (5). This method as relates to UW-Madison's campus population will be discussed in more detail in Chapter 3.

This demand can now be assigned from various origins within the hot zone to various destinations outside of the hot zone using the routes identified in the first step. The final steps involve generating results from the evacuation and analyzing these results. Measures of performance that may be of interest include hot zone clearance time, delay, travel speeds on various links, and identification of bottleneck locations and time spent in the congestion (5). Southworth states in his 1991 study on the topic of evacuation modeling, that few things as complex as a mass evacuation ever go off as intended, which is why a plan must be developed to aid in the movement of people to safety. Without any guidelines such an involved task cannot be completed successfully and may do more harm than good, such as during the evacuation of Houston, Texas during Hurricane Rita in 2005.

Over two million Houston residents filled the evacuation routes at once after days of warnings about Hurricane Rita's arrival. Since no phasing plan was executed, all 2.5 million people entered the highways in such a short period of time as to create a 100-mile-long traffic jam that stranded many on the road without gas and without escape (13). Since remaining stranded on the highway would have meant certain death when Rita arrived, Mayor Bill White was forced to request emergency military assistance in delivering fuel to stranded drivers (13). The Mayor and Harris County Judge Robert Eckels admitted later that their evacuation plan had simply not accurately anticipated the volume of traffic and therefore did not accommodate the evacuation of everyone in such a short time period. Another failure in their plan was the inability to use inbound traffic lanes on evacuation routes as contra flow lanes outbound. While officials originally announced that these inbound lanes would be available for use, they later decided that this was not a practical option and this idea was abandoned (13). Due to its proximity in time to the Hurricane Katrina disaster, many residents in the path of Hurricane Rita were terrified that similar fates awaited them if they did not evacuate as recommended. This added to the high number of evacuees and further added to the congestion. Some drivers reported spending almost ten hours on the freeway to go ten miles before exiting and returning to their homes, afraid that they would be trapped on the roadway when the storm hit (13).

Major evacuation routes used in the Houston area are I-45 northbound toward Dallas, I-10 westbound toward San Antonio and Route 290 westbound toward Austin. These routes became further congested as residents of Galveston to Houston's southeast also attempted evacuation for Hurricane Rita (13). Drivers traveling from Galveston and neighboring areas reported spending five or more hours making the fifty-mile trip to Houston where they joined the

parking lots already forming on the routes out of Houston. One Houston resident spent twelve hours in the traffic jam without even breaching the Houston city limits.

This major failure in evacuation planning raised serious concerns among residents and officials about the city's preparedness against a terrorist attack. Residents felt that they followed all of the official evacuation orders such as securing their dwellings, leaving early, checking in on neighbors, and checking routes before heading out and that once they commenced their evacuation they were left alone without assistance (13). Residents were trapped on the highway without access to gas and without access to water. While military assistance had been requested to bring fuel to stranded evacuees a separate fleet of vans and buses driven by volunteers had to be deployed to bring water to people.

Further evidence of the disorganization of the evacuation of Houston during Hurricane Rita, was that an entire high occupancy vehicle (HOV) lane went unused during the evacuation and that no police officers were present on evacuation routes to guide evacuees or aid those whose vehicles broke down after hours of being stuck in traffic (13). The emergency management coordinator for Harris County stated that the evacuation plan they were using for Hurricane Rita accommodated between 800,000 and 1.2 million people, however the actual number of evacuees ended up being over 2.5 million. Careful planning is always a necessity, particularly in a disaster with a dynamic impact perimeter such as a hurricane where a slight shift in the path of the storm may suddenly cause additional areas to evacuate and add to existing congestion. The failure of Houston's evacuation during Hurricane Rita is a perfect example of two key engineering principles; constantly improve solutions with up to date data and always plan for the worst-case scenario.

Evacuation modeling is a vital necessity for creating plans to accommodate moving a large population with little to no notice in a situation where evacuation is the only means to ensure the populations' safety (14). A key step in the development of any evacuation plan is to project the time to clear an at-risk region (referred to in this study as a hot zone). This requires some quantitative methods for predicting how long it will take for anyone in danger to clear the hot zone and arrive at some predetermined safe point. Unfortunately, for an urban network this task means that the existence of major congestion is an insurmountable problem (14). Regardless of phasing and using a multitude of evacuation routes, congestion will still occur and can lead to dangerous levels of delay such as the events in Houston during Hurricane Rita.

For this reason, many evacuation models use simulations to provide a reasonable look at the traffic flow of evacuees to safety (14). This allows for an evacuation drill of sorts to occur if the demand on various links can be determined and assigned accordingly and can give emergency management officials a way to predict clearance times for varying percentages of the population. It is without question that evacuation modeling is a fundamental step in the emergency management process. One challenge encountered in the modeling process, however, is the realistic representation of a true emergency event.

## 2.2 Traffic Demand Modeling

A large part of simulating and predicting traffic dynamics during events such as evacuations, is the implementation of traffic demand modeling. Demand modeling allows for critical variables to be addressed and approximated during a planning or policy-making procedure (20). The process involves multiple steps, usually four major distinct analyses that are tied together via a comprehensive model. Basic phases in most traffic demand models are as follows (20).

1. Trip Generation
2. Trip Distribution
3. Mode Choice
4. Route Choice (traffic assignment)

Trip generation deals primarily with analyzing how many trips can be expected to be made from certain areas. This estimation may use Census data such as households, household size, and number of employed persons per household to try to predict how attractive it is for a user within that zone to make a trip. When considering larger urban networks, such as the city of Madison and surrounding areas such as Middleton, Sun Prairie, Fitchburg, and Monona, trip generation will be evaluated as a rate per transportation analysis zone (TAZ) (20). A TAZ may be predetermined by the Metropolitan Planning Organization (MPO) such as is the case in Madison, Wisconsin. The number of TAZ's in an area may vary over time as population size and characteristics change. The variance of TAZ boundaries is necessary so that within each TAZ population demographics such as number of households, size of each households, how many cars are owned in each household, household income, and area type (residential or commercial or industrial, etc.) can be relatively homogenous. Homogeneity within an analysis zone provides planners and engineers with the ability to make better trip generation estimates based on expected traffic flows in and out of the zones (20).

In trip distribution, the analysis turns to the destinations of the trips being generated in the first step. Destinations have varying levels of attraction for users based on distance between the origin and the corresponding destination, the reason for the trip (work, school, social, etc.), and travel times along network links. Destination attractiveness and travel times allow an origin-destination matrix to be created, which can be as extensive as a 4,000,000 cell matrix for larger urban areas such as Washington, DC (20). Once trips have an origin-destination pair, the mode choice of the users will be estimated. A key step in this determination is to first establish what modes of transportation are available to users in the network (20). Specifically for the UW-Madison campus network, the available modes on any typical day on campus are personal vehicle, transit (Madison Metro bus), walking, biking, or moped. When considering the evacuation scenario, biking and mopeds will be eliminated from these options.

To establish what modes users can be predicted to take to complete their trips, a sub-model will be created. The sub-model analyzes likelihood of choosing one mode over another based on availability of each mode (does the household own a car? Is transit an option?), schedules (will transit allow users to arrive to the destination in time?), and costs in form of fares and travel time. Observations of transit utilization and transit capacity are also often used to forecast the likelihood of trips being made with transit over other modes (20).

At this point in the demand modeling procedure, trips have been generated and assigned to various destinations. These trips have additionally each been given a mode of transportation with which to complete said trip. Finally, the traffic assignment step will be completed. Traffic assignment, or trip assignment, is arguably the most complex step of the demand model. It involves predicting the routes that will be used to complete the trips (20). Some assumptions can be made about network users in order to simplify this prediction. One popular way of simplifying the trip assignment step is to make the assumption that users will choose the shortest path, whether by distance or travel time. Travel times are expected to vary on a route based on time of day, transit schedules, transit fare levels (peak hour fare versus off-peak hour fare), and the prevalence of incidents (crashes, weather, work zones, etc.).

The reliability of a traffic demand model can be validated by comparing model predictions to real-world observations. Traffic demand models are invaluable resources due to their versatility, namely their ability to be adapted for large or small networks. Demand models are also relatively sensitive, which means that they are able to be adapted to include more parameters such as tolling, HOV travel, truck forecasts, and bicycle or pedestrian movements (20).

### **2.3 VISSIM**

VISSIM is a time-step behavior based simulation modeling software, which will be used in this study to analyze the traffic characteristics of the UW-Madison campus evacuation. VISSIM is a microscopic traffic simulation program, which means that it analyzes transportation elements and characteristics in small units. Within each unit, all of the elements are considered homogeneous. The Wiedemann driver behavior model, which is referred to as a psychophysical driver behavior model, is used in the software to represent how vehicles move through the network and interact with one another. Rainer Wiedemann developed this stochastic driver behavior model in 1974 to relate following distance and vehicle speed in the network (12). As can be seen in Figure 6 below, driver perception-reaction time is considered in the Wiedemann car following model to create a more realistic network. Wiedemann's model allows the user of VISSIM more flexibility than other software to specify the type of data to be collected (LOS, delay, travel times, etc.) and where specifically in the network this data is being collected (across an intersection or along a specific route) (18).

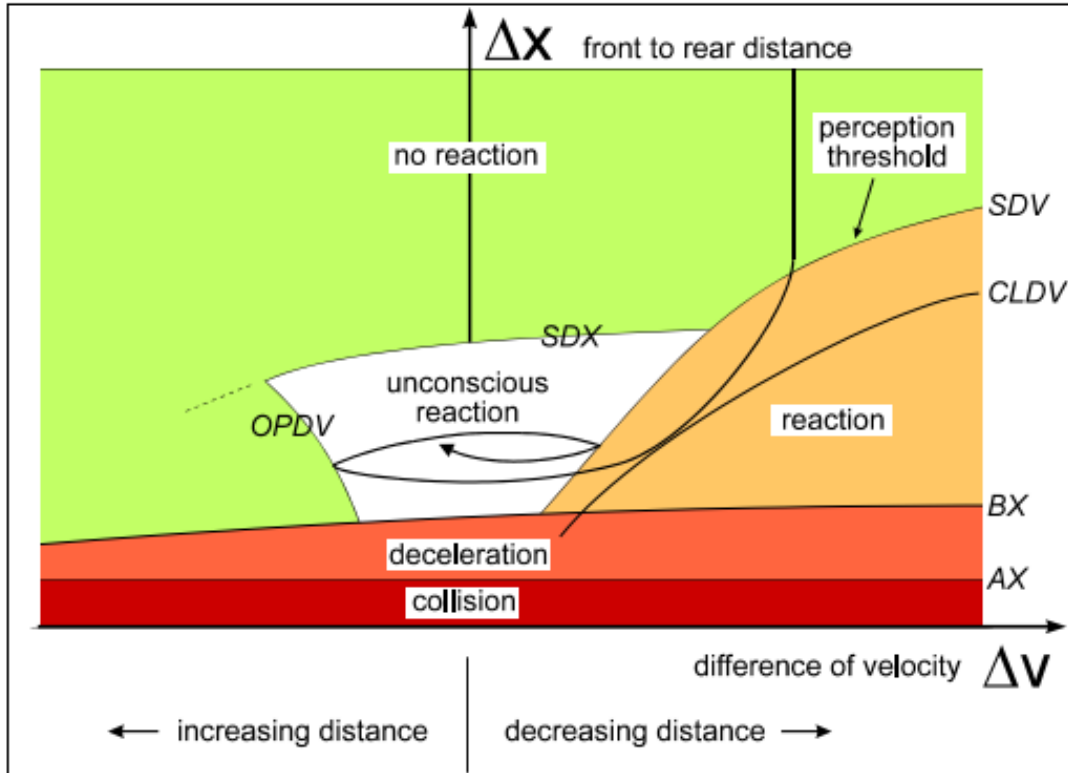


Figure 6: VISSIM Car Following Model (source 12)

The software defines four different driving modes for users in the network; approaching, following, braking, and free driving (12). Drivers in the network react accordingly to other drivers when changing driving modes, which directly affects their acceleration and deceleration behavior. For example, a driver who is approaching another driver may then decelerate and change to following behavior. Similarly, a driver who is free driving may come to congestion in the network and decelerate to change to braking. A drivers' desire to make a discretionary lane change as well as their tolerance for closely following a preceding vehicle may be adjusted in the driver behavior parameters tab of the software.

When using a microscopic traffic simulation software like VISSIM, special care should be taken to ensure that deviations in results are due to actual traffic phenomenon as opposed to randomness (18). Randomness is inherently prevalent in software like VISSIM due to the stochastic driver behavior model. Fortunately, randomness in the simulation results is a relatively simple issue to resolve. The VISSIM simulation should be run multiple times to ensure any deviations in the results are due to traffic characteristics and not randomness in the software (18). While a situation-specific ideal number of runs can be determined using an analysis of the variance in order to determine a confidence interval, running a completed simulation between ten and twenty times should account for randomness (18). To determine an appropriate confidence interval for a specific simulation scenario, four steps can be followed as detailed below (20).

Table 1: Calculating Simulation Confidence Interval (20)

1.	Calculate mean value, $\bar{x}$ of the results
2.	Calculate standard deviation $\sigma$ of the results
3.	Select significance level ( $\alpha = 0.05$ in our study)
4.	Calculate confidence interval as $1.96 * \frac{\sigma}{\sqrt{n}}$ ( $n = 10$ )

In a comparison of VISSIM with other traffic simulation software, namely CORSIM, which is also a microscopic traffic simulation software that was developed by the Federal Highway Administration, certain analyses of the software was completed. One such analysis was a sensitivity analysis, which tested how sensitive the software is to changing parameters such as an increase in traffic demands in the network. Researchers tested the sensitivity of travel times when demand was increased by 10% (110% demand level) and decreased by 10% (90% demand level) against the 100% demand level (18). The results of the simulations run at these varying demand levels suggest that VISSIM is appropriately sensitive to the changing demand levels and that travel times changed accordingly (18).

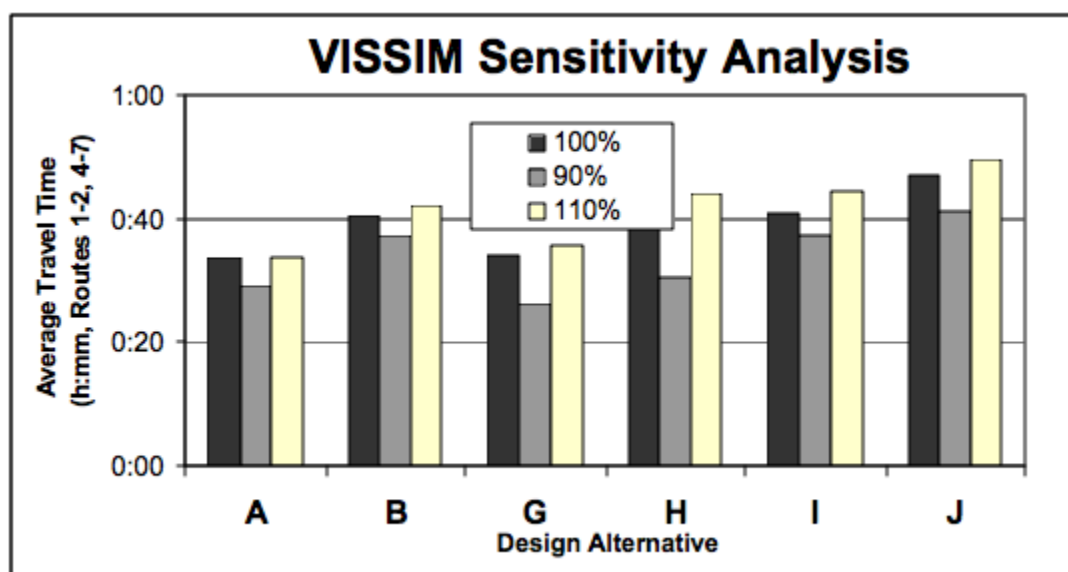


Figure 7: VISSIM Sensitivity Analysis (18).

While other traffic simulation software does exist, VISSIM has a large number of adjustable parameters for customizing the network, which makes it an attractive choice for this study. Another reason VISSIM is a good choice for this project, is the unique attributes of the campus area. When considering mega region evacuations, many researchers use network based

modeling where different zones can be used when determining trip generation and movement out of the hot zone. This allows for the use of data like the Census to estimate number of households, number of vehicles, and subsequently the number of trips per zone. However, when looking at the UW-Madison campus area, due to the nature of a campus it is generally considered one analysis zone. Even in Dane County's Emergency Management guidelines for evacuation, the campus is treated as its own area with one large analysis zone. In the case of the Census, there are only a few Census tracts that cover the entire campus area.

In mega region evacuation, drivers will pass through hundreds if not thousands of Census tracts and traffic analysis zones in order to move out of an entire region being affected, usually during a hurricane. In the case of this evacuation scenario, the scale is much smaller. The analysis involves only the campus population and the populations of surrounding zones will not be involved in the evacuation model or simulation. Simulating large regional evacuations such as the Gulf Coast mega region require network based models to better fit the scale of the traffic movements. However, for the purposes of looking at an isolated relatively homogenous population such as the UW-Madison campus, a micro simulation such as VISSIM is a good fit. The micro simulation is able to represent individual vehicle behaviors as well as collective traffic flow characteristics. A microscopic simulation software such as VISSIM allows users to focus attentions on delays along the routes, specifically at junctures such as intersections.

## **2.4 UW-Madison**

In order to approach this problem, an understanding of the University of Wisconsin – Madison's campus population is necessary. A report published by the UW-Madison Office of the Registrar shows that during the fall 2014 semester 43,193 students were enrolled at the end of the sixth week of instruction (4). This number includes undergraduate, special, graduate, law, medical, pharmacy, veterinary, and any other professional students. However, this count does not reflect the faculty and staff that also spend their time on the campus. At the close of the fall 2014 semester the University reported having a total of 21,976 faculty and staff on campus. This comes out to be a grand total of 65,169 people that could reasonably be on campus at one time not counting any visitors to the area.

While some students living in off-campus housing may own cars, students on campus are prohibited by the University from having a car and thus many students walk, bike, ride the bus, or ride mopeds to and from class. The Madison Metro currently has 214 buses in its operating fleet (21). Currently, the Metro estimates the ideal capacity of its buses as between 34 and 38 seated passengers and between 15 and 20 standees (standing passengers) (21). This number may vary by trip depending on passengers in wheelchairs or with strollers. All students at UW-Madison are eligible for a free bus pass that works on any of the Madison Metro bus routes. Additionally, routes 80, 81, 82, and 84 are free to all users and make continuous loops between various areas of campus and the hospital. The bus is highly utilized by UW-Madison students,

particularly in the winter months when adverse weather and frigid temperatures make walking across UW's over 900 acres a daunting task.

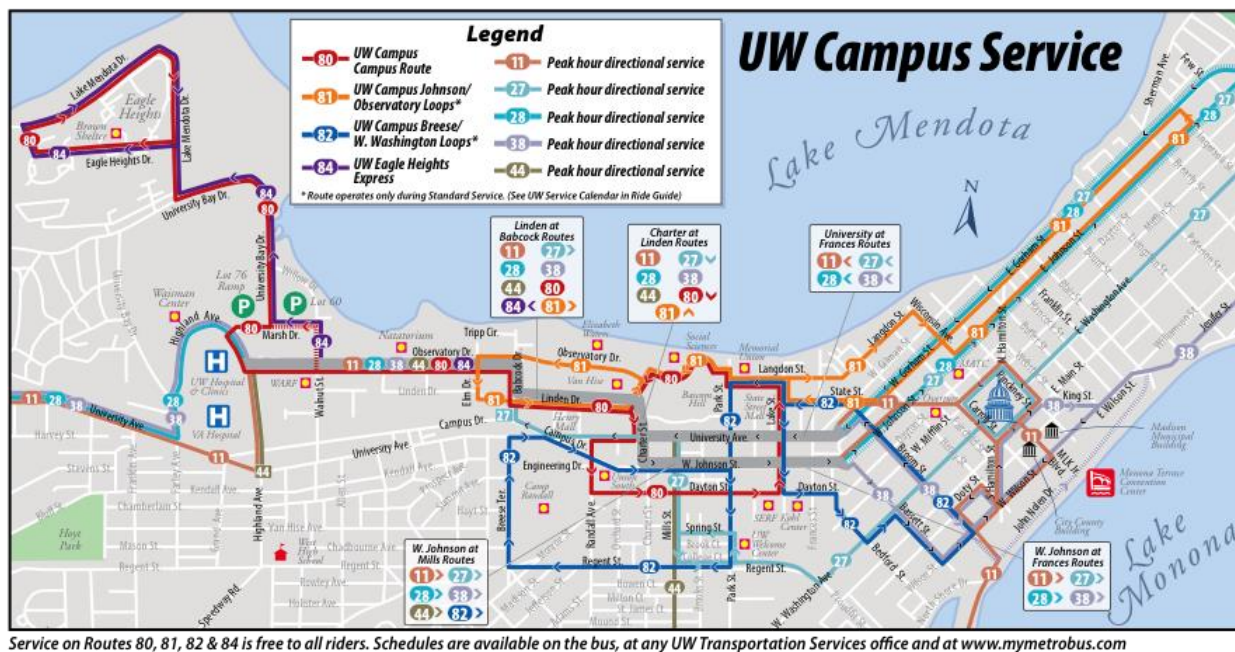


Figure 8: UW-Madison Campus Bus Service (21).

While the placement of the bomb threat that is analyzed in this project does not encompass the UW Hospital campus, it does include a majority of the main campus buildings. Additionally, while many employees work at the hospital, not many courses take place in hospital buildings according to course enrollment data that will be introduced later. The inclusion of the hospital campus also presents other challenges. The Hospital Evacuation Decision Guide provided by the U.S. Department of Health and Human Services Agency for Healthcare Research and Quality (AHRQ) discusses decision-making tools and guidelines for hospital evacuations (22).

<b>Types of Disasters<sup>1</sup></b>		
<b>Natural Hazards</b>	<b>Technological Hazards</b>	<b>Terrorism</b>
<ul style="list-style-type: none"> <li>• Floods</li> <li>• Tornadoes</li> <li>• Hurricanes</li> <li>• Thunderstorms and Lightning</li> <li>• Winter Storms and Extreme Cold</li> <li>• Extreme Heat</li> <li>• Earthquakes</li> <li>• Volcanoes</li> <li>• Landslide and Debris Flow (Mudslide)</li> <li>• Tsunamis</li> <li>• Fires</li> <li>• Wildfires</li> </ul>	<ul style="list-style-type: none"> <li>• Hazardous Materials Incidents</li> <li>• Nuclear Power Plants</li> </ul>	<ul style="list-style-type: none"> <li>• Explosions</li> <li>• Biological Threats</li> <li>• Chemical Threats</li> <li>• Nuclear Blast</li> <li>• Radiological Dispersion Device (RDD)</li> </ul>

Figure 9: Reasons for a Hospital Evacuation (22).

The AHRQ provides the table above detailing some disaster situations that could cause a hospital to make the decision to pre-evacuate patients, that is evacuate them in anticipation of a disaster occurring. Figure 10 below highlights some occurrences in which hospitals did actually evacuate, the event that prompted consideration, and the ultimate reasons evacuation was favored.

<b>Illustrative Hospital Evacuations: Type of Disaster and Ultimate Reason for Evacuation</b>				
<b>Event</b>	<b>Hospitals</b>	<b>Pre-Event Decision</b>	<b>Post-Event Decision</b>	<b>Ultimate Reasons for Evacuation</b>
Nuclear Reactor Incident (1979)	Hershey Medical Center Community General Osteopathic Hospital Harrisburg Hospital Polyclinic Medical Center (Pennsylvania) <sup>2</sup>	(No advanced warning)	Do not evacuate	N/A
Northridge (California) Earthquake (1994)	2 trauma centers, 2 general hospitals (private and county), a Veterans Affairs hospital, and a psychiatric hospital <sup>3</sup>	(No advanced warning)	Evacuate (immediately after the earthquake)	Structural and nonstructural damage <sup>3</sup>
Northridge (California) Earthquake (1994)	A general hospital (private) and a pediatric hospital <sup>3</sup>	(No advanced warning)	Evacuate (3 to 14 days after the earthquake)	Structural damage <sup>3</sup>
Chemical plant explosion (1997)	Helena Regional Medical Center (Arkansas)	(No advanced warning)	Evacuate	Anticipated air quality effects due to nearby explosion
Tropical Storm Allison (2001)	Memorial Hermann Hospital and Memorial Hermann Children's Hospital <sup>4</sup> (Texas)	Shelter-in-place	Evacuate	Loss of power
Bomb Threat (1999)	Galion Community Hospital <sup>5</sup> (Ohio)	Evacuate	Evacuated prior to the event	Anticipated effects of the bomb
Hurricane Katrina (2005)	Kindred Hospital New Orleans; <sup>6</sup> New Orleans Children's Hospital; <sup>7</sup> VA Medical Center of New Orleans; <sup>8</sup> Charity Hospital; <sup>9</sup> University Hospital (LSU Medical System) <sup>10</sup>	Shelter-in-place	Evacuate	Loss of water, loss of power, or security breakdown
Hurricane Rita (2005)	University of Texas Medical Branch (Galveston, Texas); <sup>11</sup> seven hospitals within one medical system <sup>12</sup>	Evacuate	Evacuated prior to the event	Anticipated effects of the hurricane
Wildfire (2007)	Pomerado Hospital (California) <sup>13</sup>	Evacuate	Evacuated prior to the event	Anticipated effects of the wildfire
Rising rivers (2008)	Mercy Medical Center (Cedar Rapids, Iowa)	Evacuate	Evacuated prior to the event	Anticipated effects of flooding
Levy breach (2008)	Columbus Regional Hospital (Indiana)	(No advanced warning)	Evacuate	Flooding

Figure 10: Hospital Evacuation Examples (22).

It should be noted in the figure above that one of these incidents that prompted the evacuation of a hospital was a bomb threat in Ohio, where the hospital ultimately evacuated to

avoid effects of the bomb. As can be imagined, significant and comprehensive planning must exist in order to evacuate a hospital. Hospitals contain extensive amounts of critical infrastructure, facilities, equipment, technology, and persons that are absolutely essential to their operation. Some examples of infrastructure that hospital emergency management planners must consider when evaluating whether to evacuate are municipal water, steam, natural gas, electricity, powered life support equipment, health information technology, and security (22). Asking questions such as is water used for cooling? How long can the hospital maintain a safe temperature without city water? Does the hospital have a central backup generator? How long can essential power be maintained using current fuel supply? And many other important considerations are covered in a checklist that assesses vulnerability of the facility based on these answers.

Once the vulnerability assessment is complete the hospital may use these considerations when deciding if an evacuation could be necessary, such as if the facility is especially vulnerable to electricity related losses and the likelihood of losing electricity is high. Another key consideration with any evacuation is the estimated evacuation time. However, for a hospital this aspect involves some unique and flow-disrupting challenges. This time estimation involves two major steps for hospital evacuations: the time it takes to empty the building and the time it takes to transport patients to receiving hospitals or temporary care sites (22). While some patients may be medically stable and able to self-evacuate or evacuate with the help of family members, many patients may be in critical condition or non-ambulatory, which increases the complexity of the evacuation task substantially. Whereas in the campus population there will be a certain percentage of disabled students, staff or faculty that may require assistance during the evacuation, in the hospital the prevalence of this population will be much greater. This means more resources such as equipment and staff will be necessary to evacuate each individual non-ambulatory patient as well as additional time to transport these patients safely, all of which increases the total evacuation time. Some patients that are likely to fall into this category are as follows:

- Adult Intensive Care Unit (ICU)
- Pediatric ICU
- Neonatal ICU
- Adult surgical and post-operative
- Pediatric surgical and post-operative
- Psychiatric
- Burn unit and burn ICU

Evacuation time estimates will greatly depend on available staff, especially considering the patients that require extensive assistance such as those listed above. While staffing aims to remain consistent within a unit, staff may call out sick and be unable to be replaced especially during nights and weekends when staffing numbers tend to be lower anyway (22). While

volunteer assistance can be accepted, volunteers would need to be given explicit directions, supervised, or otherwise trained to provide the necessary assistance.

Transportation resources must next be evaluated. Patients that self-evacuate are assumed to have access to transportation. However, non-ambulatory patients will require transportation and some may be required to be transported in vehicles such as ambulances that have medical support. Patients needing to be evacuated using ambulances must be ranked by severity of condition and resiliency to transportation in order to determine how to allocate transportation resources (22). Finally receiving facilities must be identified. This can be the most complicated task of the entire operation. Many patients will need to be transported to another hospital or medical facility with adequate equipment and staff to care for them. However, there is no guarantee that other hospitals in the area will have any beds to spare. Hospitals may quickly reach capacity with no definite estimate of when beds will become available. Additionally, there are limits to how far a patient can be safely transported. An assessment of these acceptable travel distances to receiving care sites can be seen in Figure 11 below.

Closest Appropriate Care Site	
• How close is the nearest care site that could provide appropriate care for:	< 1 mile
- NICU patients	1-5 miles
- PICU patients	6-10 miles
- CICU patients	11-20 miles
- Other adult ICU patients	21-50 miles
- Psych patients	51-100 miles
- Other ventilator-dependent patients	100+ miles
- Other patients with special/advanced medical needs	

Figure 11: Receiving Care Site Distances Assessment (22).

The brief review of hospital evacuation procedures here is meant to illustrate how specific and detailed the evacuation of a hospital is. It is reasonable to say that the UW Hospital would need its own distinct evacuation plan separate of the UW-Madison campus evacuation plan. When considering the scope of the task of creating an evacuation plan for the UW-Madison campus, it was therefore decided that including the hospital and medical campus was not feasible at this time.

The University of Wisconsin-Madison has an emergency notification system currently in place known as the WiscAlerts system. WiscAlerts allows the University to send consistent messages to as many members of the campus community as quickly as possible. The system, which is generally controlled by the UW Police Department (UWPD), is capable of sending alerts via text message, phone calls, and email (23). The most prominent form of communication between the UWPD and the campus community is via email alerts or updates. Any WiscMail, which is the UW-Madison's email portal, user may receive a mass email warning message about crime alerts, sexual assaults, or situations on campus (23). According to the UWPD, just about 85,000 people will receive a WiscAlerts email warning message. On a slightly smaller scale,

about 18,000 people will receive a WiscAlerts text message alert. This is because the text message option must be opted into by users who may sign up for these alerts via their My UW Portal (23).

WiscAlerts provides UWPD a conduit for reaching students in times of emergencies of various natures. Alerts are designed to provide critical safety information such as incidences of violence, locations on campus that are best avoided due to an incident or event, and weather events (23). The UW-Madison also has a series of Continuity of Operations Plans (COOP), which include planning and procedures for the continuous performance of critical campus functions in the event of an emergency (23). Additionally, the plans address severe weather incidents such as tornados, which the Madison, Wisconsin area is vulnerable to (23).

### **3 RESEARCH METHODOLOGIES**

#### **3.1 Logistics**

In discussing logistics of this project, an important clarification should be made. Certain assumptions, estimates and recommendations will be made in order to complete this project. Thus far, a full-scale evacuation drill of this nature of the UW-Madison Campus has not occurred and therefore best practices will be investigated as a part of this study. However, when discussing the logistics these can be separated into logistics used for the simulation, which is a descriptive analysis used to mimic the evacuation and logistics used for drafting the plan, which are the sets of recommendations and best practices for an actual evacuation. There is some overlap, as some of the recommendations such as recommended evacuation routes, origins, and shelter locations will also be used as origins, destinations, and routes in the simulation. For clarity, the logistics will be separated here into logistics regarding the simulation and logistics regarding the plan.

##### **3.1.1 Simulation**

For the purposes of this study, the evacuation will be assumed to take place on a Wednesday during an average point in the semester. Here an average point in the semester is one that is not within three weeks of the beginning or end of the semester and not within a week or during a break such as Spring Break or Thanksgiving. Wednesday is chosen as the day of analysis for purposes of the simulation because when considering traffic counts, Mondays and Fridays may show exceptionally high volumes particularly during the Monday morning peak period and the Friday even peak period. In order to avoid this, it is best practice to complete traffic counts on Tuesdays, Wednesdays, or Thursdays (17). Therefore Wednesday will be chosen as it is within these acceptable days and falls in the middle of the workweek, which implies that acceptable data can be gathered.

A time interval in which the majority of classes are taking place ensures that a large portion of the UW-Madison population will be captured in the evacuation simulation. Once a time of day is chosen, the percentage of classes taking place in some of the larger buildings on campus can be determined to obtain an estimate of how many people are in what geographical locations on campus during the evacuation. This will be determined in section 3.2 in the model development.

Once it is established where people are during the day, it is necessary to determine how far away from the threat they need to be evacuated, that is the hot zone perimeter needs to be established for the specific threat being analyzed. In terms of the plan, it is recommended that a table containing the standoff distances or hot zone perimeter recommendations for various threats be available for reference. The National Counterterrorism Center provides a table of bomb threat standoff distances, which includes both mandatory evacuation distances and preferred evacuation distances based on bomb type. For the purposes of this study, a SUV/van will be chosen as the bomb type as this is similar to the occurrence at Sterling Hall in 1970. As can be seen from the table below (7), a van loaded with a bomb has an explosive capacity of 1,000 TNT equivalent pounds based on the maximum volume or weight of explosive that could fit reasonably within the vehicle (7).









	Explosives Capacity <sup>1</sup> (TNT Equivalent)	Mandatory Evacuation Distance <sup>2</sup>	Preferred Evacuation Distance <sup>3</sup>
 Pipe bomb	5 LBS/ 2.3 KG	70 FT/ 21 M	1,200 FT/ 366 M
 Suicide vest	20 LBS/ 9.2 KG	110 FT/ 34 M	1,750 FT/ 518 M
 Briefcase/suitcase bomb	50 LBS/ 23 KG	150 FT/ 46 M	1,850 FT/ 564 M
 Sedan	500 LBS/ 227 KG	320 FT/ 98 M	1,900 FT/ 580 M
 SUV/van	1,000 LBS/ 454 KG	400 FT/ 122 M	2,400 FT/ 732 M
 Small delivery truck	4,000 LBS/ 1,814 KG	640 FT/ 195 M	3,800 FT/ 1,159 M
 Container/water truck	10,000 LBS/ 4,536 KG	860 FT/ 263 M	5,100 FT/ 1,555 M
 Semi-trailer	60,000 LBS/ 27,216 KG	1,570 FT/ 479 M	9,300 FT/ 2,835 M

Figure 12: NCTC Bomb Standoff Distances (7).

Once the bomb type and size are chosen, a guideline for the evacuation distances can be obtained from the NCTC's figure above. The mandatory evacuation distance is taken to be 400 feet from the origin of the explosion. The preferred evacuation distance (which is considered preferred for those inside buildings and mandatory for those outside) is 2,400 feet from the origin of the explosion. These two standoff distances are shown below.

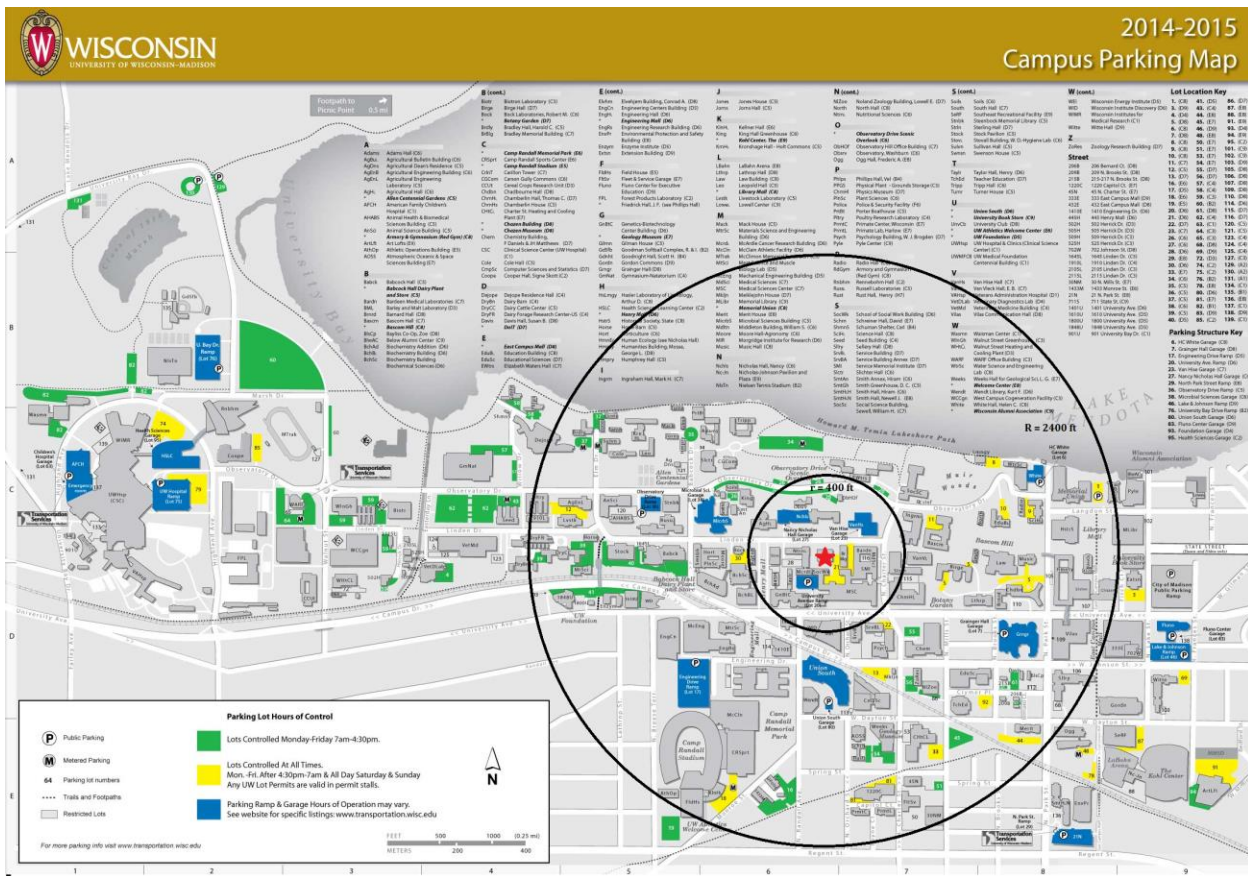


Figure 13: Bomb Standoff Distances for UW-Madison Campus

Figure 13 above shows an overlay of both the mandatory and the preferred evacuation distances on the UW-Madison campus. In Figure 13, the mandatory evacuation distance of 400 feet is represented by ‘r’ and the preferred evacuation distance of 2400 feet is represented as R. The red star in the center of the circles is Middleton Hall. Since the UW-Madison campus is widely spread between the University Bay area and the Capitol Square and isthmus areas, a central location will be chosen as the placement of the bomb in order to find a solution for a large area of impact.

For the purposes of this project, the bomb will be assumed to be located outside of Middleton Hall on Linden Drive. When overlaying the mandatory and preferred evacuation distances as radii centered at Middleton Hall, the circles encompass a reasonably large area of campus. As can be seen from Figure 13, this will capture many larger buildings on campus where a greater number of courses may occur throughout a typical day in the semester such as the Humanities Building, Van Hise Hall, Engineering Hall, the Educational Sciences Building, the Social Sciences Building, and Grainger Hall.

### **3.1.2 Plan**

#### **Origins**

A vital step in developing the evacuation plan involves the process of choosing origins on campus from which people will be evacuated. In order to choose these origins, an understanding of the distribution of people across campus by time of day is necessary. This is to say that it matters where students, faculty, and staff are located on the campus and during what times. While at this juncture it is not feasible to collect this information in the form of a survey, this information may be estimated. First, the time interval during which the most classes take place was determined, which will be chosen as the interval during which the evacuation will be simulated as mentioned in the previous section. A time interval in which the majority of classes are taking place ensures that a large portion of the UW-Madison population will be captured in the evacuation simulation. Once a time of day is chosen, the percentage of classes taking place in different buildings on campus can be determined to obtain an estimate of how many people are in what geographical locations on campus during the evacuation.

This general breakdown of what percentage of classes occur in which buildings and during what time intervals should be included in the final plan to serve as a guide for Emergency Management personnel. Via the WiscAlerts system, people will be directed to make their way to the origin nearest and most safely accessible to them. For example if one location is closest to a person's current location, but is not accessible without passing near Middleton Hall where the threat is located, then they should choose a different origin that does not require them to travel closer to the threat. Upon arriving at these locations, people will be taken to one of the safe points listed above either via a Madison Metro vehicle, a Badger Bus vehicle, or walking with a designated escort. Walking is an acceptable mode of travel for people traveling a short distance such as from the Humanities Building to Gordon Commons or from Union South to the SERF. The determination of who will be walked to a nearby safe spot versus driven to a further location will be determined by the location of the origin as well as when people arrive to the origins.

#### **Destinations**

The American Red Cross has provided a list of emergency shelter locations in Dane County. This list is referenced in the Dane County Emergency Management guidelines. Some of these shelter locations will be used in this analysis with one modification made to their listed capacities. For the purposes of their analysis, the Red Cross allots 40 square feet for each person when determining shelter capacities. This is the minimum square footage per bedridden person as determined by the Federal Emergency Management Agency (FEMA). Therefore, the Red Cross uses this space distribution to allow for the assembly and usage of cots. However, for the UW campus evacuation plan FEMA's recommended minimum of 20 square feet per standing, seated, or wheelchair-bound person will be adopted to better accommodate the large number of people to be evacuated.

Using this square footage allotment per person and the assignable square footage of the facilities, the capacities of the shelter locations being used in this plan can be determined. Here assignable square footage (ASF) is defined as the sum of all of the areas in the building that are available to be assigned for occupant use. Gross square footage (GSF) on the other hand also includes mechanical spaces such as boiler or utility rooms, structural spaces such as stairwells, and corridors, elevators, and vehicle storage spaces (15).

A total of nine locations are recommended for use as shelter locations in this plan. These locations are as follows:

1. The Alliant Energy Center
  - a. Arena
  - b. Exhibition Hall
  - c. Pavilion #1 and Pavilion #2
  - d. Veteran's Coliseum
2. Madison Area Technical College (MATC) Truax Campus
3. East High School
4. The Kohl Center
5. The Natatorium
6. The SERF
7. Sennett Middle School
8. Lafollette High School
9. Gordon Commons

The capacities of these facilities were determined using their ASF and dividing that value by the 20 square feet per person requirement given by FEMA with some exceptions.

Table 2: Shelter Capacities

Shelter Location	ASF (ft <sup>2</sup> )	Space/Person (ft <sup>2</sup> )	Capacity (persons)
Alliant Energy Center			
Arena*	22,000	20	1,650
Exhibition Hall	255,000	20	12,750
Pavilions 1 & 2	290,000	20	14,500
Coliseum***	N/A	N/A	10,230
MATC Truax (main facility)	868,000**	100	8,680
East High School	48,750	20	2,437
Kohl Center****	230,587	15.4	15,000

Natatorium	83,000	20	4,150
SERF	124,000	20	6,200
Sennett Middle School	53,100	20	2,655
Lafollette High School	23,300	20	1,165
Gordon Commons	72,366	20	3,618
		Total Capacity Provided by ALL Shelters	83,037

\*The Alliant Energy Center's Arena has seating space for 550 in addition to the 22,000 square feet of assignable space

\*\*The Director of Facilities Management at MATC provided their capacity as 100 people/square feet due to the mechanical properties of their building. Therefore the capacity of their main facility was given in persons and no ASF was provided.

\*\*\*For the Veteran's Coliseum at the Alliant Energy Center the capacity in terms of seating at a concert in which the venue is considered a full house was provided by the Alliant Energy Center and an ASF value was not provided.

\*\*\*\*For the Kohl Center, the ASF allotted per person to reach their listed capacity of 15,000 with the ASF reported by the Space Management Office at UW-Madison is 15.4 square feet per person instead of 20 square feet per person.

As can be seen above, the total capacity that is provided by all recommended shelters is 83,037 people. This number is just over 27% larger than the estimated campus population of 65,169 people, which means that full utilization of all shelter capacities, would accommodate an additional 17,868 people than are represented by the campus population estimation. While a scenario involving this will not be modeled in this study, it is important that the plan have some factors of safety. That allows some flexibility in the event of a large number of additional people are on campus during the incident or in the event that one of the other shelters has some capacity reduction.

Destinations such as MATC Truax and East High School will be accessed via the Isthmus while destinations such as the Alliant Energy Center, Lafollette High School, and Sennett Middle School can be accessed via Park Street, West Washington Avenue, Proudfit Street, John Nolen Drive, and Olin Avenue. Since Camp Randall Stadium can accommodate over 80,000 people, this will serve as a favorable origin point despite it being located within the preferred evacuation distance. Camp Randall is also somewhat shielded by the Engineering campus and is located on the edge of the preferred evacuation perimeter and thus it will be assumed that any damage from a blast will be minimal. There is also a consideration when choosing origins as to their capacities and facilities so that people waiting to be picked up may sit down, use the restroom, seek some shelter by being indoors, etc. The preferred evacuation distance of 2,400 feet is a radius within

which all people outdoors must be evacuated and all people within buildings should be evacuated. Therefore, no origins will be chosen within the mandatory evacuation distance of 400 feet. This is so in the event of the explosion occurring during the evacuation process, which is somewhat likely due to the time required to move over 60,000 people to safety, no one is trapped in the immediate blast radius.

### **Available Modes**

A major consideration in the evacuation of a campus or any area containing non-ambulatory residents or residents without personal vehicles is how to evacuate them in terms of transportation. As mentioned earlier, some of the destinations chosen as safe spots are located on the campus, such as the Kohl Center and the Natatorium. These locations were chosen very specifically for multiple reasons. First, they have reasonably large capacities for holding evacuees. Second, they are all located outside of the hot zone perimeter, which means that sheltering inside them is an acceptable option. Third, their location on campus means that it is reasonable to assume they will not be being used for a purpose other than UW-Madison operations at the time of the evacuation, which means there will not be a competition for the space.

Lastly, a considerable advantage of their location on campus means that walking is an acceptable mode choice for able-bodied students, faculty, and staff. This will eliminate the need for vehicular transportation methods for these members of the population. It is recommended that able-bodied people be escorted on foot to these destinations from certain origins based on that origin's proximity to the safe spot. For example, able-bodied people meeting at Union South may be escorted to Gordon Commons, the SERF, or the Kohl Center. Similarly, able-bodied people meeting at DeJope Hall or Tripp Circle may be escorted to the Natatorium. Additionally, any people who are already located in these destinations at the time of the evacuation notice may simply shelter in place.

The population that is unable to be evacuated on foot to nearby shelters will be evacuated using a combination of buses and passenger vehicles. Section 3.2 introduces data regarding how many faculty and staff at UW-Madison have vehicles that they drive to work, which will be used to determine how many passenger vehicles can be estimated as available for use during the evacuation. Besides passenger vehicles it is recommended that buses be used as they have large capacities for evacuating many people at once. It is recommended that UW-Madison expand on their working relationship with both the Madison Metro and Badger Bus Company to include some transportation sharing guidelines regarding the buses. As mentioned in Section 2.4, the Madison Metro currently owns and operates 214 vehicles in their fleet with an estimated maximum capacity of 75 people per bus. The Badger Bus Company reports having 140 different vehicles with a combined capacity of 7,000 people. If a reasonable amount of the campus population can be evacuated on foot to nearby shelters, then these two sources of buses may be

used to evacuate the remaining population if supplemented by the use of personal passenger vehicles.

In the event that nearby shelters were not accessible, such as in an event where a much larger evacuation distance was required, additional transportation would be required to move people to safety. Many private bus companies operate school buses in the greater Madison area, which have variable individual vehicle capacities between 60 and 85 people. While the time for vehicles to become available and make their way to the origins may vary widely, these would help provide transportation for those in the campus community without access to a car. For the purposes of this study, only Madison Metro buses, Badger Bus Company buses, and passenger vehicles will be utilized. However, it is recommended for planning purposes that partnerships be established with other bus companies regarding fulfilling transportation needs in a larger-scale evacuation.

### Available Routes

The Number of Lanes shown in the table below considers all usable lanes regardless of intended purpose. For example, University Avenue contains three lanes for regular vehicle traffic, one curb bus lane, a westbound bicycle lane separating the bus lane and vehicle travel lanes, and an eastbound contra flow bicycle lane separated by a raised concrete median on the left side of the roadway. Because the two bicycle lanes are six feet wide each, which is too narrow for vehicle travel, the three vehicle travel lanes as well as the curb bus lane will be used for travel. However, in the case of parking lanes, in order to remain conservative in the estimation of link capacity parking lanes were not considered usable in the simulation. This accounts for vehicles that may be parked along these routes at the time of the evacuation.

Table 3: Major Evacuation Routes Recommendations

Roadway	Direction	Number of Lanes	Evacuation Direction
Campus Drive/Johnson Street	OW EB	4*	OW EB
University Avenue	OW WB	4	OW EB
Park Street	BD NS	6**	OW SB
Charter Street	BD NS	2	OW SB
Babcock Drive	OW NB	2	OW SB
John Nolen Drive	BD NS	6***	OW SB
Olin Avenue	BD EW	2	OW EB
Regent Street	BD EW	2	OW EB
E. Washington Avenue	BD EW	6	OW EB
W. Washington Avenue	BD EW	4****	OW EB

\*Changes to 3 after crossing N. Bassett Street

\*\*Changes from 4 to 6 after crossing W. Washington Avenue

\*\*\*Changes from 4 to 6 after crossing E. Lakeside Street

\*\*\*Changes from 4 to 2 after crossing S. Bedford Street

Here the following abbreviations shown below are used in Table 3.

- OW = one way
- BD = bidirectional
- EB = eastbound
- WB = westbound
- SB = southbound
- EW = East-West route
- NS = North-South route

A number of considerations took place when choosing available evacuation routes. First of all the number of available lanes were considered including parking characteristics. Narrow streets with available street parking were generally not chosen for evacuation routes as these would cause some complications for buses navigating them during the evacuation. Second, the direction of the routes was considered. In the case of this study, the campus community is to be evacuated in the south and east directions, therefore arterials such as Park Street and John Nolen Drive become attractive choices for funneling the population to the southeast and East Washington Avenue becomes an attractive choice for moving people to the northeast. The Dane County Emergency Management evacuation guidelines were also used as a check method after choosing routes. That is, once key routes were chosen for this project they were compared to those highlighted in the Dane County documents. As was shown in Figure 5, the County of Dane listed Park Street, University Avenue, and Johnson Street were listed in their Primary Evacuation Routes evaluation. This is consistent with the choices made for the UW-Madison campus evacuation, and therefore these routes will not be altered at this time.

### **Continuity of Operations**

As technology continues to adapt, it becomes further integrated into university life. Students and faculty rely on technology to go about their daily lives, especially on campus. WiscMail, Learn@UW, WiscAlerts, and many other technological services are provided by the university. UWNNet, the campus wireless network, is accessible to anyone with a UW Network ID login. Due to the heavy reliance on these aspects of campus life, it is important to consider the continuity of technological operations for the university. The Division of Information Technology (DoIT) provides some operational framework regarding incident management. Incident management in this sense involves restoring normal service operations as quickly as possible following incidents (29). It also involves minimizing the impact on operations and maintaining as high a level of service as is feasible.

DoIT has established pre-arranged agreements with various vendors such that replacement hardware will be available to DoIT within 48 hours should the incident require new equipment to be obtained. The incident management at DoIT is set up in phases, which are listed below (29).

1. Phase 1: Initial Response and Notification
2. Phase 2: Assessment and Activation
3. Phase 3: Recovery

Phase 1 depends on the nature of the incident itself. Initial responses will vary based on the conditions of the incident at the time of notification. The UW Police Department has an Emergency Response guide that addresses Phase 1 for any number of emergency incidents. Phase 2 involves assessing facility conditions and any relocation that is required for safety, assessing any damage and procuring new equipment if necessary, and managing communication internally and externally. Managing communications is a vital step in the incident management process as it is how students, faculty, staff, families, and the community can be kept up to date on the situation (what has happened), what they should do, what is being done currently, and an estimate on recovery time (29).

Finally in Phase 3, the actual recovery process will begin. Some organizations may use disaster recovery vendors as offsite locations for technological restoration. However, in the state of Wisconsin the government prefers organizations such as the UW-Madison to self-insure. For that reason the main backup data center currently at the UW-Madison is at the Wisconsin Alumni Research Foundation (WARF) building located at Observatory Drive and Walnut Street near the hospital campus (29). This is outside of the hot zone and is a feasible place to manage some communications operations throughout the duration of the incident. However, the true extent of the damage that could result in the event of the bomb going off is hard to predict. While the WARF building is outside of the evacuation perimeters, the blast could still affect technological operations throughout the area. Recovery is an extensive area of the incident management process, as can be expected. It involves the immediate safety and communication to students and faculty, the continuity of teaching classes or providing computer services to the campus community, or the restoration of facilities. Each area is extremely complex and involves many details.

The execution of these phases will depend heavily on the classification of the incident. For this reason incidents can be assigned a priority and different levels of urgency are given to the resolution goals based on these priorities (29). Priorities 1-4 exist with resolution goals ranging from deferring action to resolution within four hours. These specifications are shown below.

Table 4: Incident Priority and Urgency (29)

Incident Priority		Urgency			
		Resolution Goal: defer for monitoring	Resolution Goal: 5 business days or less	Resolution Goal: 2 business days or less	Resolution Goal: 4 hours or less
Impact	Multiple units affected/critical business impact/safety	Priority 4	Priority 2	Priority 1	Priority 1
	Single unit affected/important business impact	Priority 4	Priority 3	Priority 2	Priority 1
	Few individuals affected/minimal business impact	Priority 4	Priority 3	Priority 3	Priority 2

Here the priority definitions are as follows. Priority 1 is considered a severe incident. Acknowledgement of priority 1 incidents occurs within ten minutes and these incident handling hours are 24 hours a day 7 days a week 365 days a week. Priority 2 incidents are considered standard and acknowledgement of these incidents occurs within one business day. Priority 3 incidents are routine and acknowledgement of these occurs within two business days. Finally, priority 4 incidents are considered hold incidents where acknowledgement of the incident occurs within two business days, but the status of the incident is tracked and monitored over time (29).

In the event of the bomb threat in this project, the incident would be a priority 1 and acknowledgement of the incident would occur within ten minutes. This is mainly because detonation of the bomb would critically impact multiple units within the university (students, faculty, staff, facilities, class continuation, technological operations, etc.) including the safety of the campus community, which is the number one priority. For this reason, the bomb threat could be considered what DoIT terms an All-Hands Incident. This is an incident that would result in significant disruption to business and is the highest category of impact (29). Not all severe incidents require All-Hands procedures and similarly not all All-Hands Incidents are in fact severe. The terminology is mainly given in order to begin an adequate recovery as soon as possible. Some characteristics of an All-Hands Incident are shown below (29).

- Business of the UW-Madison is significantly disrupted
- Multiple services become unavailable or impaired
- Major contributions from many groups is required for service restoration

- The incident carries a higher than normal risk of data or service loss
- Circumstances make restoration of service extremely time critical

When an All-Hands Incident is identified, guidelines must be followed in order to manage the incident. The incident responses should also be documented. Varying levels of personnel are assigned to manage various aspects of the recovery process depending on the incident details (29). Some personnel that may be required are situation managers, situation and coordinating technologists, environmental specialists, communicators, documenters, runners, external liaisons, researchers, human resource managers, and security personnel (29). The last step of the incident management process will involve a post incident review in which the process can be evaluated and improvements can be made to the guidelines for future use.

### **3.2 Campus Evacuation Traffic Demand Model**

When considering how to model a no-notice evacuation of the UW-Madison campus, one vital step is determining population estimates for the time interval in question. That is to say that it will matter a great deal where people are estimated to be on campus at the time of the evacuation. The campus is spread out over 936 acres and contains over 200 buildings. UW's some 65,000 students, faculty, and staff could be distributed in numerous ways among these buildings depending on the time of day. As discussed in Chapter 3 section 3.1, it was necessary to obtain an estimate for the time interval on a typical Wednesday in the semester during which the largest percentage of classes occur.

As is true with most traffic demand models, evacuation modeling can be addressed in a series of steps. Frank Southworth breaks evacuation modeling into five major steps in his review of regional evacuation modeling techniques. The steps outlined in his review involve the generation and the calibration of the following tasks:

1. Trip Generation
2. Trip Departure Time (mobilization)
3. Destination Assignment
4. Vehicle Utilization
5. Route Assignment and Mode Split
6. Plan Analysis (set-up, results inspection, and revision)

These sub-models combine together to form a comprehensive way to model origins and destinations, how many vehicles are in the network at once, and what modes are being used for these trips during the evacuation. The demand model will allow the user to evaluate the plan they have created and make adjustments as necessary (14). Using these steps as guidelines, a demand model can be adapted for the UW-Madison campus.

### 3.2.1 Trip Generation

The major objective of the traffic generation step is to assess the location of the population at the time of the threat notification. These distributions of people across the campus area will be necessary when determining the most realistic way to convert the number of people into the number of vehicles being used in the evacuation. In order to obtain the distribution of students, faculty, and staff among campus buildings and facilities, data was obtained from the Office of the Registrar regarding scheduling. The dataset contains class days, class times, room locations, and enrollment information for the fall and spring semesters of the 2014-2015 academic year. For this model, the fall 2014-2015 data will be used. In order to obtain the required information for the traffic generation step of the model, the data was analyzed using four important categories and sorted within these categories. First the day of the week that the classes meet is examined from the dataset. This information is then sorted so that only classes that meet on a Wednesday are included. Next these classes are sorted by class meeting time. That way, the percentage of classes occurring during which times of day can be obtained and a time interval can be chosen for the analysis.

Lastly, from the time sorted Wednesday classes the meeting location and enrollment information can be analyzed. This will allow a simplified diagram to be created showing the concentration of classes in different geographical areas of campus during the time period during which the most classes take place on a typical Wednesday in the semester. After sorting the class schedule data, the time period chosen was 1:00 p.m. to 4:00 p.m. This diagram is shown below:

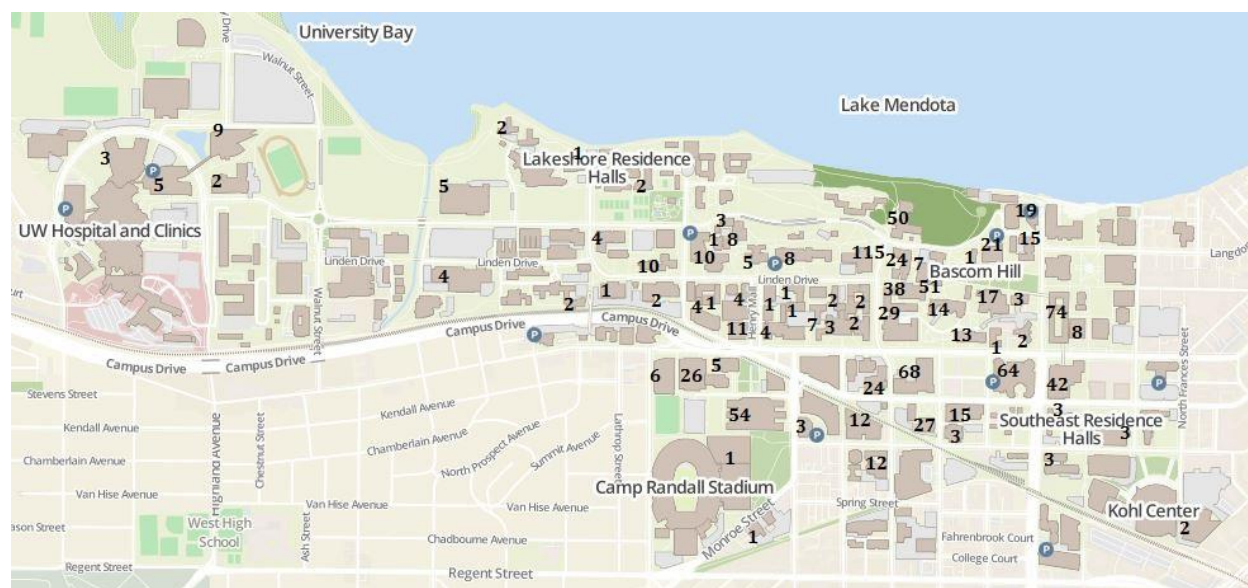


Figure 14: Number of Classes by Building during Chosen Time Period

An advantage to the dynamics of campus is that this dataset is available. Generally speaking, deriving populations of different areas during business hours can be extremely

challenging and expensive. While people are recorded in the Census at their places of residence, during the day many people attend work, school, or run errands. Therefore the populations' location is variable by time of day during business hours and obtaining an accurate estimate of the distribution of the population is extremely difficult. It is of great benefit in this sense that this project is analyzing a campus population where different offices such as the registrar have access to each student's class schedules. Additionally, this allows a much more accurate population distribution to be obtained, which makes the traffic generation portion of the demand model more accurate as well.

Using the enrollment information, the sum of students in each building during the chosen time interval,  $T$ , can be obtained using the following expression:

$$\sum_i^n E_i$$

$$\sum_{i=1}^n E_i = 32,342$$

Here  $E_i$  represents the enrollment of a course  $i$  and  $n$  is the total number of classes as obtained from the dataset. To estimate the number of staff or faculty,  $S$ , in a building based on course enrollment, it will be assumed that one staff or faculty member will be counted for each course  $i$  that is taking place during the chosen time interval  $T$ . That is to say that:

$$\sum_{i=1}^n S_i = n$$

$$\sum_{i=1}^n S_i = n = 1009$$

Next, the remaining number of students, faculty, and staff that exist in the campus population but are not represented by the expressions above must be determined and distributed. As not every student has classes on Wednesdays or has a class on Wednesday during the specific time interval  $T$  there will be a portion of the student population not captured. Similarly, faculty and staff may not be captured by the estimate of one faculty or staff member per class for all classes occurring during time interval  $T$ .

$$E_r = 43,193 - \sum_i^n E_i$$

$$S_r = 21,976 - \sum_{i=1}^n S_i$$

Here  $E_r$  represents the remaining enrolled students and  $S_r$  represents the remaining faculty and staff to be distributed. The values 43,193 and 21,976 are the total enrolled students and total faculty and staff as reported by the UW-Madison for the fall 2014 semester.

$$E_r = 43,193 - 32,342 = 10,851$$

$$S_r = 21,976 - 1009 = 20,967$$

Now it will be assumed that the remaining population will be distributed based on building occupancies, which is to say that the percentage of remaining population to be assigned to some building,  $B$ , will equal the percentage of the population already assigned to that building during time interval  $T$ . A brief example of this method is shown below; the entire table containing all of the buildings and percentages of remaining population assigned to each building can be found in the appendix.

Table 5: Population Assignment Example

<b>Building</b>	<b>Assigned Population</b>	<b>% of Total Assigned Population</b>	<b>% Remaining Population to Assign</b>	<b><math>E_r</math> Assigned to Building</b>	<b><math>S_r</math> Assigned to Building</b>
Engineering Hall	1914	5.92%	5.92%	642	1241
Grainger	2297	7.10%	7.10%	771	1489
Vilas	801	2.48%	2.48%	269	519
Van Hise	1793	5.54%	5.54%	602	1162

Now the concentration of students, staff, and faculty by geographical area can be determined and origins, or meeting spots can be chosen. These are places that the campus community will be directed to be escorted to a shelter. The diagram below shows each origin as a circle. Within the circles are the percentages of the total population that are being assigned to that origin based on proximity of the origin to their original location. This assignment also made the assumption that people would not choose an origin if traveling to it required passing closer to the threat at Middleton Hall, which is shown in the diagram as a red star. That is to say it is assumed all people will make the choice of one of the fourteen origins given to them in the WiscAlerts warning based on the closest origin that does not require them to go toward the threat.

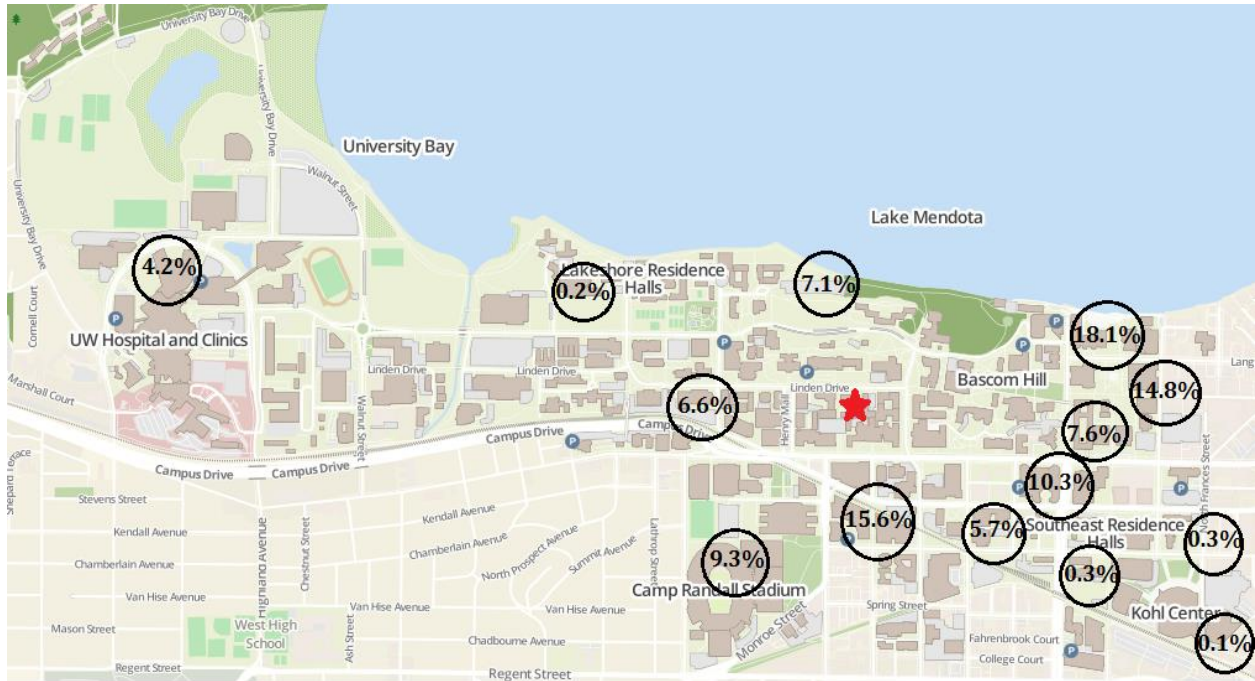


Figure 15: Population Breakdown by Origin

The origins are also shown in Table 5 below with the percentages of assigned populations and the number of people being assigned to that origin.

Table 6: Origin Population Assignment

Origin	% of Population Assigned	Number of People Assigned
Camp Randall Stadium	9.3	6,067
Union South	15.6	10,140
Lot 34/Tripp Circle	7.0	4,607
Lot 40/Babcock Hall	6.5	4,275
Memorial Union	18.1	11,789
Library Mall (State Street @ Lake Street)	14.8	9,618

Humanities Building	7.6	4,972
Grainger Hall	10.3	6,705
Art Lofts	0.1	32
Dejope Hall	0.2	156
Educational Sciences	5.7	3,682
Ogg Hall	0.3	204
Witte Hall	0.3	204
Already Clear of Hot Zone	4.2	2,718
TOTAL	100.0	65,169

\*Values are rounded

### 3.2.2 Trip Departure Time

Next an approach must be selected to approximate the trip departure times of vehicles into the network. A couple of different methods exist for estimating trip departures, which translates into traffic loading into the network. Since previous evacuation data does not exist to evaluate for the UW-Madison campus, the approximation will be made considering the existing WiscAlerts system and human response to an emergency as well as the time for transportation to become available.

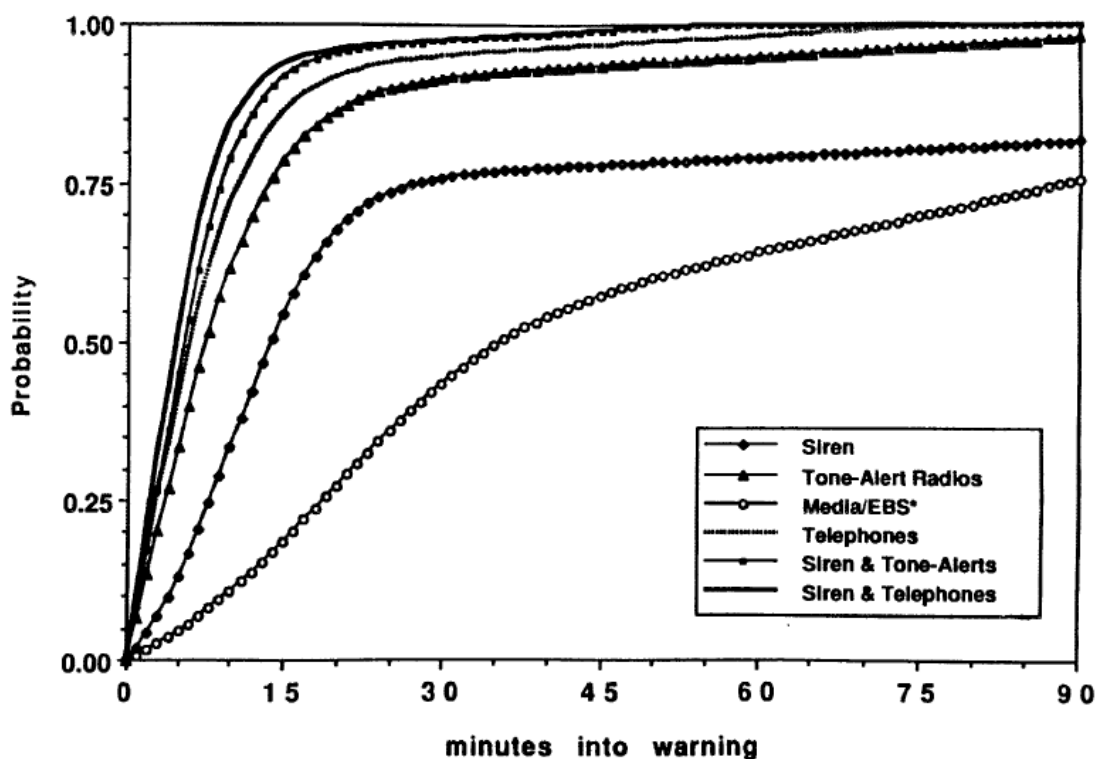


Figure 16: Effectiveness of Warning Systems (14).

As can be seen from Southworth's figure above, the probability of evacuation occurring less than 15 minutes following warning is highest if a combination of siren and telephone notification is used. The next highest probability occurs when a combination of siren and tone-alerts are used. The third highest probability occurs when telephones are used as the notification system. Using these results, it can be assumed that using a text WiscAlerts warning in addition to the email warning. Text message alerts have grown in popularity and versatility of use as cell phone technology has become more advanced. Cellular providers such as Verizon may use text alerts to alert customers when they're close to using their monthly data. Credit card companies use text alerts to notify customers of upcoming bills or low balance warnings. Additionally, communication providers such as Rapid Notify provide multiple emergency notification system options using text message alerts for mass emergency notification (26).

Based on this graph, it can be seen that using WiscAlerts text and email warnings can be effective in notifying students, faculty, and staff of the incident. Once notification occurs there is nearly a 99% probability that evacuation procedures will begin within fifteen minutes as can be seen in Figure 16 above. In the case of this evaluation, this is taken to mean that within fifteen minutes of receiving the WiscAlerts warning, the campus community will begin moving to the appropriate origin to be evacuated to an assigned shelter.

### 3.2.3 Destination Assignment

The destinations for the UW-Madison campus evacuation have been selected as detailed in Section 3.2.1. However, now each vehicle leaving the campus origins must select a specific destination from these choices. It is generally assumed that evacuees will attempt to leave the hot zone in favor of the closest safe destination. Here the evaluation of which destination is closest may be made using distance or estimated travel time (14). Southworth describes in his research that there are four main ways of modeling destination choice for evacuation. The method used here will combine two of these, namely operating under the assumption that evacuees will choose the closest destination as mentioned above and that evacuees will choose from pre-specified destinations based on an established plan (14).

The existence of a detailed evacuation plan can allow for evacuees to be directed to specific routes via pre-established route planning as well as guidance from police or fire personnel at certain junctures in the route (14). Combining the established routes method with the additional level of control of directing evacuees to the closest destination based on their origins will provide the most efficient evacuation. While the nature of an evacuation implies that some level of chaos may occur, having an organized plan in place will help eliminate any chaos that may occur on the planning side. This will help prevent situations such as the evacuation of Houston during Hurricane Rita, where the plan developed to facilitate the evacuation failed and increased the disorder and breakdown of the process. It will be assumed for the purposes of this study that evacuees will be directed to the pre-determined shelter destinations based on their origin. Communication of these origin-destination pairs will occur via the WiscAlerts system to all users.

### 3.2.4 Vehicle Utilization

The next task to complete in the demand modeling process is to estimate vehicle occupancies. It is recommended for this situation that the following vehicles be used in the transportation of the campus population during the evacuation.

1. Madison Metro buses,  $V_M$
2. Badger Bus buses,  $V_B$
3. Staff/faculty personal vehicles,  $V_P$

After determining these as the recommended vehicles for use in the evacuation, it was necessary to determine how many vehicles each category provides and what the capacity or recommended capacity is of each. The Madison Metro provides bus capacities as 53 or 56 persons (including standees) depending on the seating configuration of the bus. However, it was determined that the maximum capacity of a Madison Metro bus is 75 and thus this will be used in the estimate below. The number of Badger Bus vehicles and the total capacity of their fleet were provided by John Meier of Badger Bus Lines, Inc. This fleet includes motor coaches,

double decker motor coaches, trolleys, mini coaches, school buses, wheelchair vans, large vans, and minivans.

In order to determine how many faculty and staff may use a personal vehicle to drive to campus, the active permit holder status was requested from the University Transportation Services. Currently there are 8,753 active parking permits on campus, not including the hospital specific lots. With 21,976 faculty and staff members this means that about 40% of the faculty and staff is permit holders. While this number does not reflect the hospital, visitor parking, or those who choose to drive and park on neighborhood streets, it will serve as a conservative estimate of how many personal vehicles can be utilized in the evacuation. When determining the capacity of personal vehicles, all vehicles should be assumed to have the capacity of the smallest passenger vehicle. Therefore, each personal vehicle will be assumed to have a capacity of two passengers, so the driver and one additional passenger.

Table 7: Available Vehicle Capacity

<b>Vehicle Type</b>	<b># Available Vehicles</b>	<b>Total Capacity (persons)</b>
$V_M$	214	16,050
$V_B$	140	7,000
$V_P$	8,753	17,506
	<b>Total Vehicle Capacity</b>	40,556

### 3.2.5 Route Assignment and Mode Split

Now that origins and destinations have been selected and the vehicle utilization has been determined, the trips can be generated. Table 8 shows the first round of assignment of the population to each O-D pair as well as the distance in miles between the origin and the destination. The destination column is shown as “Shelter 1” here because some origins may require two destinations to accommodate their evacuating population. The second round of assignment will be shown in Table 9. The Shelter 1 Capacity column is dynamically represented here, such that each time a shelter is used again its subsequent capacity change will be represented in the Shelter 1 Capacity column. For example, the Alliant Energy Center is used as the shelter for the Camp Randall origin. Along that row its starting capacity is shown as 39,130. The Alliant Energy Center is used again as the shelter for the Lot 34/Tripp Circle origin. Here, the number of people being sent to the Alliant Energy Center from Camp Randall (6,067) has been subtracted from its initial capacity (39,130) and therefore the remaining assignable capacity is now 21,274, which is the value entered in the Shelter 1 Capacity column for the Lot 34 to Alliant Energy Center pair.

Table 8: Trip Assignment Iteration 1

<b>Origin</b>	<b># People at Origin</b>	<b>Shelter 1</b>	<b>Shelter 1 Capacity</b>	<b>People to Shelter 1</b>	<b>Distance to Shelter 1 (mi)</b>	<b>Remaining Population</b>
Camp Randall	6,067	Alliant Energy Center	39,130	6,067	2.9	0
Union South	10,140	Kohl Center	15,000	10,140	0.6	0
Lot 34/Tripp Circle	4,607	Alliant Energy Center	33,063	4,607	3.5	0
Lot 40/Babcock Hall	4,275	Natatorium	3,994	3,994	0.4	281
Memorial Union	11,789	Alliant Energy Center	28,456	11,789	2.8	0
Library Mall	9,618	MATC	8,680	8,680	5.3	938
Humanities Building	4,972	SERF	6,200	4,972	0.3	0
Grainger Hall	6,705	SERF	1,228	1,228	0.3	5,477
Art Lofts	32	Kohl Center	4,860	32	0.1	0
Dejope Hall	156	Natatorium	4,150	156	0.4	0
Educational Sciences	3,682	Kohl Center	4,828	3,682	0.4	0
Ogg Hall	204	Gordon Commons	3,618	204	0.1	0
Witte Hall	204	Gordon Commons	3,414	204	0.1	0
Clear of Hot Zone	2,718	N/A	N/A	N/A	N/A	N/A

Now the remaining population can be assigned among the shelters that still have capacity. This assignment is shown in Tables 9 and 10 below. Once again the shelter capacities are represented dynamically as population is assigned to them.

Table 9: Trip Assignment Iteration 2

<b>Origin</b>	<b># People Remaining</b>	<b>Shelter 2</b>	<b>Shelter 2 Capacity</b>	<b>People to Shelter 2</b>	<b>Distance to Shelter 2 (mi)</b>	<b>Remaining Population</b>
Lot 40/Babcock Hall	281	Alliant Energy Center	16,667	281	3.3	0
Library Mall	938	East High School	2,437	983	3.1	0
Grainger Hall	5,477	Gordon Commons	3,210	3,210	0.2	2,267

Table 10: Trip Assignment Iteration 3

<b>Origin</b>	<b># People Remaining</b>	<b>Shelter 3</b>	<b>Shelter 3 Capacity</b>	<b>People to Shelter 2</b>	<b>Distance to Shelter 2 (mi)</b>	<b>Remaining Population</b>
Grainger Hall	2,267	Alliant Energy Center	16,386	2,267	2.7	0

As can be seen from Tables 8, 9, and 10 above, two shelter locations were not used during the assignment of the campus population. Lafollette High School and Sennett Middle school did not have any population assigned to them as they are the two farthest shelter destinations recommended for use. Lafollette High School, which is located directly next to Sennett Middle School, is 6.9-8.9 miles away from the Memorial Union depending on the chosen route. It is 7.6-9.7 miles from Lot 40/Babcock Hall to Lafollette High School/Sennett Middle School depending on the chosen route. For this reason, it was decided that these two shelters would be assigned population last if additional capacity was needed. In this case, it was not. However, when choosing shelter locations more capacity than was needed was allotted as a factor of safety as described previously in Section 3.1.2.

The breakdown above brings the total number of trips being made during the evacuation to 17. The mode choice for these trips is then established based on proximity of shelters to the origin points. Any shelters that are within one mile of the origin point will be made on foot. All other trips will be made using a mixture of passenger vehicles and buses that will be determined next.

Table 11: Mode Choice by Trip

<b>Trip #</b>	<b>Origin</b>	<b>Shelter</b>	<b>Distance (mi)</b>	<b>Mode</b>
1	Camp Randall	Alliant Energy Center	2.9	Bus/Car
2	Union South	Kohl Center	0.6	Walk
3	Lot 34/Tripp Circle	Alliant Energy Center	3.5	Bus/Car
4	Lot 40/Babcock Hall	Natatorium	0.4	Walk
5	Memorial Union	Alliant Energy Center	2.8	Bus/Car
6	Library Mall	MATC	5.3	Bus/Car
7	Humanities Building	SERF	0.3	Walk
8	Grainger Hall	SERF	0.3	Walk
9	Art Lofts	Kohl Center	0.1	Walk
10	Dejope Hall	Natatorium	0.4	Walk
11	Educational Sciences	Kohl Center	0.4	Walk
12	Ogg Hall	Gordon Commons	0.1	Walk
13	Witte Hall	Gordon Commons	0.1	Walk
14	Lot 40/Babcock	Alliant Energy Center	3.3	Bus/Car
15	Library Mall	East High School	3.1	Bus/Car
16	Grainger	Gordon Commons	0.2	Walk
17	Grainger	Alliant Energy Center	2.7	Bus/Car

Now that all of the trips occurring have an assigned mode, the vehicle utilization per trip using vehicles can be determined. That is to say that the percentage of buses and cars will be determined for trips 1, 3, 5, 6, 14, 15, and 16 respectively based on capacity. The available vehicles were shown previously in Table 6. Using that capacity information by vehicle type, the vehicles can be assigned to specific trips as shown below.

Table 12: Vehicle Utilization

# People	$V_M$	$V_B$	$V_P$	Total
6,067	81	0	0	81
4,607	62	0	0	62
11,789	71	70	1,482	1,623
8,680	0	50	3,090	3,140
281	0	6	0	6
938	0	7	294	301
2,267	0	7	959	966

Now these inputs can be used in VISSIM to examine various routes and determine an optimal set of routes and procedures. The procedures will be established into a controllable and comprehensive plan as outlined in the next section.

### 3.2.6 Plan Analysis

Using the aforementioned information, the plan can be established in steps. Each step may be revisited and revised as new information becomes available from the simulation regarding routes and clearance times. The recommended best practices are detailed below in a timeline of steps. Certain actions may occur simultaneously and are therefore listed in the same step. These steps have been established using the information presented in Section 3.2 thus far.

1. Discovery of threat; notification of threat to authorities
2. Risk assessment of threat; WiscAlerts sent to tell population to avoid area; transportation contacted; shelter locations contacted
3. Threat confirmed; evacuation procedures begin; transportation requested; shelter notified of imminent evacuation
4. Police/fire road blocks to keep traffic from entering hot zone; on campus shelter areas contacted regarding current occupancies
5. WiscAlerts sent containing evacuation instructions
6. Designated personnel stationed at origins to meet arriving population
7. Designated personnel escort walking evacuees to on campus shelters until capacities are reached at each location
8. First wave of buses arrive to take people to offsite shelters

9. Faculty and staff with cars may now begin to leave with as many passengers as safely fit in their car (number of seatbelts = number of passengers) and follow buses along evacuation routes
10. Continue evacuation until all areas are cleared/all people are sheltered; wait for further instruction
11. Recommend that DOIT technological support set up communications at larger shelters such as Kohl Center, Alliant Energy Center, and MATC to maintain continuity of technological operations
12. Transportation will stay where it is assuming students will need rides back to campus; people in personal passenger vehicles asked not to leave until situation is stabilized
13. Red Cross and Salvation Army may be contacted for assistance if necessary as they provide shelter kits and feeding services as well as any medical assistance

Using these steps as a general procedure, emergency management personnel as well as faculty and staff can have a general idea for how things may pan out during the evacuation. It is especially important to have a guideline to follow in the event that communications between parties becomes disrupted by the detonation of the bomb or other factors. In addition to these steps, some recommendations for information to be included in the plan are as follows.

- Call list of personnel to perform certain actions during an evacuation
- Standoff distances and evacuation perimeters for various types of threats
- Course enrollment and room location information
- Students or other population members with disabilities or special needs
- Shelter points of contact
- Transportation companies points of contact
- Red Cross and other emergency services points of contact

### **3.3 VISSIM Evacuation Simulation**

A microscopic simulation using VISSIM allows for a descriptive analysis of the network, meaning a way to mimic what is happening during the theorized evacuation. The purpose of the simulation is essentially to practice completing the evacuation in a controlled setting for a much lower cost than a full-scale drill, which would involve shutting down many roads and transportation services. Additionally, the simulation aims to produce output such as clearance time of the hot zone using various routes so that optimal routes can be chosen from each origin to each destination, which will be discussed in the following section of this study. In the simulation vehicles can be assigned to various starting links and then these vehicles travel through the network using specified routes. By controlling entrance link locations, volume inputs at these starting nodes, allowable movements, and turning percentages, the evacuation can be modeled as if vehicles are following a pre-established set of guidelines. However, despite this level of control, due to VISSIM's sophisticated driver behavior parameters vehicles will still interact

with one another in the network in a realistic manner. These interactions will allow driver behavior to be dynamic as drivers react to queue build up. This allows queues and bottlenecks to build and occur in a realistic manner based on volumes, link capacities, and driver behavior within the network.

Initially, the simulation process requires the user to build a network comprised of links, traffic control devices, speed zones, conflict areas, and any other necessary elements. Many users also choose to insert traffic detectors into the network in order to measure performance in terms of delays and travel times. In order to ensure accuracy of the network, a detailed background image should be chosen to load into VISSIM. This image is then scaled, usually by measuring the width of a standard travel lane. For this project, a map was created using Google Maps at the 500-foot view level. Each individual 500-foot section of maps was stitched together to form the equivalent of a 2-mile view of the campus and surrounding areas. Now the ability exists to zoom in to the 500-foot level on any section of the map in order to see each relevant road and landmark when building the network. Once this map was completed it was loaded into VISSIM and scaled for accuracy.

After loading and scaling the map of the campus and surrounding areas of Madison, the network was built. Due to the nature of evacuations, most often all routes become outbound routes leading away from the hot zone. Similarly, routes chosen as evacuation routes as detailed in the previous section, are all traveling outbound from campus. This means that all available lanes will be used for one-directional traffic. Of course, some links will be available for inbound travel to allow vehicles such as buses to travel to pick-up points. However, for the purpose of this study the simulation will begin at the point that all vehicles are loaded with passengers and are leaving campus to one of the nine safe nodes. As for the contra flow links, special attention was paid while constructing the network towards turning motions. Because vehicles will be turning sometimes from a 'wrong-way' lane onto another link, conflict areas were carefully analyzed to ensure orderly movement of vehicles.

One area that should be addressed is the use of traffic control devices such as signals. As can be expected, normal traffic operations will not be occurring during the evacuation. Thus, normal traffic control will not suffice and may hinder travel especially in the case of contra flow links where signals and signs will be backwards. Due to the nature of evacuations, traffic is assumed to be slow moving and vehicles traveling in the platoon out of the hot zone should make fewer movements. Certain junctures will occur where some lanes will turn onto a separate link to reach a destination, however traffic streams completely crossing one another should not be prevalent. For this reason in the simulation conflict areas will be assigned such that minor approaches and turning traffic must yield to through traffic, which will be assigned the priority. This can aim to imitate a situation in which traffic signals are set to flashing yellow instead of their normal operations.

Once the network is complete, vehicles and routes may be assigned. VISSIM allows users to set relative vehicle flow compositions, which determines what types of vehicles make up the traffic flow in the network (24). Flows can be comprised of various types of vehicles. VISSIM contains six default vehicle types: car, HGV (heavy vehicles), bus, tram, bicycle, and pedestrian, however other types of vehicles may be created by the user (24). For the purposes of the evacuation simulation, each trip has a different vehicle utilization as shown in the previous section. The vehicle utilization breakdown by trip is shown again below.

Table 13: Vehicle Utilization Review

# People	$V_M$	$V_B$	$V_P$	Total
6,067	81	0	0	81
4,607	62	0	0	62
11,789	71	70	1,482	1,623
8,680	0	50	3,090	3,140
281	0	6	0	6
938	0	7	294	301
2,267	0	7	1,917	1,924

Using this information, the vehicle compositions can be defined for each trip in the simulation. There are a total of seven vehicle compositions defined for the evacuation simulation corresponding to the seven of the sixteen total trips being made using vehicles (as opposed to on foot). The relative flows of cars versus buses is determined by calculating what percentage of the total vehicles used per trip are cars or buses and the results are shown in the table below.

Table 14: Relative Vehicle Flows by Trip

Vehicle Composition # (VISSIM)	Corresponding Trip #	Car Relative Flow	Bus Relative Flow
1	1	0.00	1.00
2	3	0.00	1.00
3	5	0.92	0.08
4	6	0.98	0.02

5	14	0.00	1.00
6	15	0.97	0.03
7	16	0.99	0.01

When assigning vehicle inputs to each origin link in the simulation, these vehicle compositions will be used to ensure the vehicle composition for that trip is in accordance with the vehicle utilization determined by the model for that trip.

After vehicles have been assigned to the links and routes established, travel time sections can be input for analysis purposes. These sections will provide average travel times across the segment defined by the user and is calculated and smoothed continuously while the simulation is running. Additional performance measures that can be used in VISSIM include queue counters and delay measures, however those are more applicable for intersection and signal timing analyses.

Once all of the information necessary is put into the VISSIM model, the simulation can be run. As mentioned earlier, some randomness inherently occurs in VISSIM simulation outputs due to the software's stochastic driver behavior model. For this reason, an ideal number of runs can be determined using a confidence interval based on some preliminary simulation runs. The values analyzed here to run the test will be the travel times from the Memorial Union (Langdon Street) at Park Street to Park Street at Regent Street. The simulation was run a total of four times to obtain some initial travel time results for this section.

Table 15: Preliminary Runs Travel Times

<b>Preliminary Run</b>	<b>Average Travel Time (seconds)</b>
1	106.00
2	106.00
3	106.8
4	103.8
<b>Average</b>	<b>105.65</b>

Using this average travel time across this segment the standard deviation was calculated using the equation below.

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2}$$

Table 16: Standard Deviation Calculation

Travel Times ( $x$ )	$(x - \mu)$	$(x - \mu)^2$
106.00	0.35	0.12
106.00	0.35	0.12
106.8	1.15	1.32
103.8	-1.85	3.42
<b><math>\sigma</math></b>	<b>0.63</b>	

Using the standard deviation calculated above, a confidence interval can be expressed using the standard deviation, the z-statistic, and a margin of error. In the case of the simulation results reliability, a 95% confidence interval will be determined such that it can be stated that with 95% certainty, the true mean of the travel times will fall between certain ranges when the simulation is run a certain number of times. In this case, the standard deviation is known and therefore the normal distribution will be used to compute the confidence intervals.

$$\bar{x} \pm 1.96 \left( \frac{\sigma}{\sqrt{n}} \right)$$

The intervals were computed in Excel for four different number of simulation runs: 10, 20, 25, and 30 runs. As can be expected the greatest range occurred at 10 simulation runs, where it is with 95% certainty that the true mean of the travel times falls within 0.39 seconds of the calculated mean of 105.65 seconds. The smallest range occurred at 30 simulation runs, where it is with 95% certainty that the true mean of the travel times falls within 0.22 seconds of the calculated mean of 105.65 seconds. In this study there isn't a specific performance target to reach regarding travel times out of the hot zone; the values are purely informative giving feedback about the network performance. For this reason, the range obtained at 25 simulation runs will be used. The true mean range at a 95% level of confidence for 25 simulation runs is shown below.

$$105.65 \pm 0.25$$

Now the simulation will be run a total of 25 times to obtain average travel times across six key segments. These six segments are listed below.

1. Park Street at Memorial Union (Langdon Street) to Park Street at Regent Street
2. Langdon Street at Library Mall (Park Street) to Langdon Street at Frances Street
3. State Street at Library Mall to State Street at Frances Street
4. Lot 40/Babcock Hall (Linden Street) to Park Street at Regent Street
5. Lot 34/Tripp Circle (Babcock Drive) to Park Street at Regent Street
6. Park Street at Johnson Street (Grainger Hall) to Park Street at Regent Street

Additionally, the simulation will be evaluated in terms of queue build up and spillback into the hot zone as this would pose dangers to evacuees during an actual evacuation.

## **4 RESULTS ANALYSIS**

### **4.1 Travel Times**

Using the trip assignments determined in section 3.2.5, the VISSIM simulation was run a total of 25 times as was determined using the confidence interval in Section 3.3. During the simulation results regarding travel times out of the hot zone were collected across five key routes. These routes began in the hot zone at Lot 34/Tripp Circle, the Memorial Union, Library Mall, Grainger Hall, and Lot 40/Babcock Hall. The travel time segments analyzed here were as follows.

1. Park Street at Memorial Union (Langdon Street) to Park Street at Regent Street
2. Langdon Street at Library Mall (Park Street) to Langdon Street at Frances Street
3. State Street at Library Mall to State Street at Frances Street
4. Lot 40/Babcock Hall (Linden Street) to Park Street at Regent Street
5. Lot 34/Tripp Circle (Babcock Drive) to Park Street at Regent Street
6. Park Street at Johnson Street (Grainger Hall) to Park Street at Regent Street

The first 25 runs of the simulation using the initial routes produced the following average travel times across the three aforementioned segments. Each simulation run produced a set of average travel times across these segments. The average travel times for each segment were then averaged across all 25 simulation runs to obtain the results in Table 17 below.

Table 17: Travel Times across Key Segments

<b>Segment</b>	<b>Average Travel Time (seconds)</b>
1	66.9
2	28.1
3	29.9
4	125.4
5	140.9
6	48.5

These travel times give an initial result for how long on average it will take a vehicle departing from one of the origins to clear the hot zone in the evacuation traffic conditions. Visually, the biggest slowdown of vehicle progression through the network is along Park Street heading south toward Olin Avenue and the Alliant Energy Center and along East Washington Avenue north toward MATC and East High School. Because the second congestion occurs well outside of the hot zone perimeter and does not create queue spillback into the hot zone perimeter, those routes will be left as is. However, the congestion along Park Street did initially create some queue spillback into the hot zone perimeter, which could trap vehicles in the hot zone. For this reason the routes of vehicles traveling on this section of Park Street will be analyzed further.

Currently vehicles traveling from the Memorial Union to the Alliant Energy Center and vehicles traveling from lot 40/Babcock Hall to the Alliant Energy Center are all at some point utilizing Park Street to access Olin Avenue south of the intersection with West Washington Avenue. In an effort to relieve some of the congestion some alternative routes will be introduced into the simulation in an effort to relieve congestion along Park Street.

In order to combat this small bit of congestion, the vehicle composition option in VISSIM's routing tab will be manipulated such that car traffic must divert along Proudfit Street via Regent Street in order to access John Nolen Drive when heading to the Alliant Energy Center. This will open up Park Street to Olin Avenue to bus traffic only and should ease some congestion. Once this routing change is made the simulation is run an additional 25 times using the new route conditions. The secondary travel times across the key segments is once again analyzed and shown below.

Table 18: Travel Times across Key Segments after Route Changes

Segment	Average Travel Time (seconds)
1	64.1
2	27.6
3	29.6
4	120.6
5	134.9
6	46.7

Using the secondary travel times obtained by averaging the travel times for each segment across 25 simulation runs using the new routes, the percent change in travel time can be assessed. This will help determine if the route changes made helped to alleviate the congestion on Park Street during the evacuation simulation.

Table 19: Percent Change in Travel Times after Route Changes

Segment	Travel Time 1	Travel Time 2	% Change
1	66.9	64.1	-4.19
2	28.1	27.6	-1.78
3	29.9	39.6	-1.00
4	125.4	120.6	-3.83
5	140.9	134.9	-4.26
6	48.5	46.7	-3.71

From the raw data it appears that all of the travel times have improved along all segments of interest. However, some of these changes could be due to noise or randomness despite the simulation being run 25 times. For this reason a significance analysis can be completed to see if the change in the travel times can be confidently attributed to the route change and not chance. For this significance test a Student's T-Test will be used. The average percent change in the travel times for segment 1 will be calculated in the first 25 runs before the route change. This will look at how this travel time value varied across the first 25 simulation runs. Next the percent

change between the average travel time across segment one over all of the first 25 simulation runs and the new travel time for segment one can be calculated.

The average percent change between the initial travel time across segment 1 and the new travel times in the second 25 runs can be calculated. Next the standard deviation of the percent changes in travel times across segment 1 was calculated. Here the value of  $n$  is 25 as there are 25 secondary simulation runs that produced travel times to compare to the first set average on segment 1. The  $t$ -value can be calculated as shown by the equation below.

$$t = |(\mu - \bar{x}) / \frac{\sigma}{\sqrt{n}}|$$

Finally, the probability,  $p$ , that the change is due only to chance can be computed using the  $t$ -distribution function in Excel. The Excel table is shown below.

Table 20: T-Test Results Segment 1

Variable	Value
$\mu$	-0.01%
$x_{bar}$	4.19%
$\sigma$	0.03
$n$	25.00
$t$	798.02
$p$	0.00%

As can be seen from the  $t$ -test results above, the  $t$ -test produced a probability of 0.00% that the change in the travel times were due to chance for segment 1. This same procedure can be carried out for each of the five remaining segments to ensure that noise or chance has not contributed to the decrease in travel times. The results for  $p$  for each segment are shown below.

Table 21: T-Test Probabilities for All Segments

Segment	$p$ (%)
1	0.00
2	0.00
3	0.00
4	0.00

5	0.00
6	0.00

## 4.2 Emergency Action Plan

**Organization Name:** University of Wisconsin-Madison

**Address:** Madison, WI 53706

**Organization Contact:** Hannah Silber

**Telephone:** (202) 746-8507

**Email:** hsilber@wisc.edu

### Alerts

In the event of an emergency, employees and students are alerted by:

WiscAlerts Email Warning

WiscAlerts Text Message Warning

A WiscAlerts email warning will be sent by UWPD to ALL community members with a UW network ID

A WiscAlerts text message warning will be sent by UWPD to those students and other community members who have registered for text message alerts and to ALL faculty

Faculty are required by terms of employment to provide their cellular phone number for emergency communications purposes

### Policy

The policy of this establishment in the event of fire or other emergency is as follows

In the event of fire, ALL employees and students shall evacuate immediately

In the event of other emergencies, ALL employees and students shall follow evacuation instructions sent using WiscAlerts

### Routes

In the event of an emergency necessitating evacuation, employees and students shall evacuate as follows

For a fire, ALL employees and students shall evacuate using the nearest available marked emergency exit

For a general evacuation, ALL employees and students shall follow WiscAlerts directions regarding assembly locations and choose the nearest available assembly location that can be accessed without passing closer to the identified threat

Faculty members are expected to direct students when possible and assist in evacuation procedures

#### On-Campus Shelters Walking Routes

Union South to Kohl Center USE W DAYTON STREET

Lot 40/Babcock Hall to Natatorium USE LINDEN DRIVE TO OBSERVATORY DRIVE

Humanities Building to Southeast Recreational Facility (SERF) USE EAST CAMPUS MALL TO W DAYTON STREET

Grainger Hall to Southeast Recreational Facility (SERF) USE PARK STREET TO W DAYTON STREET

Art Lofts to Kohl Center USE FRANCES STREET

Dejope Hall to Natatorium USE ELM STREET TO OBSERVATORY DRIVE

Educational Sciences to Kohl Center USE JOHNSON STREET TO BROOKS STREET TO W DAYTON STREET

Ogg Hall to Gordon Commons USE W DAYTON STREET

Witte Hall to Gordon Commons USE LAKE STREET TO W DAYTON STREET

Grainger Hall to Gordon Commons USE PARK STREET TO W DAYTON STREET

#### Off Site Shelters Vehicle Routes to Clear Campus (full routes given in Section 7.1.5)

Camp Randall to Alliant Energy Center USE REGENT STREET TO PARK STREET

Lot 34/Tripp Circle to Alliant Energy Center USE OBSERVATORY DRIVE TO BABCOCK DRIVE TO JOHNSON STREET TO PARK STREET

Memorial Union to Alliant Energy Center USE PARK STREET

Library Mall to MATC Truax Campus USE STATE STREET

Lot 40/Babcock Hall to Alliant Energy Center USE BABCOCK DRIVE TO JOHNSON STREET TO PARK STREET

Library Mall to East High School USE LANGDON STREET

Grainger Hall to Alliant Energy Center USE PARK STREET

### **Extinguishers**

Portable fire extinguishers are provided in campus facilities for employee use. In the event of a fire, any employee may use extinguishers to attempt to extinguish the fire before evacuating. Students may not use extinguishers to attempt to extinguish the fire before evacuating.

### **Operations**

In the event of an emergency, the following employees are to remain on campus if it is reasonably safe to do so to shut down or monitor critical operations before they evacuate

Division of Information Technology (DoIT) Situation Managers

Office of the Registrar Situation Managers

University Transportation Services Situation Managers

UWPD Emergency Management

### **Duties**

The following employees are to perform rescue or medical duties during an emergency

UWPD

City of Madison Fire Department

City of Madison Police Department

Licensed Paramedics

### **Assembly**

After the call for an emergency evacuation, employees and students are to gather in the following location(s)

Camp Randall Stadium | 1400 Monroe Street, Madison, WI 53711

Union South | 1308 W Dayton Street, Madison, WI 53715

Lot 34/Tripp Circle | 1480 Tripp Circle, Madison, WI 53706

Lot 40/Babcock Hall | 1655 Linden Drive, Madison, WI 53706

Memorial Union | 800 Langdon Street, Madison WI 53706

Library Mall | 728 State Street, Madison, WI 53706

Humanities Building | 455 N Park Street, Madison, WI 53706

Grainger Hall | 975 University Avenue, Madison, WI 53706

Art Lofts | 111 N Frances Street, Madison, WI 53703

Dejope Hall | 640 Elm Drive, Madison, WI 53706

Educational Sciences | 1025 W Johnson Street, Madison, WI 53706

Ogg Hall | 835 W Dayton Street, Madison, WI 53706

Witte Hall | 615 W Johnson Street, Madison, WI 53706

### **Accounting**

After an emergency evacuation, the procedure for accounting for students is as follows

Appointed situation managers will be given handheld scanners to scan Wiscards at shelter locations

The number of Wiscards scanned will be compared with enrollment data for the day and time of the incident occurrence

Students that are unaccounted for will be contacted by Office of the Registrar Situation Managers

### **Additional Information**

Additional Evacuation Plan and Procedures

Vehicle availability recommendations

Madison Metro Bus

Badger Bus Company

Personal Vehicles if accessible

Other private bus companies (i.e. Lamers)

## 5 CONCLUSIONS AND FUTURE RECOMMENDATIONS

As populations and prevalence of disasters both natural and technological continue to increase the years go by, the importance of establishing clear, efficient and effective emergency management systems also increases. It is unfortunately apparent that horrible things are at risk of happening all the time. Hurricanes, floods, wildfires, plane crashes, airborne toxins, and explosions are infrequent, yet detrimental occurrences. Without proper engineering systems in place to anticipate the effects of and suggest responses and procedures for these disasters, it would be impossible to keep people safe and recover efficiently.

At the University of Wisconsin-Madison campus, the community has already experienced one such disaster. In 1970, a bomb was detonated outside of Sterling Hall on campus. This disaster caused extensive damage and at the time was the worst act of domestic terrorism yet experienced. Students, faculty, staff, families, and the greater community count on their daily environment to be safe. No one plans to be involved in a disaster when they leave for work or school. It is the responsibility of emergency management personnel to have comprehensive plans and procedures to keep the population of interest safe in the event of a disaster.

For the aforementioned reasons, it was the goal of this study to analyze various aspects of the campus population, geographical features, roadways, and many other factors in order to develop an evacuation plan for the UW-Madison campus community. Various logistics were considered in the development of this plan regarding the type of threat, the size of the daytime population on campus, the distribution of this population during different times of day, transportation needs, and plan procedures. These logistics were used to develop a six step traffic demand model that determined trip origins, shelter destinations, trip departure time based on available warning systems, vehicle utilization, route assignment and mode split based on available transportation, and finally how all of these steps combine to form a plan for an evacuation. Based on the trip generation and population assignment determined in the model, a simulation was created and run using VISSIM, a microscopic traffic simulation software. Using a stochastic driver behavior model and many sensitive adjustable parameters, VISSIM allowed for an evacuation of the campus population to be descriptively simulated. This provided a visual evaluation of the initial route and travel times from origins to points out of the hot zone. The simulation was run and some points of congestion were identified. Based on these preliminary results, the routes were analyzed and expanded to relieve congestion along Park Street, one of the key corridors used in the evacuation. The result of this re-routing caused a decrease in average travel times across all travel time analysis segments. Finally these changes in travel times were tested for significance to ensure all improvements occurred due to route changes and not chance or noise in the network data.

While this project has provided a set of recommendations for evacuation procedures based on an extensive analysis of the campus dynamics, room for improvement always exists.

One area that should be examined is regarding the nuclear reactor located on campus. A disaster resulting from instability of the reactor would cause much more damage and affect a larger area than the incident analyzed in this study. Establishing standoff distances and evacuation or sheltering procedures for a situation involving the nuclear reactor would involve a much larger area. Additionally, many more features such as an increased transportation need and the possibility that city transportation such as the Madison Metro may no longer be available for use by the campus. This would provide many complications to be addressed in an emergency management plan. While an evacuation of this extent was outside the scope of this study, the plan and procedures created here can be adapted to fit other disaster situations such as the reactor.

Another area that would be beneficial to improve upon would be the real-time dynamics of a full-scale evacuation of the campus population. This would involve an evacuation drill including as many members of the campus population as is possible. A full-scale evacuation would provide invaluable feedback regarding clearance times and logistical issues, it would be a costly and time consuming endeavor. A drill of this nature would critically disrupt many operations such as class instruction, technology use, transportation services, city and campus vehicular traffic, and operations occurring at the shelter locations. However, it is an option that could be explored and would allow for the testing of various steps. WiscAlerts warning message formats and effectiveness as well as testing of the use of other types of siren warnings could also be evaluated to improve the trip departure step of the model without undertaking a full-scale evacuation.

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## **7 APPENDICES**

### **7.1 Plan**

#### **7.1.1 Steps**

1. Discovery of threat and notification of threat to authorities
2. Risk assessment of threat, WiscAlerts warning sent to tell population to avoid area, transportation (buses) contacted, shelter locations contacted: warning
3. Threat confirmed, evacuation procedures begin, transportation (buses) requested, shelters notified of imminent evacuation
4. Police/fire road blocks to keep traffic from entering hot zone, on campus shelter areas contacted regarding current occupancy
5. WiscAlerts warning sent containing evacuation instructions (where to meet)
6. Designated personnel stationed at origins to meet arriving people
7. Designated personnel escort walking evacuees to on campus shelters until capacities are reached at each location
8. First wave of buses arrive to take people to shelters
9. Faculty and staff with cars may now begin to leave with as many passengers as safely fit in their car (number of seatbelts = number of passengers) and follow buses along evacuation routes
10. Continue evacuation until all areas are cleared/all people are sheltered and wait for further instruction
11. Recommend that DOIT tech trucks be deployed to set up communications at larger shelters such as Kohl Center, Alliant Energy Center, and MATC to keep people updated on the situation.
12. Transportation will stay where it is assuming students will need rides back to campus afterward
13. Red Cross and Salvation Army can be contacted for assistance if necessary as they provide shelter kits and feeding as well as any medical assistance (stress or minor injuries etc.)

### 7.1.2 Origins

1. Camp Randall Stadium | 1440 Monroe Street, Madison, WI 53711
2. Union South | 1308 W Dayton Street, Madison, WI 53715
3. Lot 34/Tripp Circle | 1480 Tripp Circle, Madison, WI 53706
4. Lot 40/Babcock Hall | 1655 Linden Drive, Madison, WI 53706
5. Memorial Union | 800 Langdon Street, Madison, WI 53706
6. Library Mall | 728 State Street, Madison, WI 53706
7. Humanities Building | 455 N Park Street, Madison, WI 53706
8. Grainger Hall | 975 University Avenue, Madison, WI 53706
9. Art Lofts | 111 N Frances Street, Madison, WI 53703
10. Dejope Hall | 640 Elm Drive, Madison, WI 53706
11. Educational Sciences | 1025 W Johnson Street, Madison, WI 53706
12. Ogg Hall | 835 W Dayton Street, Madison, WI 53706
13. Witte Hall | 615 W Johnson Street, Madison, WI 53706

### 7.1.3 Shelters

1. Alliant Energy Center | 1919 Alliant Energy Center Way, Madison, WI 53713
  - a. Arena
  - b. Exhibition Hall
  - c. Pavilions 1 & 2
  - d. Coliseum
2. MATC Truax Campus | 1701 Wright Street, Madison, WI 53704
3. East High School | 2222 E Washington Avenue, Madison, WI 53704
4. Kohl Center | 601 W Dayton Street, Madison, WI 53703
5. UW Natatorium | 2000 Observatory Drive, Madison, WI 53706
6. Southeast Recreational Facility (SERF) | 715 W Dayton Street, Madison, WI 53715
7. Sennett Middle School | 502 Pflaum Road, Madison, WI 53716
8. Lafollette High School | 702 Pflaum Road, Madison, WI 53716
9. Gordon Commons | 770 W Dayton Street, Madison, WI 53706

### 7.1.4 Transportation

Table 22: Available Vehicle Capacities

Vehicle Type	# Available Vehicles	Total Capacity (persons)
$V_M$	214	16,050
$V_B$	140	7,000
$V_P$	8,753	17,506

Table 23: On Campus Shelters Walking Routes

Origin	Shelter	Distance (miles)	Route
Union South	Kohl Center	0.6	Dayton Street
Lot 40/Babcock Hall	Natatorium	0.4	Linden Drive → Observatory Drive
Humanities Building	SERF	0.3	East Campus Mall → Dayton Street
Grainger Hall	SERF	0.3	Park Street → Dayton Street
Art Lofts	Kohl Center	0.1	Frances Street
Dejope Hall	Natatorium	0.4	Elm Street → Observatory Drive
Educational Sciences	Kohl Center	0.4	Johnson Street → Brooks Street → Dayton Street
Ogg Hall	Gordon Commons	0.1	Dayton Street
Witte Hall	Gordon Commons	0.1	Lake Street → Dayton Street
Grainger Hall	Gordon Commons	0.2	Park Street → Dayton Street

### 7.1.5 Routes

Table 24: Off Site Shelters Vehicle Routes

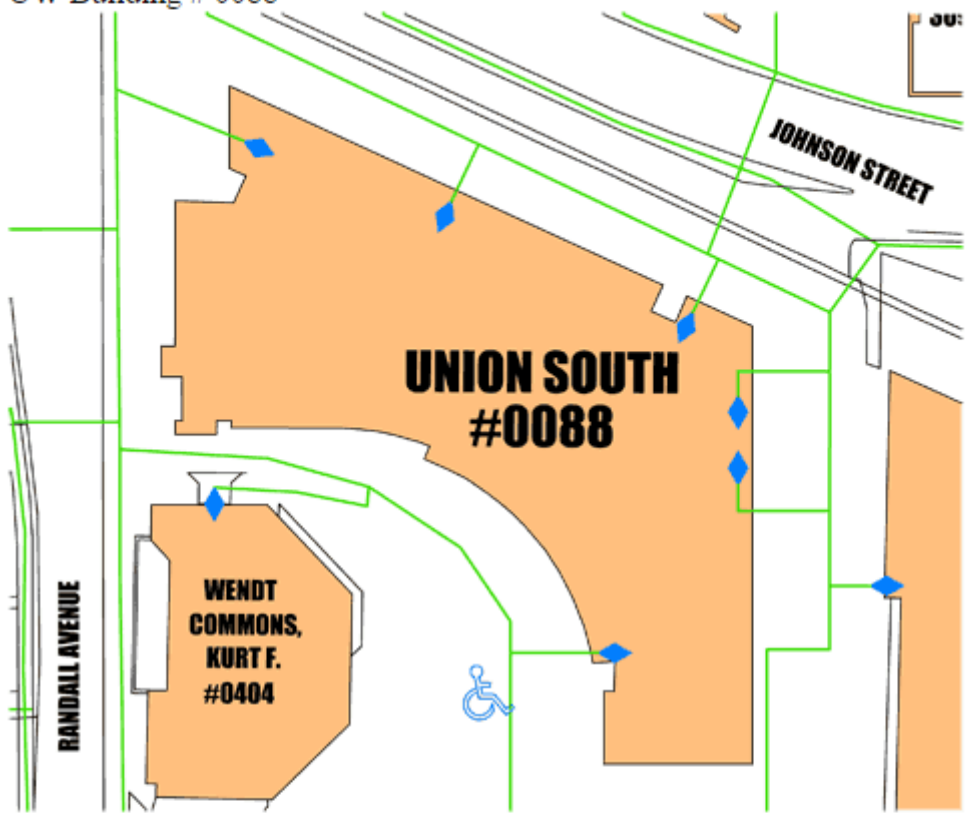
<b>Origin</b>	<b>Shelter</b>	<b>Distance (miles)</b>	<b>Route</b>
Camp Randall	Alliant Energy Center	2.9	Regent Street → Park Street → Olin Avenue → Expo Way
Lot 34/Tripp Circle	Alliant Energy Center	3.5	Observatory Drive → Babcock Drive → Johnson Street → Park Street → Olin Avenue → John Nolen Drive
Memorial Union	Alliant Energy Center	2.8	Park Street → Olin Avenue → John Nolen Drive
Library Mall	MATC Truax Campus	5.3	State Street → Mifflin Street → East Washington Avenue → Stoughton Road
Lot 40/Babcock Hall	Alliant Energy Center	3.3	Babcock Drive → Johnson Street → Park Street → Olin Avenue → Expo Way
Library Mall	East High School	3.1	Langdon Street → Carroll Street → Johnson Street
Grainger Hall	Alliant Energy Center	2.7	Park Street → Regent Street → Proudfit Street → John Nolen Drive



Union South

**Union South**

UW Building # 0088












-  Power door
-  Gentle slope paved (0-6%)
-  Gentle slope unpaved (0-6%)
-  Moderate slope paved (6-9%)
-  Steep slope paved (>9%)
-  Disabled parking-restrictions may apply
-  Parking ramp with elevator
-  Railroad tracks
-  Emergency telephone

Figure 18: Union South (30).

Babcock Hall

**Babcock Hall**

UW Building # 0106

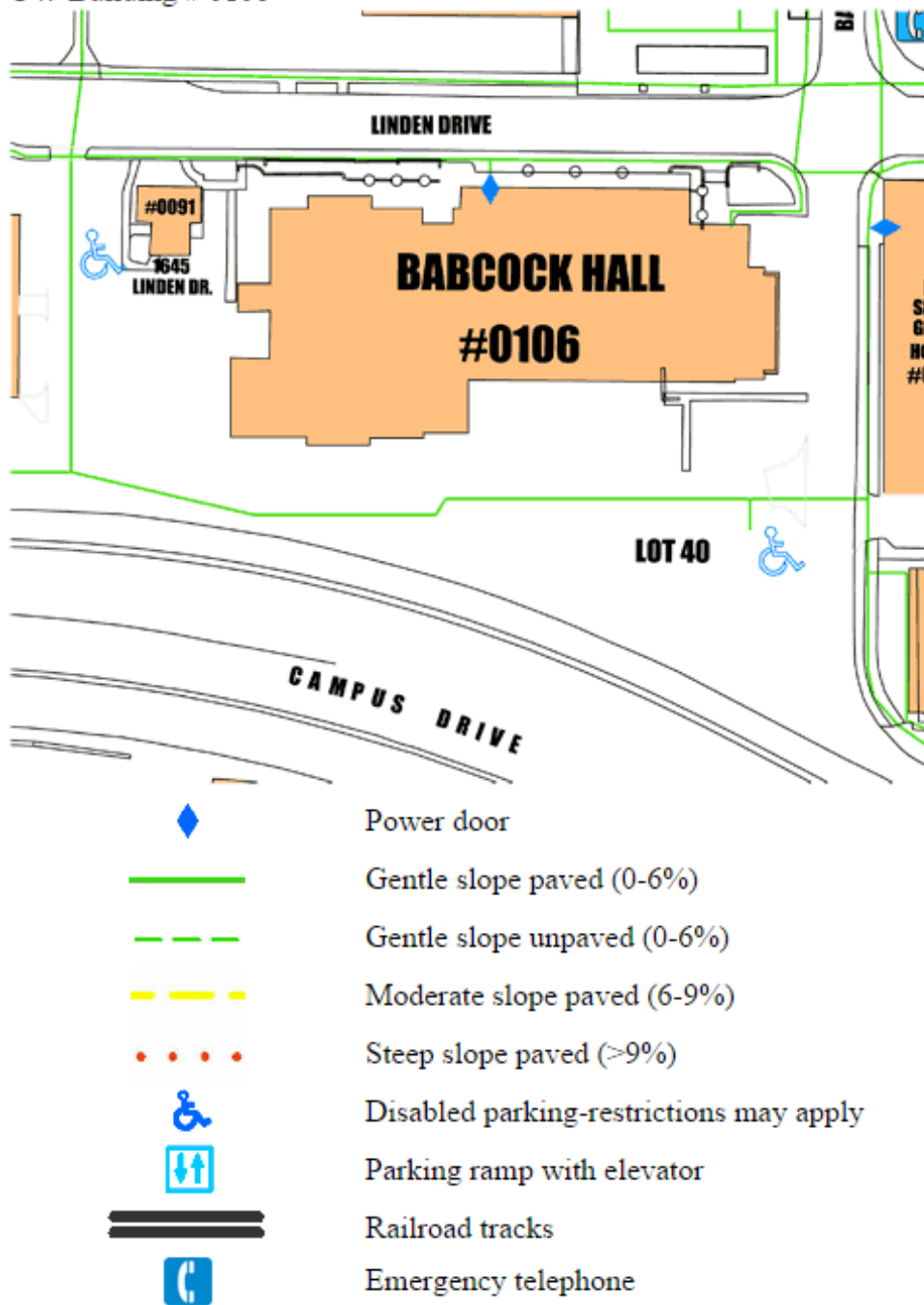
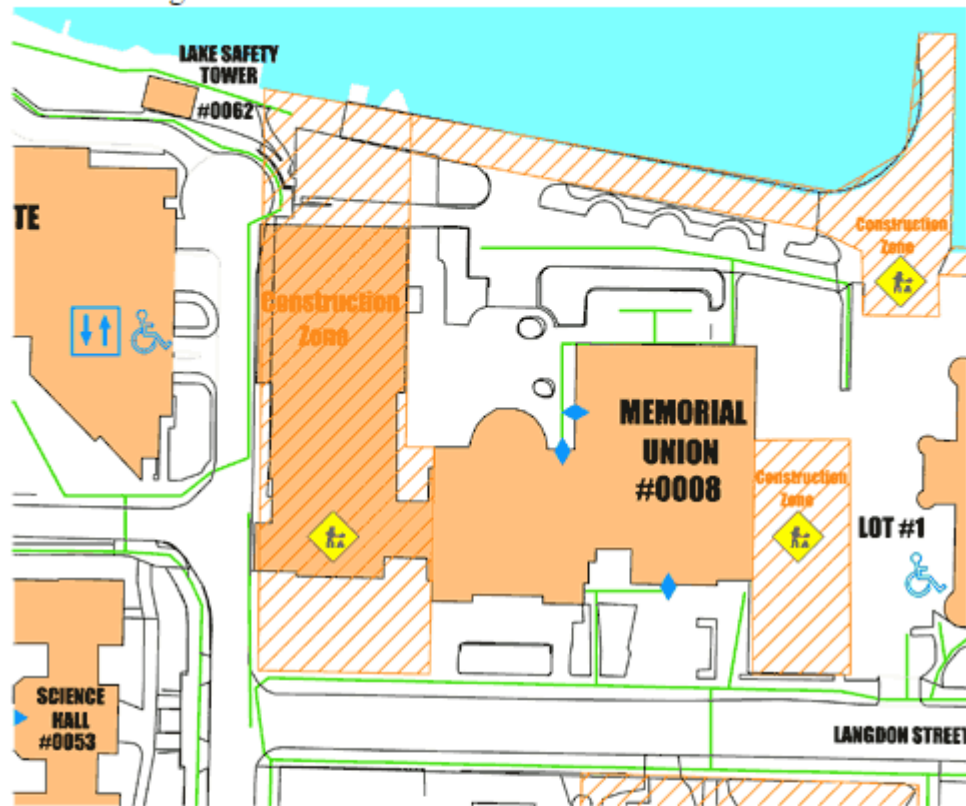


Figure 19: Babcock Hall (30).

Memorial Union

# Memorial Union

UW Building # 0008












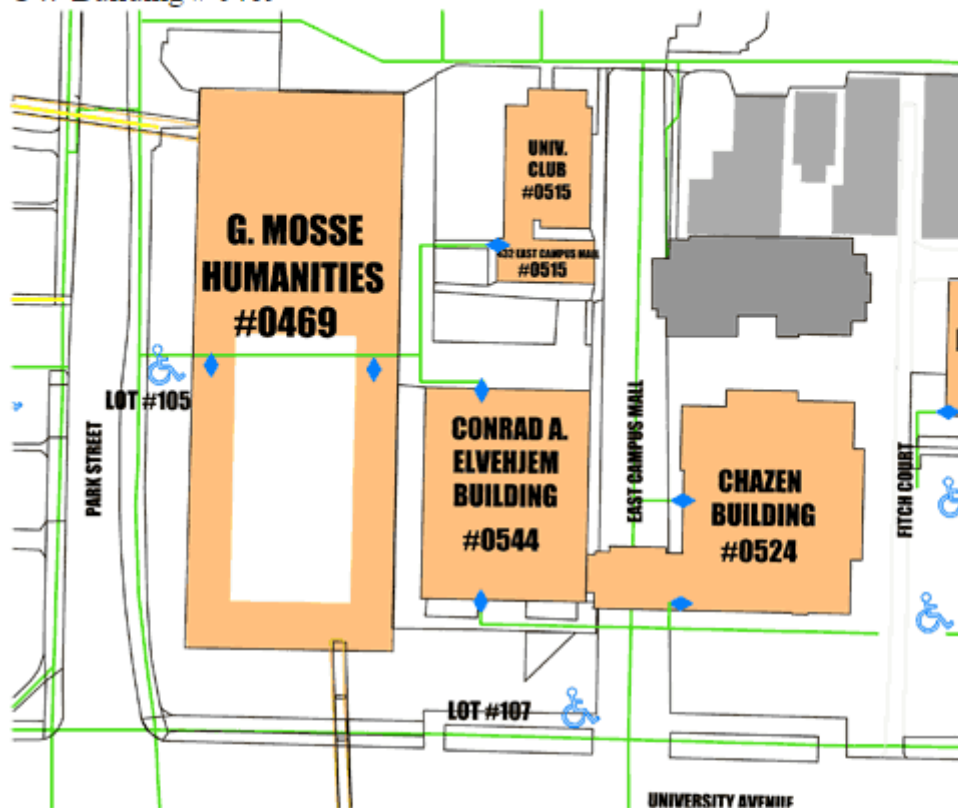
-  Power door
-  Gentle slope paved (0-6%)
-  Gentle slope unpaved (0-6%)
-  Moderate slope paved (6-9%)
-  Steep slope paved (>9%)
-  Disabled parking-restrictions may apply
-  Parking ramp with elevator
-  Railroad tracks
-  Emergency telephone

Figure 20: Memorial Union (30).

Humanities Building

## Humanities Building, Mosse, George L

UW Building # 0469












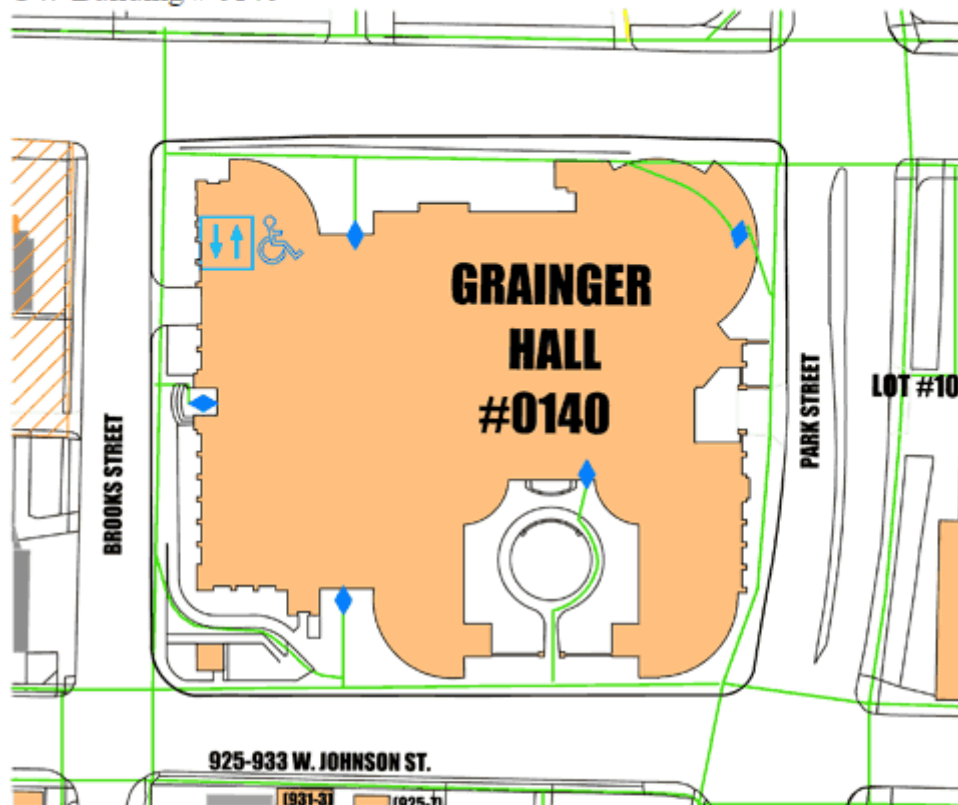
-  Power door
-  Gentle slope paved (0-6%)
-  Gentle slope unpaved (0-6%)
-  Moderate slope paved (6-9%)
-  Steep slope paved (>9%)
-  Disabled parking-restrictions may apply
-  Parking ramp with elevator
-  Railroad tracks
-  Emergency telephone

Figure 21: Humanities Building (30).

Grainger Hall

**Grainger Hall**

UW Building # 0140












-  Power door
-  Gentle slope paved (0-6%)
-  Gentle slope unpaved (0-6%)
-  Moderate slope paved (6-9%)
-  Steep slope paved (>9%)
-  Disabled parking-restrictions may apply
-  Parking ramp with elevator
-  Railroad tracks
-  Emergency telephone

Figure 22: Grainger Hall (30).

### Art Lofts

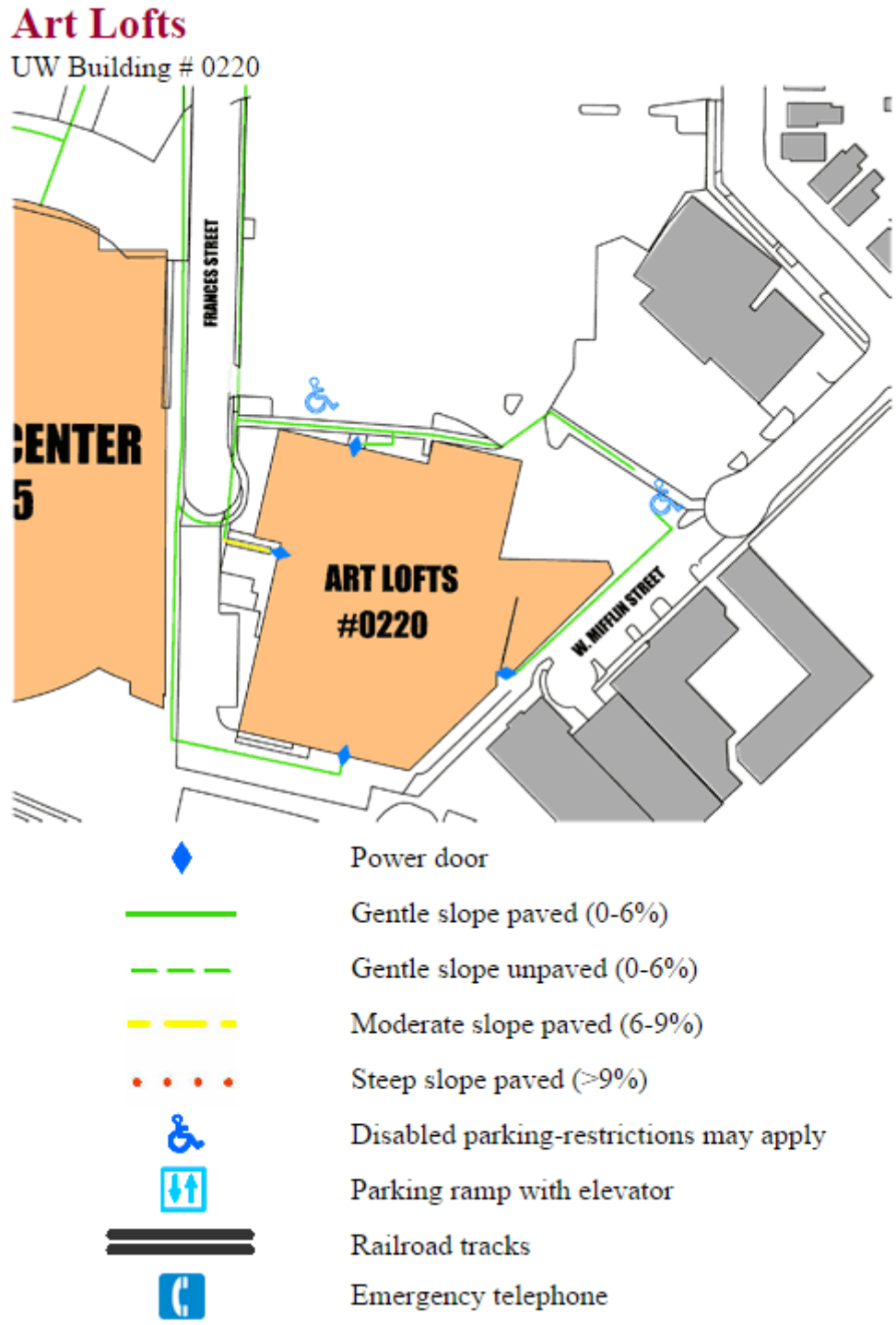
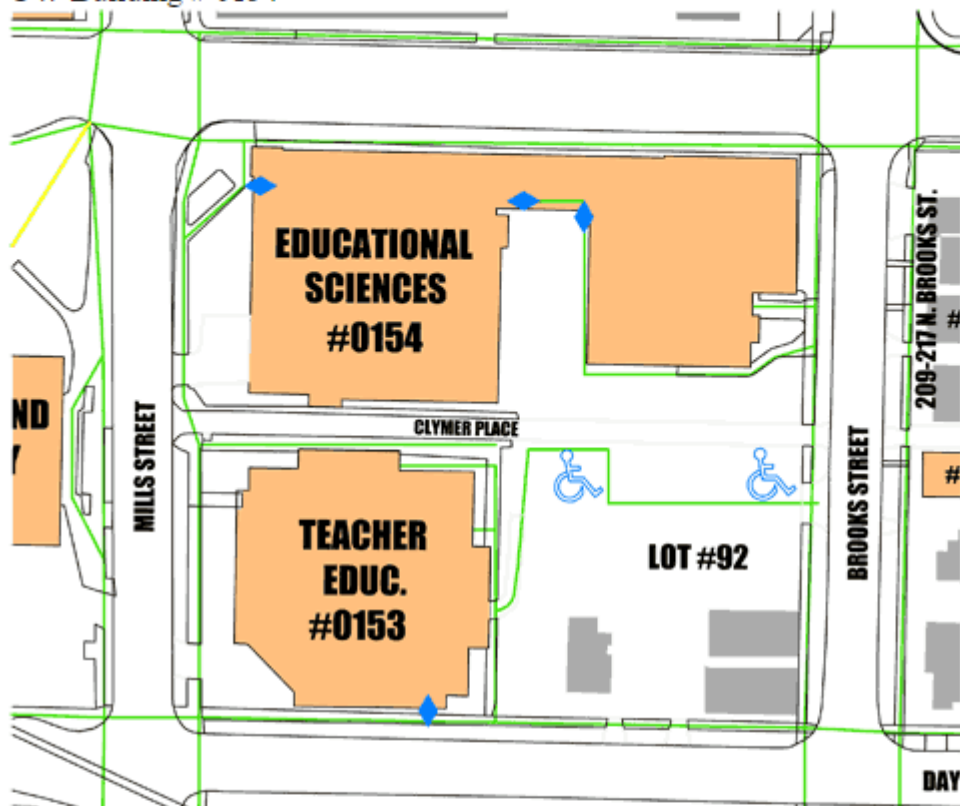


Figure 23: Art Lofts (30).

Educational Sciences

## Educational Sciences

UW Building # 0154












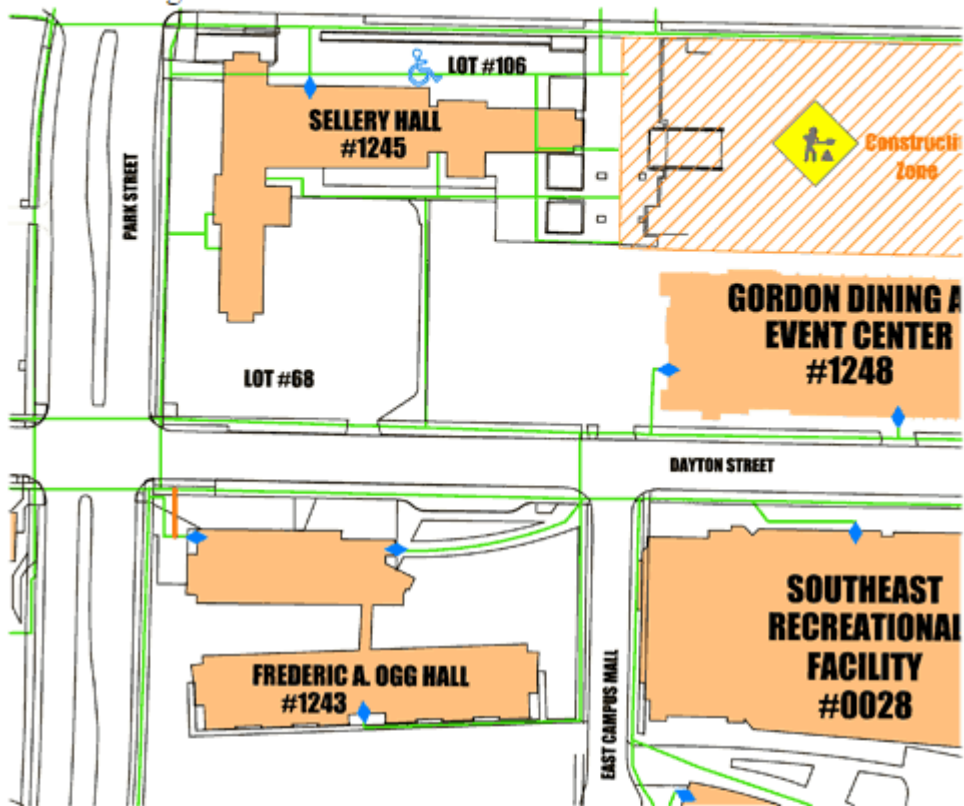
-  Power door
-  Gentle slope paved (0-6%)
-  Gentle slope unpaved (0-6%)
-  Moderate slope paved (6-9%)
-  Steep slope paved (>9%)
-  Disabled parking-restrictions may apply
-  Parking ramp with elevator
-  Railroad tracks
-  Emergency telephone

Figure 24: Educational Sciences (30).

Ogg Hall

# Ogg Residence Hall, Frederic A

UW Building # 1243












-  Power door
-  Gentle slope paved (0-6%)
-  Gentle slope unpaved (0-6%)
-  Moderate slope paved (6-9%)
-  Steep slope paved (>9%)
-  Disabled parking-restrictions may apply
-  Parking ramp with elevator
-  Railroad tracks
-  Emergency telephone

Figure 25: Ogg Residence Hall (30).

### 7.1.7 On-Campus Shelter Buildings Accessibility Information

#### Kohl Center

## Kohl Center, The

UW Building # 0225

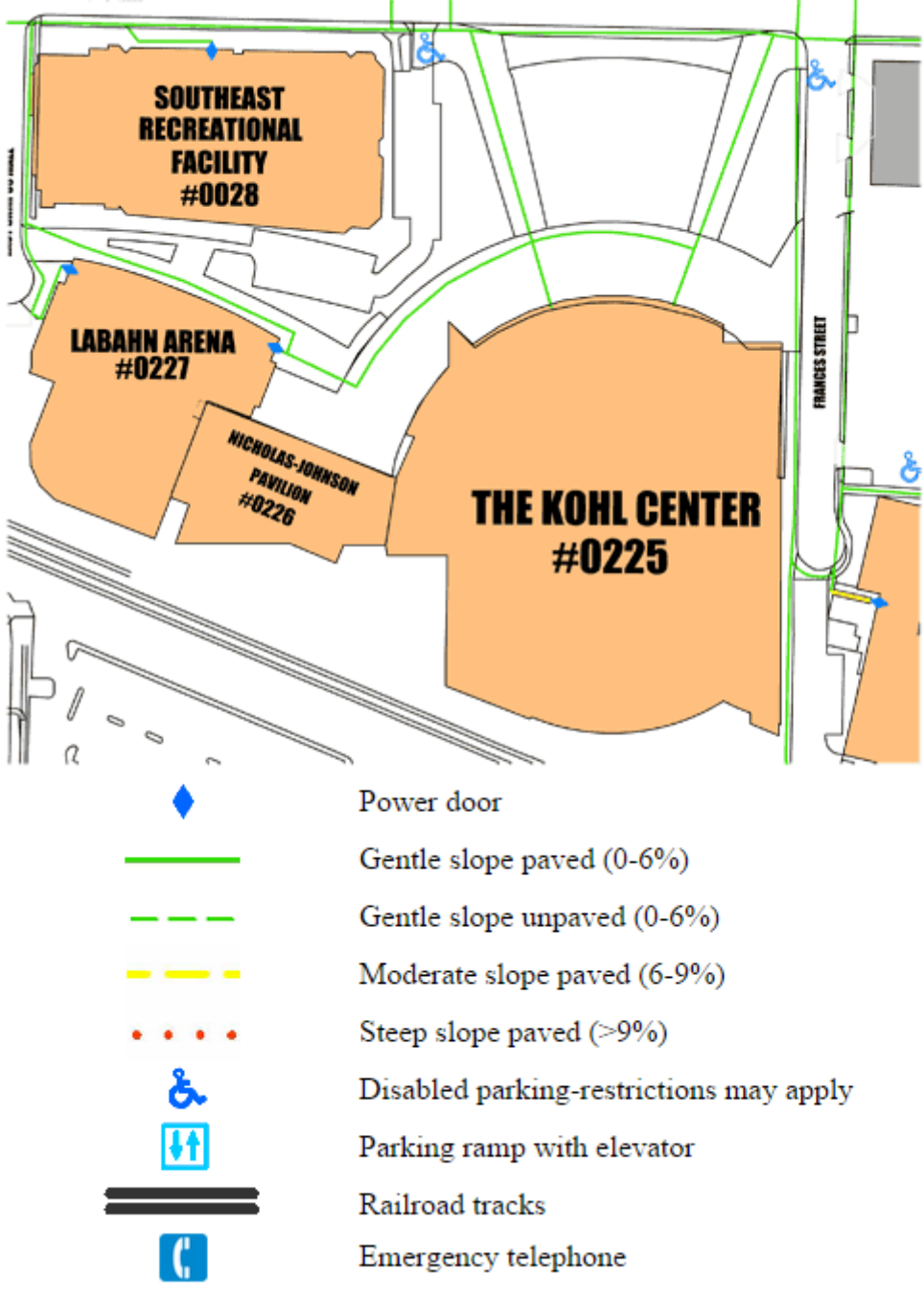
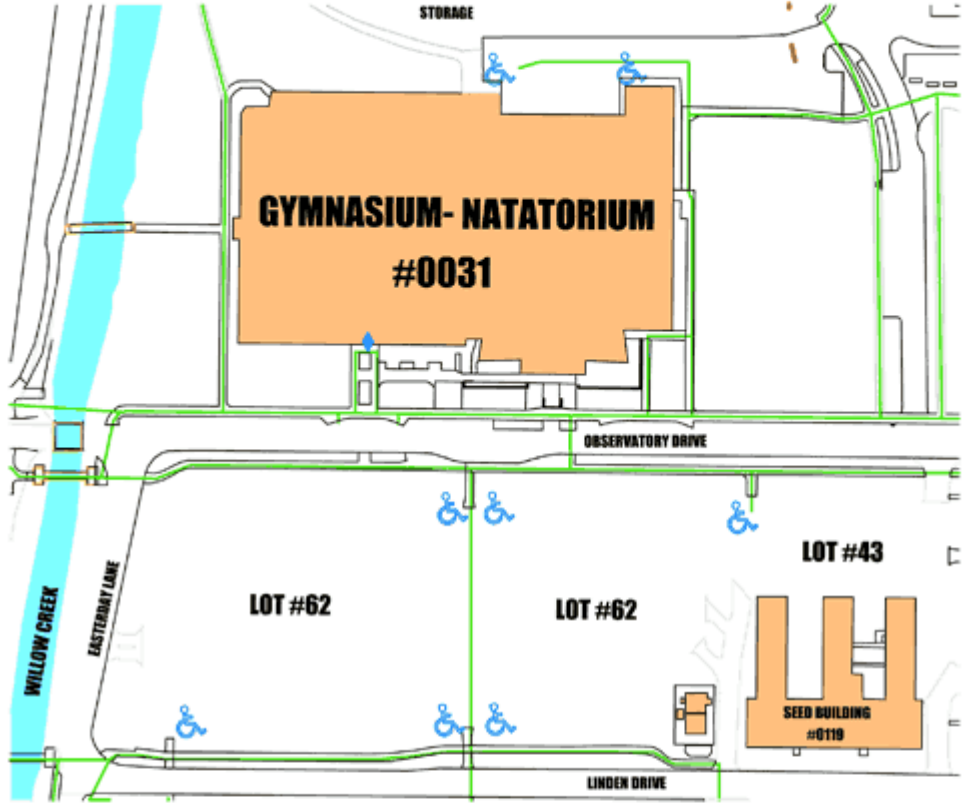


Figure 26: Kohl Center (30).

Natatorium

### Gymnasium-Natatorium

UW Building # 0031












-  Power door
-  Gentle slope paved (0-6%)
-  Gentle slope unpaved (0-6%)
-  Moderate slope paved (6-9%)
-  Step slope paved (>9%)
-  Disabled parking-restrictions may apply
-  Parking ramp with elevator
-  Railroad tracks
-  Emergency telephone

Figure 27: Natatorium (30).

SERF

# Southeast Recreational Facility

UW Building # 0028

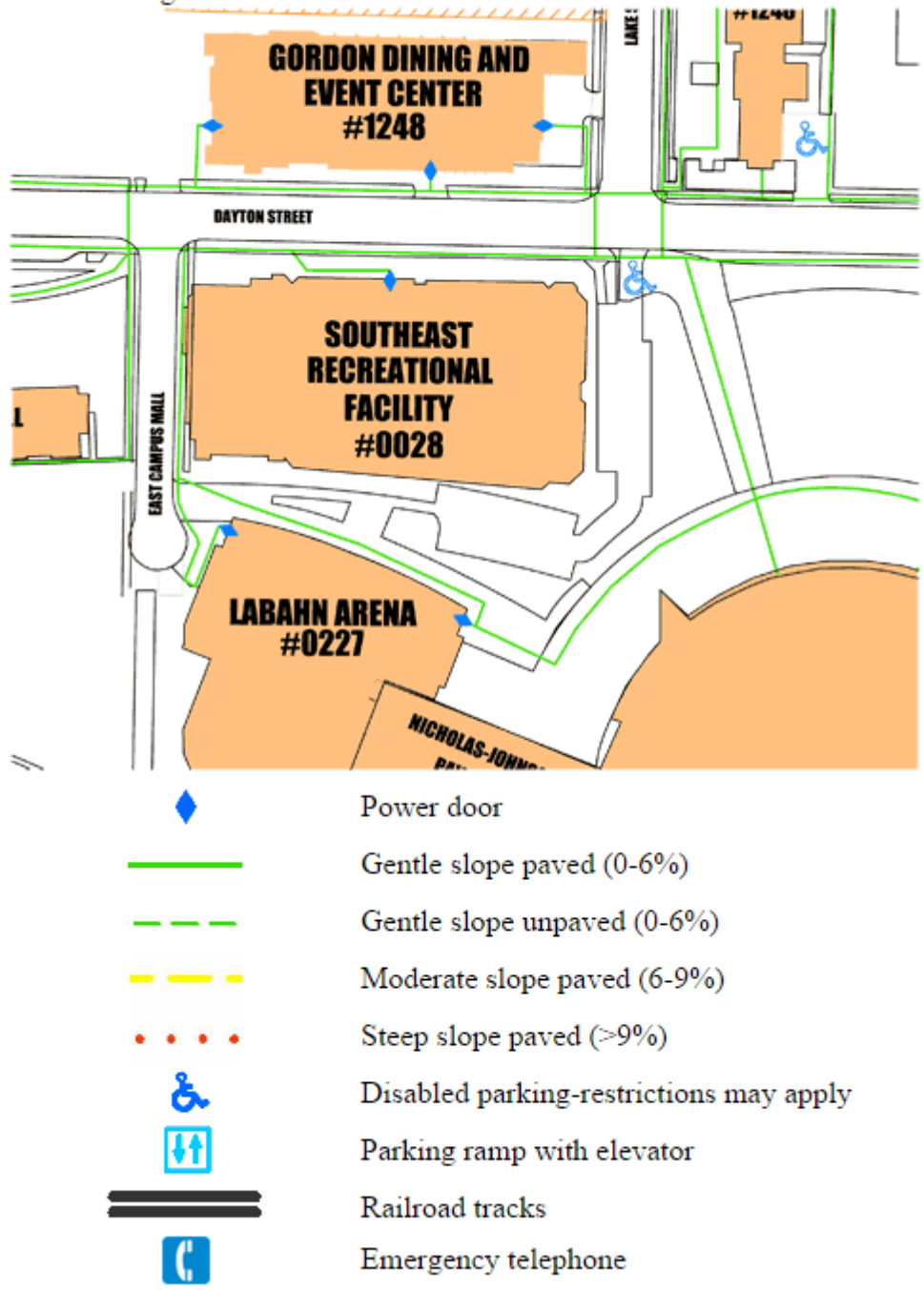


Figure 28: Southeast Recreational Facility (SERF) (30).

## 7.2 Bomb Threat Form UWPD

### Bomb Threats

If you receive a bomb threat by telephone, here are some helpful things to keep in mind:

1. **Remain Calm.** When bomb threat is received, the person taking the call must remain calm and obtain as much information as possible.
  - a. **DO NOT put the caller on hold**
  - b. **DO NOT attempt to transfer the call**
2. The person taking the call should immediately notify another staff person in the office, preferably while the caller is still on the line.
3. Pay close attention to the caller and his/her words and speech:
  - a. Does the caller have any distinguishing voice characteristics such as an accent, stuttering, mispronunciation?
  - b. Is the caller angry, excited, irrational or agitated?
  - c. Is the caller a man or woman, young, middle-aged, old?
  - d. If you have caller ID, please note the phone number of the caller
4. Listen for background noises (traffic, train whistle, music, radio, TV, children, etc.).
5. It is important that you document all that you know and hear. This should include filling out the **Bomb Threat Checklist**.

#### **BOMB THREAT CHECK LIST**

*(STAY CALM AND COLLECT ALL THE INFORMATION YOU CAN)*

**NAME OF PERSON**

Who Received Threat: \_\_\_\_\_

**DATE & TIME** \_\_\_\_\_

A.M.

Threat Received: \_\_\_\_\_

P.M.

How was **THREAT REPORTED**: Telephone \_\_\_\_\_ E-mail \_\_\_\_\_ Give Phone Number (include Area Code): \_\_\_\_\_

In Person \_\_\_\_\_ Voice-Mail \_\_\_\_\_ Fax \_\_\_\_\_

By MAIL Carrier (e.g. FED EX): \_\_\_\_\_ Campus \_\_\_\_\_ US Mail \_\_\_\_\_ Courier \_\_\_\_\_

**LOCATION THREATENED:** \_\_\_\_\_

*(Give name of Bldg/Dept/Office/Agency, etc.)*

**EXACT WORDS USED** to make the threat (if possible): \_\_\_\_\_

#### **QUESTIONS TO ASK THE PERSON MAKING THE THREAT:**

1. **WHEN IS THE BOMB GOING TO EXPLODE?** \_\_\_\_\_
2. **WHERE is the bomb located?** \_\_\_\_\_
3. **WHAT kind of bomb is it?** \_\_\_\_\_
4. **WHAT does it look like?** \_\_\_\_\_
5. **WHO placed the bomb?** \_\_\_\_\_
6. **WHY was the bomb placed?** \_\_\_\_\_
7. **Where are you calling from?** \_\_\_\_\_

Figure 29: Bomb Threat Checklist (28).

### 7.3 Class Schedule Data Tables

Table 25: Wednesday Classes by Time of Day

Classes Beginning Between	Cells	# Classes	Percent	Enrollment
7:00-10:00	2-799	798	29.05%	26519
10:15-1:00	800-1531	732	26.65%	28229
1:10-4:00	1532-2540	1009	36.73%	32342
4:10-7:00	2541-2733	193	7.03%	4176
7:05 on	2734-2748	15	0.55%	309

Total Classes                      2747

Table 26: Origin Codes

Code	Origin
1	Camp Randall
2	Union South
3	Lot 34/Tripp Circle Babcock Hall/lot
4	40
5	Memorial Union
6	Library Mall (State @ Lake)
7	Humanities
8	Grainger
9	Art lofts (walk only)
10	Dejope (walk only)
11	Already out of evacuation bubble
12	Education Sci (walk only)
13	Ogg (walk only)
14	Witte (walk only)

Table 27: Origin Population Percentages

Origin Code	%	Decimal	People
1	0.1	0.0005	32.58
1	0.1	0.0005	32.58
1	0.3	0.0032	208.54
1	5.9	0.0591	3851.49

	1	0.3	0.0028	182.47
	1	2.5	0.0251	1635.74
	1	0.2	0.0019	123.82
<b>Sum</b>		<b>9.3</b>	<b>0.0931</b>	<b>6067.23</b>
	2	8.2	0.082	5343.86
	2	1.1	0.0111	723.38
	2	0.2	0.0023	149.89
	2	0.2	0.0018	117.30
	2	0.2	0.0017	110.79
	2	0.6	0.0061	397.53
	2	3.6	0.0363	2365.63
	2	0.1	0.0011	71.69
	2	0.4	0.0038	247.64
	2	0.9	0.0094	612.59
<b>Sum</b>		<b>15.6</b>	<b>0.1556</b>	<b>10140.30</b>
	3	0.1	0.0005	32.58
	3	0.5	0.0048	312.81
	3	0.1	0.0012	78.20
	3	0.4	0.0042	273.71
	3	0.4	0.0037	241.13
	3	5.6	0.0563	3669.01
<b>Sum</b>		<b>7.1</b>	<b>0.0707</b>	<b>4607.45</b>
	4	0.0	0.0003	19.55
	4	0.3	0.0028	182.47
	4	1.0	0.0102	664.72
	4	0.8	0.0082	534.39
	4	0.1	0.0006	39.10
	4	0.0	0.0003	19.55
	4	2.6	0.0258	1681.36
	4	0.1	0.0012	78.20
	4	0.1	0.0011	71.69
	4	0.1	0.0005	32.58
	4	0.5	0.0048	312.81
	4	0.8	0.0076	495.28
	4	0.2	0.0019	123.82
	4	0.0	0.0003	19.55
<b>Sum</b>		<b>6.6</b>	<b>0.0656</b>	<b>4275.09</b>
	5	2.0	0.0202	1316.41
	5	1.2	0.012	782.03
	5	4.8	0.0477	3108.56
	5	0.0	0.0004	26.07
	5	1.1	0.011	716.86
	5	7.8	0.0778	5070.15

	5	1.2	0.0118	768.99
<b>Sum</b>		<b>18.1</b>	<b>0.1809</b>	<b>11789.07</b>
	6	1.5	0.015	977.54
	6	3.1	0.0307	2000.69
	6	1.5	0.0145	944.95
	6	0.1	0.0014	91.24
	6	2.4	0.0241	1570.57
	6	6.2	0.0619	4033.96
<b>Sum</b>		<b>14.8</b>	<b>0.1476</b>	<b>9618.94</b>
	7	0.1	0.0007	45.62
	7	0.5	0.0046	299.78
	7	7.1	0.071	4627.00
<b>Sum</b>		<b>7.6</b>	<b>0.0763</b>	<b>4972.39</b>
	8	0.0	0.0003	19.55
	8	7.1	0.0709	4620.48
	8	0.7	0.0067	436.63
	8	2.5	0.025	1629.23
<b>Sum</b>		<b>10.3</b>	<b>0.1029</b>	<b>6705.89</b>
	9	0.1	0.0005	32.58
<b>Sum</b>		<b>0.1</b>	<b>0.0005</b>	<b>32.58</b>
	10	0.0	0.0003	19.55
	10	0.1	0.0009	58.65
	10	0.1	0.0012	78.20
<b>Sum</b>		<b>0.2</b>	<b>0.0024</b>	<b>156.41</b>
	11	0.5	0.0046	299.78
	11	0.5	0.0046	299.78
	11	0.6	0.0063	410.56
	11	1.7	0.0165	1075.29
	11	0.8	0.0081	527.87
	11	0.2	0.0016	104.27
<b>Sum</b>		<b>4.2</b>	<b>0.0417</b>	<b>2717.55</b>
	12	3.0	0.0297	1935.52
	12	2.6	0.0259	1687.88
	12	0.1	0.0009	58.65
<b>Sum</b>		<b>5.7</b>	<b>0.0565</b>	<b>3682.05</b>
	13	0.2	0.0019	123.82
	13	0.1	0.0013	84.72
<b>Sum</b>		<b>0.3</b>	<b>0.0032</b>	<b>208.54</b>
	14	0.2	0.0022	143.37
	14	0.1	0.0009	58.65
<b>Sum</b>		<b>0.3</b>	<b>0.0031</b>	<b>202.02</b>

## 7.4 VISSIM Results Tables

Table 28: First 25 Run Travel Times

Sim Run	Segment	TT	
1	1	1	66.8
1	1	2	28.1
1	1	3	29.9
1	1	4	126.2
1	1	5	140.9
1	1	6	48.6
2	2	1	66.9
2	2	2	28.1
2	2	3	29.9
2	2	4	125.4
2	2	5	140.9
2	2	6	48.5
3	3	1	66.9
3	3	2	28.1
3	3	3	29.9
3	3	4	125.4
3	3	5	140.9
3	3	6	48.5
4	4	1	66.9
4	4	2	28.1
4	4	3	29.9
4	4	4	125.4
4	4	5	140.9
4	4	6	48.5
5	5	1	66.9
5	5	2	28.1
5	5	3	29.9
5	5	4	125.4
5	5	5	140.9
5	5	6	48.5
6	6	1	66.9
6	6	2	28.1
6	6	3	29.9

6	4	125.4
6	5	140.9
6	6	48.5
7	1	66.9
7	2	28.1
7	3	29.9
7	4	125.4
7	5	140.9
7	6	48.5
8	1	66.9
8	2	28.1
8	3	29.9
8	4	125.4
8	5	140.9
8	6	48.5
9	1	66.9
9	2	28.1
9	3	29.9
9	4	125.4
9	5	140.9
9	6	48.5
10	1	66.9
10	2	28.1
10	3	29.9
10	4	125.4
10	5	140.9
10	6	48.5
Sim Run	Segment	TT
11	1	66.9
11	2	28.1
11	3	29.9
11	4	125.4
11	5	140.9
11	6	48.5
12	1	66.9
12	2	28.1
12	3	29.9
12	4	125.4

12	5	140.9
12	6	48.5
13	1	66.9
13	2	28.1
13	3	29.9
13	4	125.4
13	5	140.9
13	6	48.5
14	1	66.9
14	2	28.1
14	3	29.9
14	4	125.4
14	5	140.9
14	6	48.5
15	1	66.9
15	2	28.1
15	3	29.9
15	4	125.9
15	5	140.9
15	6	48.5
16	1	66.9
16	2	28.1
16	3	29.9
16	4	125.4
16	5	140.9
16	6	48.5
17	1	66.9
17	2	28.1
17	3	29.9
17	4	125.4
17	5	140.9
17	6	48.5
18	1	66.9
18	2	28.1
18	3	29.9
18	4	125.4
18	5	140.9

18	6	48.5
19	1	66.9
19	2	28.1
19	3	29.9
19	4	125.4
19	5	140.9
19	6	48.5
20	1	66.9
20	2	28.1
20	3	29.9
20	4	125.4
20	5	140.9
20	6	48.5
Sim Run	Segment	TT
21	1	66.9
21	2	28.1
21	3	29.9
21	4	125.4
21	5	140.9
21	6	48.5
22	1	66.9
22	2	28.1
22	3	29.9
22	4	125.4
22	5	140.9
22	6	48.5
23	1	66.9
23	2	28.1
23	3	29.9
23	4	125.4
23	5	140.9
23	6	48.5
24	1	66.9
24	2	28.1
24	3	29.9
24	4	125.4
24	5	140.9
24	6	48.9

25	1	66.9
25	2	28.1
25	3	29.9
25	4	125.4
25	5	140.9
25	6	48.5

Table 29: Second 25 Run Travel Times

Sim Run	Segment	TT
1	1	64.1
1	2	27.6
1	3	29.6
1	4	120.6
1	5	135.5
1	6	46.7
2	1	64.1
2	2	27.6
2	3	29.6
2	4	120.6
2	5	135.5
2	6	46.7
3	1	64.1
3	2	27.6
3	3	29.6
3	4	120.6
3	5	135.5
3	6	46.7
4	1	64.1
4	2	27.6
4	3	29.6
4	4	120.6
4	5	135.5
4	6	46.7
5	1	64.1
5	2	27.6
5	3	29.6

5	4	120.6
5	5	135.5
5	6	46.7
6	1	64.1
6	2	27.6
6	3	29.6
6	4	120.6
6	5	135.5
6	6	46.7
7	1	64.1
7	2	27.6
7	3	29.6
7	4	123.9
7	5	135.5
7	6	46.7
8	1	64.1
8	2	27.6
8	3	29.6
8	4	120.6
8	5	135.5
8	6	46.7
9	1	64.1
9	2	27.6
9	3	29.6
9	4	124.6
9	5	135.5
9	6	46.7
10	1	64.1
10	2	27.6
10	3	29.6
10	4	120.6
10	5	135.5
10	6	46.7
Sim Run	Segment	TT
11	1	64.1
11	2	27.6
11	3	29.6
11	4	120.6

11	5	134.9
11	6	46.7
12	1	64.1
12	2	27.6
12	3	29.6
12	4	120.6
12	5	134.9
12	6	46.7
13	1	64.1
13	2	27.6
13	3	29.6
13	4	120.6
13	5	134.9
13	6	46.7
14	1	64.1
14	2	27.6
14	3	29.6
14	4	120.6
14	5	134.9
14	6	46.7
15	1	65.8
15	2	27.6
15	3	29.6
15	4	120.6
15	5	134.9
15	6	46.7
16	1	66.2
16	2	27.6
16	3	29.6
16	4	120.6
16	5	134.9
16	6	46.7
17	1	64.1
17	2	27.6
17	3	29.6
17	4	120.6
17	5	134.9

17	6	46.7
18	1	64.1
18	2	27.6
18	3	29.6
18	4	120.6
18	5	134.9
18	6	46.7
19	1	64.1
19	2	27.6
19	3	29.6
19	4	120.6
19	5	134.9
19	6	46.7
20	1	64.1
20	2	27.6
20	3	29.6
20	4	120.6
20	5	134.9
20	6	46.7
Sim Run	Segment	TT
21	1	64.1
21	2	27.6
21	3	29.6
21	4	120.6
21	5	135.5
21	6	46.7
22	1	64.1
22	2	27.6
22	3	29.6
22	4	120.6
22	5	135.5
22	6	46.7
23	1	64.1
23	2	27.6
23	3	29.6
23	4	120.6
23	5	135.5
23	6	46.7

24	1	64.1
24	2	27.6
24	3	29.6
24	4	120.6
24	5	135.5
24	6	46.7

25	1	64.1
25	2	27.6
25	3	29.6
25	4	120.6
25	5	135.5
25	6	48.6