**Center for Accessibility and Safety for an Aging Population**

**Florida State University**

**In Partnership with Florida A&M University and University of North Florida**

# RESEARCH FINAL REPORT

# Needs Assessment for Multi-modal Emergency Transportation Operations with a Focus on an Aging Population


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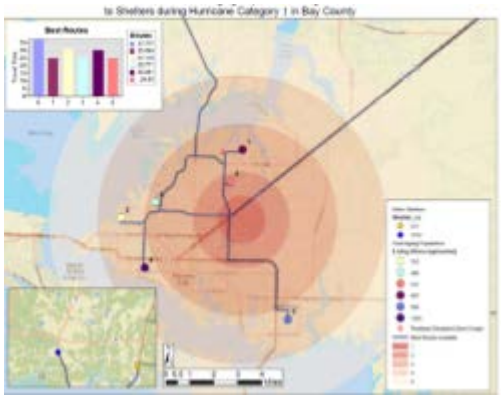

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**Needs Assessment for Multi-modal Emergency Transportation Operations with a Focus on an Aging Population**

# Final Report


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16. Abstract

In the aftermath of disasters, evacuating aging victims and maintaining an optimal transportation of critical resources in order to serve their needs becomes problematic, especially for Gulf Coast states in the USA such as Florida, where more than 6.9 million (36.9%) of the overall population are over age 50. Recent experience with Hurricane Katrina showed that fatalities are disproportionately aging people who live independently and who are not willing or able to evacuate. From a transportation perspective, this problem becomes even more challenging when we consider roadway disruptions that can drastically affect the emergency transportation operations. Scanning the literature, there is no substantial prior work that has synthesized the requirements for a detailed multi-modal operational emergency needs assessment that could facilitate safe and accessible evacuation of aging people, and optimize the transportation of critical resources into the affected disaster region to satisfy the needs of those who remain. This project describes the conceptual foundation and components necessary to create such a knowledge base with importance given to both ensuring the resiliency of the transportation infrastructure and meeting the needs of aging population. Evaluating this comprehensive knowledge base, operational emergency transportation needs in order to serve the aging populations are also identified. To help address these needs, geographic information system (GIS)-based tools can assist agencies with optimal and efficient solutions/strategies to transport aging victims, optimize shelter locations, and provide vital commodities in the aftermath of disasters. Therefore, following a thorough analysis of the knowledge base, this project focuses on the development of more efficient emergency management methodologies with a focus on aging populations. These methodologies are also supported by an aging victim-focused and GIS-based case study application set in the District 3 region as identified by the Florida Department of Transportation.

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## List of Abbreviations

American Association of Retired Persons (AARP)
Association of State and Territorial Health Officials (ASTHO)
Centers for Disease Control and Prevention (CDC)
Conference of Minority Transportation Officials (COMTO)
Dynamic Traffic Assignment (DTA)
Federal Emergency Management Agency (FEMA)
Federal Highway Administration (FHWA)
Geographic Information Systems (GIS)
Florida Department of Transportation (FDOT)
Florida Health Care Association (FHCA)
Florida State University (FSU)
Florida A&M University (FAMU)
State Emergency Response Team (SERT)
University of North Florida (UNF)
US Government Accountability Office (GAO)

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**Abstract**

In the aftermath of disasters, evacuating aging victims and maintaining an optimal transportation of critical resources in order to serve their needs becomes problematic, especially for Gulf Coast states in the USA such as Florida, where more than 6.9 million (36.9%) of the overall population are over age 50. Recent experience with Hurricane Katrina showed that fatalities are disproportionately aging people who live independently and who are not willing or able to evacuate. From a transportation perspective, this problem becomes even more challenging when we consider roadway disruptions that can drastically affect the emergency transportation operations. Scanning the literature, there is no substantial prior work that has synthesized the requirements for a detailed multi-modal operational emergency needs assessment that could facilitate safe and accessible evacuation of aging people, and optimize the transportation of critical resources into the affected disaster region to satisfy the needs of those who remain. This project describes the conceptual foundation and components necessary to create such a knowledge base with importance given to both ensuring the resiliency of the transportation infrastructure and meeting the needs of aging population. Evaluating this comprehensive knowledge base, operational emergency transportation needs in order to serve the aging populations are also identified. To help address these needs, geographic information system (GIS)-based tools can assist agencies with optimal and efficient solutions/strategies to transport aging victims, optimizing shelter locations, and provide vital commodities in the aftermath of disasters. Therefore, following a thorough analysis of the knowledge base, this project focuses on the development of more efficient emergency

management methodologies with a focus on aging populations. These methodologies are also supported by an aging victim-focused and GIS-based case study application set in the District 3 region as identified by the Florida Department of Transportation.

# Chapter 1 Introduction

Disasters, natural or man-made, are extreme events often occurring with little or no warning. Figure 1.1, which depicts the natural disasters that occurred between 1900 and 2011, clearly shows that we are vulnerable to disasters all around the world (1). Some recently affected countries like Turkey, Haiti and Japan are extremely vulnerable to severe earthquakes that can kill many people and seriously disrupt the daily lives of survivors. Moreover, the Gulf Coast States in the USA such as Florida and Mississippi frequently experience major hurricanes such as the infamous Hurricane Katrina. There is also a growing need for research on emergency response due to other disasters such as nuclear power plant failures, industrial accidents, and man-made attacks. Millions of people each year are affected by disasters, which makes the management of emergency supply flow over transportation networks a key issue for the survival of victims.

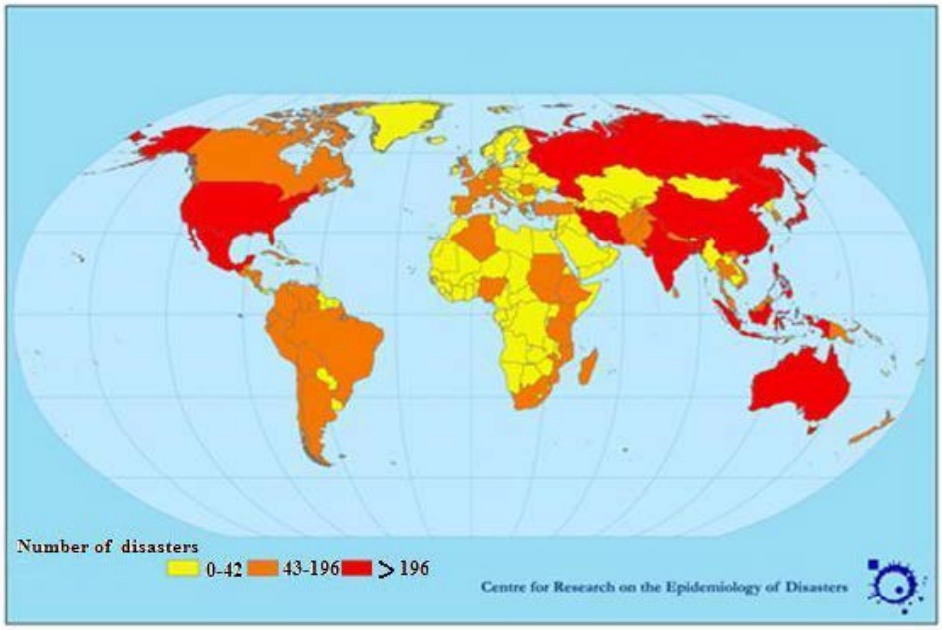



**Figure 1.1.** Number of Natural Disasters by Country between 1900 and 2011 (1).

This issue even becomes more problematic when the focus is on the aging population. A real story that happened in the aftermath of Katrina clearly reflects this by presenting the importance of efficient emergency supply management. It reveals the inadequate distribution and availability of vital resources:

> *An elderly man came into our shelter in Waveland. He said that his wife just had surgery yesterday and that they were still staying at their property. I asked if there was anything he needed. I still tear up when I remember what he said: "It would be nice if we could have a blanket for my wife."* (2)

This anecdote reflects what happened in the aftermath of hurricane Katrina and clearly shows that one of the most important issues to consider after a disaster is addressing the basic survival needs of aging population victims. Among the 1,800 persons died in Hurricane Katrina and its aftermath, the fatalities were mostly aging people, with 71% of the victims older than 60, and 47% over the age of 75 since most of the aging victims living independently were either disabled or had mobility restrictions (3). Moreover, a nationwide survey conducted as a part of an American Association of Retired Persons (AARP) report similarly stated that, among the interviewees that experienced Katrina, 13 % of adults that were over the age of 50 or older and 25 % over the age of 75 needed assistance for evacuating (Figure 1.2) (4).

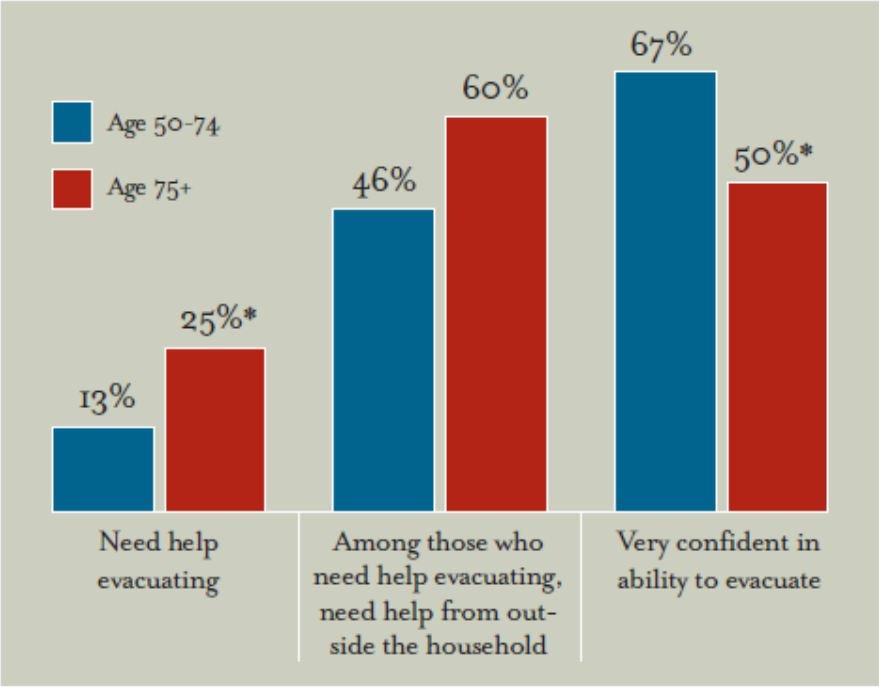



**Figure 1.2.** Help Needed Evacuating in Event of Natural Disaster by Age

*Difference from 50-74 is statistically significant at 5% (4).

The recent superstorm Sandy in the Northeast USA also had a devastating effect on the elderly who were not willing to or unable to evacuate. According to a Guardian report (5), some of these aging victims actually drowned while trying to flee or stay at home due to flooding. Moreover, survival needs were not effectively satisfied at emergency shelters after Hurricane Katrina (Table 1.1) (6). According to this study, 56% of shelter residents were left without adequate food, 54% without adequate water, and 32% without medical supplies.

**Table 1.1** Experiences of Houston Shelter Residents (6)

| | Residents (Total=680) (%) |
|---|---|
| Spent time inside the New Orleans Superdome | 35 |
| Spent time inside the New Orleans Convention Center | 7 |
| Spent at least 1 day living on a street or overpass | 40 |
| Went without adequate food | 56 |
| Went without adequate water | 54 |
| Went without prescription medicine | 32 |

Therefore, painful lessons learnt during recent disasters such as Hurricane Katrina reveal the vulnerability of aging people during emergency evacuations due to their functional or economical limitations, sensory, physical and cognitive disabilities. This indicates that, after the disasters, life was not very simple for the aging victims who were trying to meet these survival needs. For example, of the 1,833 people who died during/after Katrina, almost 71% of the victims were 60 and older (3). These aging victims were living alone in the rural areas, needed special assistance to evacuate as a result of their mobility restrictions or lacked access to vehicles. Therefore, during the recovery period after a disaster, the emergency evacuation, rescue, and commodity supply activities should be able to satisfy the basic needs of aging people even if the transportation network is heavily damaged or degraded. In the literature, there are a number of objectives pursued by planners, researchers and engineers to develop efficient emergency transportation management methodologies. The majority of studies on emergency demand and supply management, however, focus on a general disaster situation without specifically addressing the specific needs of aging victims. Emergency transportation management for aging people, in nature and characteristics, should be primarily concerned with

their welfare, and therefore should try to better incorporate information on their behavioral, disability and other health needs (effects of physical, mental and psychological limitations or disabilities of aging population on emergency operations planning). These planning and operational needs compel us to develop efficient and successful emergency management methodologies with a focus on aging people.

In the context of humanitarian logistics, emergency transportation management is a complex task that depends on the characteristics of an extreme event and the population in the affected region. The need to study the unique features of emergency logistics have been recently recognized (7-11). Although this is critical, transportation with a focus on aging populations is a research area which has not been largely addressed by researchers and officials planning for emergency operations (12). The majority of studies focus on humanitarian logistics without addressing the specific needs of aging victims. Emergency transportation management for aging people should be primarily concerned with their welfare, and therefore should try to better incorporate information on their physical, mental and psychological limitations or disabilities, and other health needs. These planning and operational considerations motivate us to develop more effective emergency management methodologies with a focus on aging people. Since aging people may need special assistance both during emergency evacuation and sheltering, disaster plans should clearly specify how these needs can be addressed and how related problems can be solved by public and/or private humanitarian agencies. To help solve these problems, geographic information system (GIS)-based tools can assist government agencies with practical, optimal, and efficient solutions/strategies to transport aging victims and vital commodities in the aftermath of disasters.

Focusing on these problems, the aim of this project is to answer the following key questions that emergency transportation plans and models should attempt to address:

- Can the aging people secure or be provided enough resources (food, water, clothing, etc.) and adequate shelter so that they can survive for a relatively extended period of time after the disaster?
- Will aging people have the opportunity to receive the emergency care they may need? Will adequate resources be in place?
- Can relief shelters be located and allocated optimally to conduct safe and accessible emergency evacuation for the whole population including those who are aging?
- How can we assess whether the transportation infrastructure in the impact area is sufficient for emergency evacuation and the distribution of vital supplies?
- Can the aging victims be effectively identified and tracked in the aftermath of a disaster?

Following from these questions, the main emphasis of this research is:

- to state and study the characteristics of the emergency transportation needs of the aging population,
- to identify critical issues during the emergency evacuation focusing on the safety and accessibility for the aging,
- to identify critical issues related to the logistics and flow of vital commodities and sheltering locations,
- to articulate research directions and provide leadership in solving emergency operations problems critical for the safety and survival of aging victims in the aftermath of disasters.

The novelty of this research is that for the first time in the emergency management field the system requirements to create such a GIS-based multi-modal knowledge base will be identified with importance given to both ensuring the sustainability and suitability of the transportation infrastructure and satisfying the needs of an aging population ('the aging population' can be thought of as those people aged 65+ in this research project). Our objective in this research, therefore, is threefold. The first objective is to understand the critical components that form the proposed research methodology that is focused on safe and accessible emergency evacuation for the aging. The second aim is to highlight the operational issues involved with the optimal location/allocation of shelters, and efficient distribution of emergency relief goods supply flows to these locations in support of the disaster relief efforts for the aging population. Followed by the identification of these critical operational issues, the third objective is to develop more effective emergency management methodologies with a focus on aging people. Based on these objectives, this project report is organized as follows. Firstly, an overview of the proposed methodology is provided. Next, the steps of this methodology will be extensively supported by the evaluation of a transportation network based on the developed methodology, with an application to the District 3 region of Florida, as identified by the Florida Department of Transportation (FDOT) (13). Finally, several conclusions and recommendations for future studies are provided.

## Chapter 2 Methodology

The main focus of this research is to identify key issues required to create a multi-modal emergency transportation and decision making framework for evacuating aging victims and transporting vital supplies. Our initial study is set in the context of Florida Department of Transportation (FDOT) District 3. Therefore, the main challenge is to develop an effective methodology to extract the vast amount of knowledge from available sources and to incorporate them into an aging population-focused emergency management framework. This knowledge extraction process is achieved using a proven scientific methodology tested for this kind of problem in the past (14). The methodology proposed by the PIs in order to obtain this knowledge where the problem domain is large and expertise is scattered is the one called “knowledge base development”, which involves the following steps:

- **Knowledge Acquisition:** Since knowledge and experience exists in disparate sources (several places and with a number of people in addition to the published literature), a large domain of knowledge should be surveyed. This step includes acquiring and reviewing the existing practice, documents and other resources to clarify the diversity of available knowledge. Following these efforts, a metadata-based assessment and an extensive review of existing knowledge are conducted including the following sources: previous studies, generic tools such as transportation planning models, and relevant published data.
- **Knowledge Elucidation:** This step involves assessing the collected information and literature reviewed in the prior step in order to add value to the knowledge acquired through comprehensive synthesis, compiling the following:

- Location, accessibility and capacity attributes for intermodal origins (airports, watersports, railway terminals, intermodal connection terminals) and destinations (staging areas, distribution centers, points of distribution, shelters) in the affected region are determined for the decision making framework. This information is presented in GIS-based maps/compatible database formats so that planners/officials could access these attributes to evaluate a facility for emergency use.
- Existing federal, state and commercial tools are evaluated based on their usage, advantages and disadvantages during emergency operations focusing on the needs of the aging victims.
- Regional transportation network models developed using transportation demand modeling software such as CUBE, which is also actively used by Florida Department of Transportation (15), are evaluated.
- Data sources (transportation infrastructure, facility locations, truck routes/restrictions, real-time traffic and disaster data) needed for the framework are clearly identified.

• **Knowledge Representation:** This task is completed through the development of material including tables, flowcharts, visual illustrations and guidelines using the knowledge obtained and processed in the previous stages. Based on the collected data, basic GIS-based and regional transportation network models are used to test hypothetical emergency scenarios with the goal of assessing the performance of the transportation network in evacuating the aging population and providing the flow of emergency supplies into the affected regions under extreme conditions.

• **Validation and Verification of the Framework:** Most of the information reviewed are highly technical and procedural, and therefore it is important to verify and validate this

information very carefully before actually using it. Upon carrying out different steps of the framework, they are evaluated by the experts and the PIs to ensure their accuracy and appropriateness for emergency operations. Depending upon the results of this step, the PIs decide whether or not to go back to the previous steps, and to make adjustments.

The proposed intense knowledge base development process that involves this four-step approach is presented in Figure 2.1 that ensures a detailed study of the problem from all perspectives.

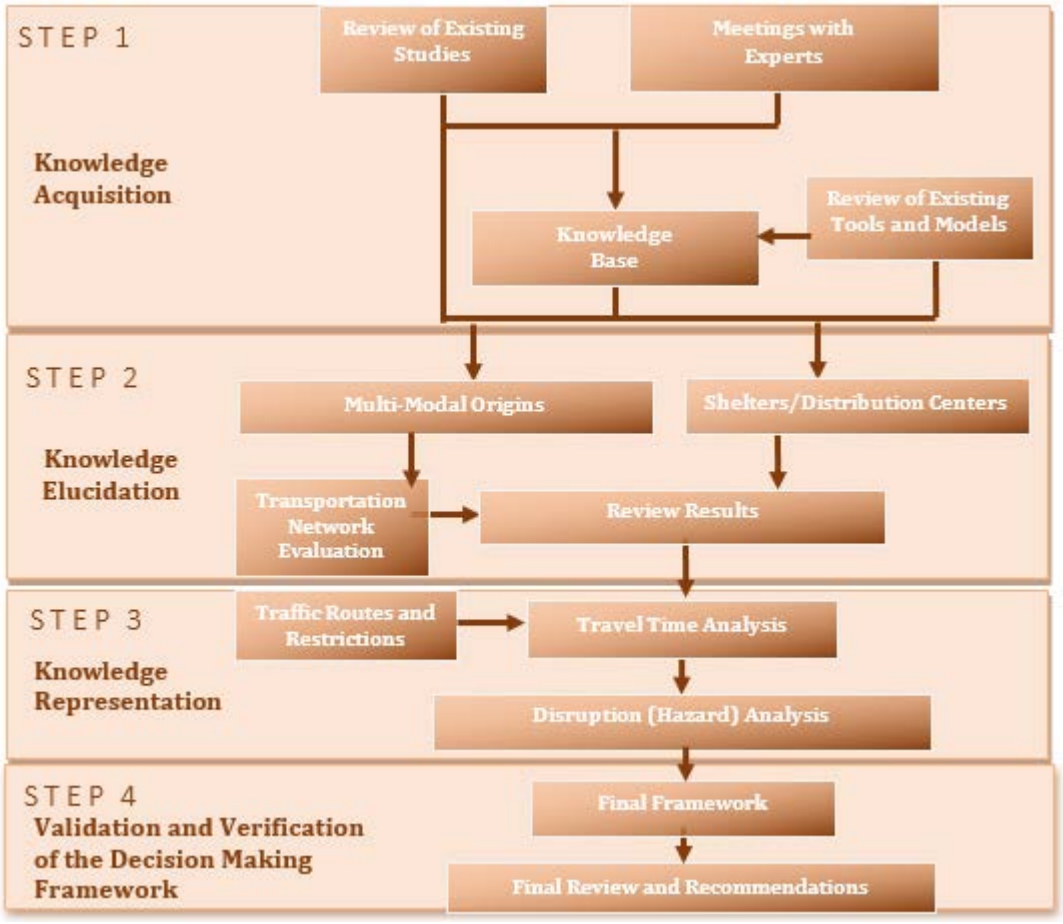



**Figure 2.1.** Work Plan

The following chapters include the detailed information related to these steps.

# Chapter 3 Knowledge Acquisition

This chapter includes detailed information regarding Step 1. This step involves a comprehensive review of agency reports, research literature and other resources in order to acquire the required understanding to develop the content of the metadata-based knowledge base. Therefore, a literature search was performed to identify the experiences of aging population and better understand their transportation needs in the aftermath of disasters, and determine promising approaches/best practices to improve their disaster-related mobility. As a part of this step, the PIs sought out several critical Florida Department of Transportation and Florida Division of Emergency Management data and reports that could be critical for the research.

The literature review conducted in this study included several steps. First, we introduced specific evaluation criteria for the review of the related work on emergency transportation operations with a focus on an aging population. Based on this criteria, we reviewed articles, agency reports and other relevant documents covering a time period of 1988-2013, which resulted in a collection of 132 critical works. An example metadata table of literature can be seen in Table 3.1. The remaining metadata tables can be found in Appendix A. Criteria used to evaluate the existing literature is listed as follows:

- Scope
- Objective
- Methodology
- Spatial Coverage
- Temporal Coverage
- Data Analysis
- Media/Source Type

- Contribution.

**Table 3.1** Sample Metadata-based Assessment Tables

LITERATURE REVIEW

| Criteria | Sorensen and Shumpert (2004) | McGlown(2001) | Blanchard and Dosa (2009) | Dosa and Hyer (2012) | Li and Raeside (2012) | Pekovic and Seff (2008) | Burnett and Dyer (2008) |
|---|---|---|---|---|---|---|---|
| Scope | Evacuation or Shelter-in-Place | Evacuation of Health care facilities | A Comparison of the Nursing Home evacuation experience betwen Katrina and Gustav | To Evacuate or Shelter in Place : Implications of Universal Hurrican Evacuation Policies on Nursing Home Residents | Population aging, gender, and the transportation system | Planning for and responding to Special Needs of Elders in Natural Disasters | Rapid Needs Assessments for Older Adults in Disasters |
| Aim of the research | Provide a framework for decision making during an emergency especially hazardous chemicals. | Compares two models from studies related to evacuation process : Vogt`s adaptation and McGlown`s model by examining variables of decision making | Examine whether nursing home administrative directors were more prepared with the experience of Katrina before Gustav. | Examines the differential morbidity/mortality associated with evacuation versus sheltering in place for nursinh home residents exposed to the 4 most recent Gulf hurricanes. | Reviews the nature of older people`s interaction with the transport system by gender, older people`s attitude to travel and involvement of aging as road traffic casualties | Explores the special needs of healthy and frail elders in relation to planning for and responding to natural disasters,including hurricanes, tornadoes, ice storms etc. | Lessons learned in the Astrodome,Houston . |
| Methodology | Decision trees / Padre | Data collection/ Cluster grouping | Data collection / Surveys | Data collection / Surveys / Instrumental variable modelling | Data collection / Surveys | No methodology | No methodology |
| Time Coverage | 1987-2002 | 1969-1999 | 2005-2009 | 1982-2011 | 1995-2011 | 1985-2006 | 1996-2006 |
| Data Analysis | No | Yes | Yes | Yes | Yes | No | Partial |
| Inclusion criteria of papers | Academic journals | Academic journals, books, reports | Academic journals, reports, websites | Academic journals,reports, websites | Academic journals,reports, websites | Academic journals. Practitioners journals, guidebooks, reports | Academic journals, websites, guidebooks. |
| Differentiation | Describes a model for detailed analysis of specific emergency scenarios | Data collected from the source-managers and decision makers.Issues of importance to managers were ascertained. | Is the first of its kind to compare the hurricane preparedness and evacuation experiences of nursing home administrators. | Although there is significant increased morbidity and mortality related to exposure, there is added risk in evacuation. | Involvement of older women increases in transportation system and population structure day by day. More research and policy changes needed for aging. | Emphasis on planning, identifying and coordination among agencies. | Introduction and emphasis on SWIFT (senior without family triage) tool |

LITERATURE REVIEW

| Criteria | Fernandez and Byard (2002) | Rosenkoetter and Covan (2007) | Mitchell (2003) | Adams and Kaufman (2011) | Enarson (1999) | McGuire and Ford (2007) | Cocanour and Allen (2002) |
|---|---|---|---|---|---|---|---|
| Scope | Frail Elderly as Disaster Victims : Emergency Management Strategies | Perceptions of Older Adults Regarding Evacuation in the Event of aNatural Disaster | Prayer in Disaster : Case Study of Christian Clergy | Aging Disaster: Mortality, Vulnerability, and Long-term Recovery Among Katrina Survivors | Women and Housing Issues in Two U.S Disasters: Hurrican Andrew and the Red River Valley Flood | Natural Disasters and older US adults with disabilities : Implications for evacuations | Lessons learned from the evacuation of an Urban Teaching Hospital |
| Aim of the research | Identifying the vulnerabilities of elderly to disasters, and to develop strategies to address these vulnerabilities. | To investigate the evacuation need and beliefs of older adults in Georgia, to identify heatlh risk factors | to investigate the role of faith and prayer in hazards adjustment | Offers insight on how older adults copes with disasters and illustrates that long-term catastrophes `age` in specific ways. | Examines root causes reproducing women`s disaster vulnerability in developed nations, among them economic dependency,male violence etc. | To estimate the number of community dwwlling people aged 65 years or older with a disability and requiring special equipment by BRFSS. | To investigate the lessons learned after Tropical Storm Allison |
| Methodology | A relevant literature search. | Data collection / Surveys | Data collection / Survey / Questionnaire | A relevant literature search. | Data collection / Surveys / Interviews / Group Sessions | Data collection / Surveys | A Case study |
| Time Coverage | 1988-2001 | 1991-2005 | 1961-2000 | 1976-2009 | 1982-1998 | 1992-2005 | 1982-2002 |
| Data Analysis | No | Yes | Yes | No | Yes | Yes | No |
| Inclusion criteria of papers | Academic journals, government materials, news reports | Academic journals, government materials, news reports | Academic journals, government materials, news reports | Academic journals, government materials, news reports | Academic journals, government materials, news | Academic journals, government materials, news reports | Academic journals |
| Differentiation | Addresses `insurance`problems of aging evacuees. | Addresses `memories/photos` of evacuees and their look for trust. | Demonstrates that the people of different religious groups hold contrary beliefs on prayers. Secondly, addresses the main reason to evacuate NHs as flooding. | Emphasis on the lack of recovery support, before and after catastrophes, is tied in the US to larger social structural relationships. | Provides a framework for women in disaster housing. | Baseline data of older adults with needs of special equipment is crucial.Many older adults requires assistance. | |

This review revealed the needs and vulnerabilities of aging people based on their cognitive, behavioral, and health limitations. In the following chapters, these papers and reports will be utilized with respect to discussing the operational needs of aging people during emergency transportation operations. Figure 3.1 shows a word cloud based on the review of these existing studies, where the words “assistance”, “homes”. “emergency”, “nursing”, “evacuation”, “hospitals”, “disaster”, “patients” and “needs” appear to be words significant.


**Figure 3.1.** Word Cloud based on the Literature Review

The following chapter will provide information on the evaluation of the available literature related to aging populations and emergency transportation operations.

# Chapter 4 Knowledge Elucidation

This step involves assessing the collected information in order to clarify different aspects of the knowledge acquired from the cited resources. Our review clearly shows that rapid aging is one of the most crucial socio-economic changes affecting our world (16). As a socio-demographic process, the USA's 65-and-older population is projected to reach 83.7 million in the year 2050, almost double in size from the 2012 value of 43.1 million (17). In addition, in 2013, Florida had the highest proportion of residents aged 65-and-older in the nation, comprising 18.17% of the state's population (18). Growth among aging Floridians is expected to continue, with those age 60 and older comprising 41% of the state population by 2030 (19, 20). This indicates that community stakeholders should ensure that services provided to the aging enable them to respond to and recover from a disaster (21). Moreover, disasters create an abundance of needs and a scarcity of resources while amplifying vulnerabilities and exposing gaps in planning and service delivery (22). Perspectives offered concerning the disaster need of aging in the disaster management literature are generally global, national and/or local (23-40) rather than being regional (e.g.: scale of FDOT District 3). In this context, this section explores the relief and evacuation needs of the aging population in Florida with a focus on FDOT District 3 region in conjunction with emergency transportation operations.

## 4.1 Vulnerability of Aging People to Disasters

Aging people are vulnerable by nature to extreme events, and suffer substantially higher casualties in time of disasters as they are influenced by physical limitations, limited sensory awareness, health conditions, and social and economic restraints (41, 42), physical frailty and social isolation (43), and functional and cognitive disability (44). Please see (45) for a more detailed discussion on the vulnerability of aging people to disasters. A range of health,

physiological, psychological, social, and economic factors place people at greater risk as they age, affecting their ability to prepare for, respond to, and recover from a disaster (46, 47). Other factors that increase aging people vulnerability in disasters include living alone and in isolated rural areas (48). This is critical for states like Florida where a substantial amount of aging people are living independently in rural areas. Aging adults are also more vulnerable to the impacts of disasters as compared with other age groups (41, 48, 49, 50). Especially catastrophic disasters tend to result in severe psychological stresses in aging victims (49). As disasters may critically impact aging adults, it becomes crucial for emergency planners and aging people care givers to understand the factors that create this vulnerability (48). Aging people are also more vulnerable to disasters since they have sensory impairments, they are reluctant to evacuate due to their fear for dangerous environments, loss of property and pets, and language/cultural barriers (22, 51). Medical conditions can also make one more susceptible to certain illnesses/diseases that can be brought on by disasters, and they put one at risk if medication becomes unavailable (52).

### 4.2 Emergency Evacuation

Emergency evacuation is one of the most effective and widely used tactics to protect people from disasters including hurricanes (53, 12), extreme wind and flooding (54) and many others. In relation with disaster evacuations, aging adults are part of the low mobility groups whose movement is a research area which has been largely unaddressed by officials planning for evacuations (55). To achieve efficient emergency evacuations, the mechanisms for transporting aging persons safely and providing accessible, appropriately equipped and staffed shelters are critical (48). According to (26), in preparing for and carrying out the evacuation of aging populations, officials face challenges in identifying these groups, determining their needs, and

providing for and coordinating their transportation, mostly due to the poor understanding of the size, location, and composition of the aging people in their community.

Roadway-based evacuation and simulation models have been extensively used to solve the associated problems with evacuation (examples include (56-59)). A review of evacuation research, development and practice can be found in (60), where the evolution of multi-modal evacuation-based simulation models over the past decade are presented. Although much attention has been paid to the emergency evacuations, relatively few studies focus on the needs of an aging population during evacuations.

Several researchers state that aging people are the last to evacuate for reasons including past experience with disasters, health issues, insufficient resources, particular life style (living alone), fear of new environment, attachment to their natural and traditional areas of living (51, 61). Even when not living alone or in rural areas without public transportation, aging people may not be able to evacuate during disasters because their local transportation services may be interrupted/suspended. Those residing in institutions may also be too frail to be evacuated quickly (62). For instance, disaster evacuations have greater risks associated with aging with disability as not all vehicles have the capacity to transport wheelchairs (63). Disaster victims who are house-bound, socially isolated, or who have impaired mobility, poor vision may be compromised in their ability to respond to and recover from disasters during a rapid evacuation (52). Decision of health care administrators to evacuate is bounded within the internal and external environment conditions, infrastructure and management operations, and focus on community/organizational level. (52, 64).

Communicating evacuation information to the aging population is also critical during emergency evacuations; however, there are difficulties related to this effort in terms of

efficiency, real-time feedback, financial aspects, and appropriate communication for the aging population who can be worried and confused (65). Research on the use of multi-modal facilities such as airports, sea ports, and railway terminals for evacuating aging people is also very limited (68, 69). The use of transit systems has been recently studied for evacuating vulnerable populations (66, 67); however, to the authors' knowledge, there has not been any research on transit-based evacuations with a focus on aging populations.

### 4.3 Sheltering

"Sheltering" itself is a general term that can refer to situations ranging from people leaving their primary residence to stay with family or friends during a disaster or hurricane, to the relocation of people in temporary structures outside of a storm zone (53). There is clearly a temporal element to this definition, and in our work, we focus on the 'emergency shelter' which refers to locations where actual or potential disaster victims seek quarters outside of their own permanent homes for shorter periods; hours in many cases, overnight or possibly a few days at most (53). People choose to use shelters because an evacuation order has been issued and they do not (or cannot) leave the forecasted affected region. In the context of disaster evacuation, the older adults are considered part of the low mobility groups (also including prisoners, those of the lowest socioeconomic status, the disabled, etc.) whose movement limitations and needs have been identified as an area for future disaster-related research (55).

Shelter location placement falls within the realm of facility location problems in spatial optimization. This broad field is concerned with choosing appropriate locations to place infrastructure such as warehouses, stores, or emergency facilities (70). Models are used to select at least one new facility among several alternatives in order to optimize some objective such as minimizing transportation costs or maximizing service coverage (71). Most models are of a

discrete nature with candidate facility locations and service demand confined to transportation network locations (71). Applications of these models are as diverse and varied as siting health care facilities and medical centers (72, 73), locating hydrogen refueling stations (74), or hurricane relief goods distribution facilities (75).

Several studies have looked at hurricane disasters and shelter location optimization in a spatial modeling setting. For instance, a nonlinear mixed integer programming model is proposed in (76) which determines shelter locations and evacuation paths so as to minimize the system-wide evacuation time. Their capacitated facility location model optimally selects shelter locations among potential alternatives consistent with available resources. The role of demand uncertainty is considered in the context of shelter and evacuation planning (77). The spatial location adequacy, and socio-economic and physical suitability of evacuation shelters in Florida is explored through implementing a GIS-based suitability model in 17 South Florida counties (78). Suitability was defined to decrease with proximity to hazardous facilities but to increase with road accessibility and proximity to health care facilities. Other work includes (79) where a bi-level model is designed to determine the locations of safety shelters in a transportation network and A GIS-based multi-objective model is presented to locate emergency shelters and identify evacuation routes in (80). Scanning the current optimization literature however, there has been little direct focus on the sheltering needs of special needs populations and that of the aging populations. The next section describes our study area and modeling approach aimed at addressing this issue.

## 4.4 Transportation of Vital Supplies (Relief Goods)

Relief goods distribution and transportation is a rapidly expanding field of research with most works aiming for efficiency through minimizing transport costs, integrating spatial

considerations with regards to a range of disasters including hurricane hazards. A model is designed in (81) that minimizes transportation costs while maximizing the amount of deliveries for relief supply from a given distribution center to several camps. Similarly, disaster relief operations as a multi-commodity, multi-network flow model with time windows are studied in (82) whereas the impacts of earthquake events on transportation networks and accessibility in Tokyo (Japan), and Seattle, WA are examined in (83). A multimodal network flow model that allocates first-aid items in the context of general disaster relief is presented in (84), and a multi-objective programming method to distribute relief in a post-earthquake environment is designed in (85). Most of this research was published after 2005 (86) with no direct connection with disaster issues.

More recent research addressing relief distribution with specific respect to hurricanes (73, 87, 88, 89, 90, 91) demonstrated all the crucial role transportation networks play in connecting disaster victims to relief sites and defining their accessibility to potential goods distribution sites. Many models aim for some level of efficiency through minimizing transport costs or the access burden of people reaching distribution centers. In particular, possible impacts of relief distribution point locations on disadvantaged populations are examined by using socio-economic characteristics as the key factor for facility placement (88, 90). However, no efforts have considered the influence of aging populations' locations on relief facility placement.

Substantial transportation scholarship has tried to understand the socioeconomic impacts of transportation policies and of differential accessibility in various transport-related contexts, though far less so when it comes to disaster relief issues (90). In the past, GIS-based studies using spatial modeling techniques have extensively probed client accessibility for medical facilities (92, 93), rail transit stops (94) or shelters for homeless people (95). Efforts looking to

maximize accessibility for hurricane relief distribution facilities are less abundant. A model that handles the efficient provision of relief goods to facilities within populated places with disaster-trapped citizens is proposed in (96). The influence of changing demand assumptions on accessibility to disaster relief for socioeconomic groups with the lowest income levels is studied in (90) and; hurricane relief distribution siting is explored based on equity and efficiency objectives in light of populations' socioeconomic differences in (96). In a slightly different analysis, a blended GIS and spatial optimization modeling to implement a hierarchical capacitated-median model that sites relief facilities providing different and distinctive levels of assistance is presented in (98). None of those efforts has considered the impact of age-based characteristics on relief distribution accessibility.

In the aftermath of disasters, the availability of resources may be limited due to disruptions in the transportation network and unavailability of personnel and vehicles. However, commodity supply activities should be able to satisfy the basic needs of aging at any time where the lack of even one medicine can be critical. An analysis on the points of distribution (PODs) after Hurricane Ike also reveals that increasing the capabilities of existing PODs are preferable to additional ones, and mobile PODs are found to be more efficient (99). Several emergency relief planning models have been developed to focus on the delivery of the vital products during the disasters. Please refer to (11) for a detailed review of these studies. The critical point, however, is that, none of these studies specifically focus on the needs of the aging population which represents a crucial research and practice gap. Moreover, to address the needs of Florida residents who do not take heed of hurricane evacuation orders either by choice, or inability to evacuate, state and local governments implement comprehensive disaster relief management plans describing the mechanism of distributing relief goods in the event of an emergency (90).

Guidelines to conduct relief operations in a hurricane context are detailed by the Florida Department of Emergency Management, FDEM (38) specifying how the facilities providing relief supplies, or ‘‘Points of Distribution” (PODs), should be set up and operated. These guidelines which incorporate only a vague strategy for the spatial placement of these PODs throughout a region (98), however, inspire the many existing potential designs for hurricane relief goods distribution systems. Many efforts make use of the classic distribution model with local PODs serving relief received from larger and more distant warehouses to the affected neighborhoods.

Furthermore, several papers use variants of the efficiency-oriented p-median model (sometimes compared with the equity-oriented p-center (97). While a few studies investigate the movement of goods along the full supply chain (87), most research has argued that the accessibility of neighborhoods to relief distribution points be given the most weight (90, 98, 96, 97). Our project embraces the latter mentioned strategy through a specific focus on the neighborhood-distribution facility linkage and the realization that no other research has looked directly at the influence aging populations could have on relief center location placements.

It is important to note that federal and military involvement in disasters can also be critical for a safe and accessible evacuation/sheltering and supply transportation for aging people. In these situations, the Governor has the absolute authority in deciding the use of Florida National Guard and all other resources available for emergency duty, and can request an assistance from FEMA and other federal sources (38, 100, 101, 102).

It is clear that there are a wide range of studies for the emergency management and relief operations whereas aging-focused emergency transportation and relief management is still a very open area of research. As the threat posed by natural disasters challenges both emergency

practitioners and the scientific community resulting in substantial research, little of this focuses explicitly on disaster relief and/or disaster evacuation with respect to the aging population. Aging adults are also generally placed in the low mobility groups whose movement and/or relief provision is a research field which has been largely unaddressed in planning for evacuations and those who may remain behind (55).

# Chapter 5 Knowledge Representation

This step involves the development of material including tables, flowcharts, visual illustrations and guidelines using the knowledge obtained and processed in the previous stages. Based on the collected data, basic GIS-based software and regional transportation network models are used to test hypothetical emergency scenarios with the goal of assessing the performance of the transportation network in evacuating the aging population and providing the flow of emergency supplies into the affected regions under extreme conditions.

Project research work focuses on the 2014 Florida's Aging Road User (65+) Priority Counties developed as a part of the strategic safety planning initiative started by the Safe Mobility for Life Coalition (SMFL) (Figure 5.1) (107). Designated priority counties by SMFL in District 3 are as follows:

- Urban Priority Counties in District 3: Leon, Bay and Escambia.
- Rural Priority County in District 3: Walton.

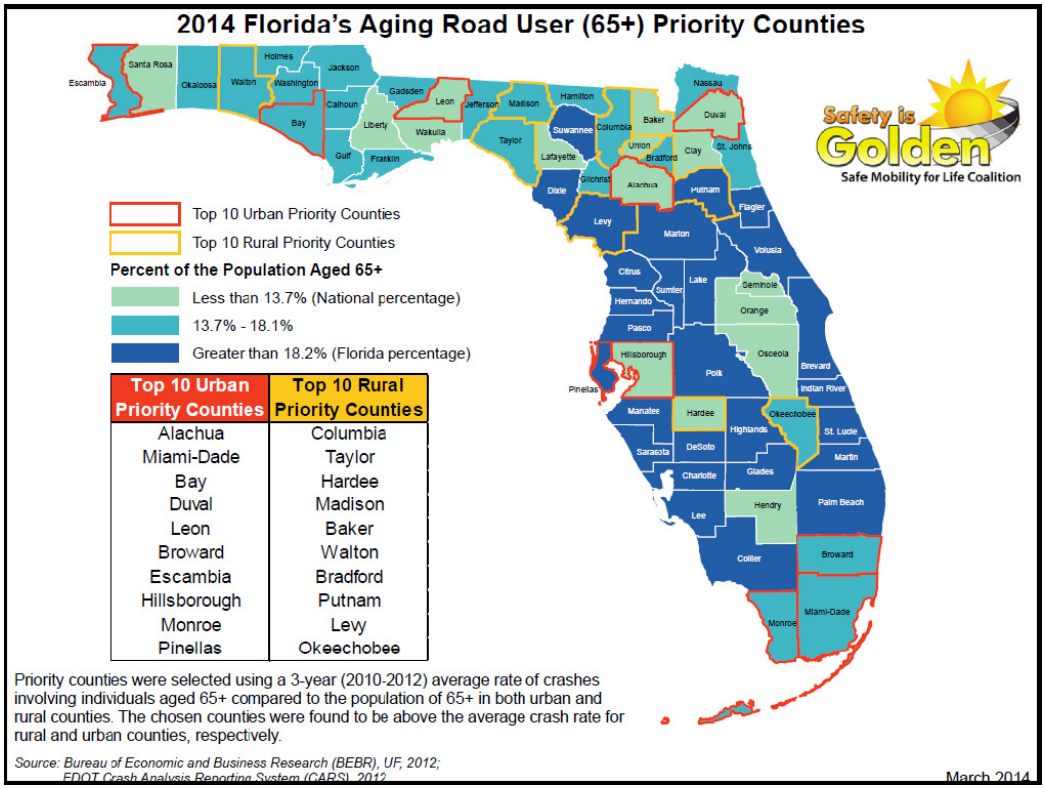



**Figure 5.1.** 2014 Florida's Aging Road User (65+) Priority Counties (107)

Thus, in this project, after evaluating the whole FDOT District 3 Region for emergency transportation operations, the PIs conduct a more detailed analysis on these four counties based on the available multi-modal transportation facilities, roadway network, locations of assisted living facilities and shelters, and the effect of disasters such as hurricanes and nuclear plants. GIS-based evaluation maps for Bay and Escambia counties will be discussed in the following sections, those maps for Leon and Walton counties can be found in Appendix B.

## 5.1 Evaluation of Transportation Modes for Emergency Transportation

Emergency transportation management is a critical and complex task that depends on the characteristics of a disaster. It is also directly related with the transportation infrastructure, disaster area security, evacuee demand, demand for vital supplies, availability and accessibility of nursing homes, private homes, distribution centers, inventories and shelters, etc. An efficient

management strategy should be based on a collaborative approach supported by tracking of emergency evacuation and flow of supplies. Evacuees can be transported out of the affected region and vital supplies can be transported to the affected disaster region by different transportation modes that include air, waterway, rail and truck (roadway) transportation. Especially truck transport for emergency operations is critical since it can be easier and more convenient to carry the vital supplies to the disaster region by trucks as long as the roadway network is available.

Table 5.1, which is adapted and extended from (103), highlights the prominent features of these different transportation modes for emergency operations with a focus on an aging population. The comparative evaluation process presented in Table 5.1 leads to identifying the entire scale and levels of the network, relative speed, reliability/efficiency, accessibility, flexibility, and capacity criteria listed in the following rows of Table 5.1. This evaluation criteria can be revised depending on the type of disaster, the population characteristics of the area focused on and the available transportation network. Here, GIS-based maps can also offer a comprehensive evaluation for the evaluation of the multi-modal transportation modes in terms of visually identifying the advantages and disadvantages of the available transportation network (Figure 5.2).

*5.1.1 Network*

As shown in Figure 5.2, state roadways comprise a significant portion of the District 3's major urban highway network (particularly around larger cities such as Tallahassee in Leon County, Panama City in Bay County, and Pensacola in Escambia County) whereas the railway network is very limited with a fixed infrastructure (Figure 5.2). Railway terminals in District 3 are also limited to freight transportation only. On the other hand, there are four major airports

(regional, with limited capacity) and three major sea ports (used for freight transportation only) in District 3 (Figure 5.2). Based on this information, roadways are found to be integral for aging-focused emergency transportation in District 5.2.

*5.1.2 Accessibility*

Accessibility of each transportation mode network is of critical importance in order to evacuate aging victims and transport vital supplies into the affected region successfully. Accessibility specific rating criterion for the transportation modes is given as follows (Table 5.1):

- **High:** Transportation mode network passes within 10 miles of highly populated aging population blocks, or multi-modal transportation facility is located within 10 miles of highly populated aging population blocks.
- **Medium:** Transportation mode network passes within 10-50 miles of highly populated aging population blocks, or multi-modal transportation facility is located within 10-50 miles of highly populated aging population blocks.
- **Low:** All others.

*5.1.3 Capacity*

Similar to the previous criterion, this one focuses on the serving capacity of the modes for emergency transportation operations (both for evacuating aging victims and transporting critical supplies). Capacity specific rating criterion for the transportation modes is given as follows (Table 5.1):

- **High:** Transportation mode is able to transport large quantities of supplies, or can sustain high capacity evacuations for aging.

- **Medium:** Transportation mode is limited in terms of actual capacity; however, increasing the amount of vehicles can lead to the completion of aging evacuation and supply transportation operations satisfactorily.
- **Low:** Transportation mode can only transport limited quantities of supplies, or can evacuate limited number of aging people.

*5.1.4 Relative Speed*

Relative speed of transporting aging victims and vital supplies with respect to different modes is critical for effective emergency transportation operations. Speed specific rating criterion for highways is given as follows (Table 5.1):

- **Fast:** Relative speed provided by the transportation mode is substantially high with respect to the other modes.
- **Medium:** Relative speed of transportation is average with respect to the other modes.
- **Slow:** All others.

*5.1.5 Reliability/Efficiency*

This criterion can be used to assess the vulnerability of the mode networks based on disruptions that can occur in the aftermath of disasters (e.g.: roadway disruptions such as traffic congestion and flooding) especially in the highly populated locations. This criterion is based on the emergency performance of the modes for evacuation and supply transportation as well as their advantages and disadvantages (Table 5.1):

- **High:** Mode network that can provide fast and efficient emergency evacuation and supply transportation. Vital for cases where emergency agencies have time constraints, but may be costly.

- **Medium:** Mode network that has high and direct accessibility but medium capacity and relative speed, usually with relatively lower cost.
- **Low:** Mode network that is limited to certain locations, which indicates limited accessibility.

*5.1.6 Flexibility*

This criterion focuses on the flexibility of the emergency transportation operations with respect to each transportation mode network (Table 5.1):

- **High:** Direct access and relatively fast evacuation and/or supply delivery with relatively lower cost.
- **Medium:** Although fast and reliable, modes that have limited capacity and multi-modal transfer locations may not be easily accessible.
- **Low:** Limited network, fixed infrastructure and multi-modal locations with limited accessibility.

**Table 5.1.** Matrix of Transportation Modes (Adapted and Extended from (103))

| CRITERIA | MODE | | | |
|---|---|---|---|---|
| | ROAD | RAIL | WATERWAY | AIR |
| **Relative Speed** | Moderate | Moderate | Slow | Very High |
| **Reliability** | Good | Good | Limited | Very Good |
| **Flexibility** | High | Low | Low | Medium |
| **Efficiency** | Good | Limited | Limited | Good |
| **Network** | Extensive/Large Network | Limited and Fixed Infrastructure | Restricted Network | Limited Network |
| **Accessibility** | High | Moderate | Low | Moderate |
| **Capacity** | Low | Moderate | High | Very Low |
| **Emergency Performance For Transportation of Vital Supplies** | •Small Quantities<br>•Short and Medium Distances (Between Inventories and Shelters) | •Large Quantities (i.e., from port to inland emergency sites) | •Large Quantities<br>•Pre-positioning Mostly<br>•Long Distance<br>•No Time Constraints | •Critical for Emergency Operations<br>•Small Quantities Possibly<br>•Perishable/Vital Commodities<br>•Short or Long Distances<br>•Time Constraints |
| **Emergency Performance for Evacuation** | •Short and Medium Distances (Between Distribution Centers and Shelters) | •Limited Performance<br>•Depends on the Availability of the Transit Network<br>•Helpful for Highly Populated Areas | •Very Limited Use for Evacuation (Coastal Areas Only) | •Critical for Emergency Evacuation<br>•Short or Long Distances<br>•Time Constraints |
| **Advantages** | •Relatively Fast<br>•Direct Access<br>•Relatively Low Cost<br>•High Flexibility | •Economical<br>•Large Loading Capacities | •Economical<br>•Large Loading Capacities<br>•Minimal Cost | •Fast and Reliable<br>•Direct Access |
| **Disadvantages** | •Roadway Network Disruptions<br>•Delays | •Inflexible<br>•Difficulty Finding Freight Cars<br>•Difficulty Accessing Railway Terminals (Especially in Rural Areas)<br>•Delays | •Slow<br>•Inflexible<br>•Good for High Supply Volumes<br>•Available Only at Ports | •Expensive<br>•Restricted to Trips between Landing Sites<br>•Limited Capacity |

For emergency relief operations, speed and reliability criteria become critical while considering the choice of transportation mode. For different disasters with distinct

characteristics, these modes will meet the speed, reliability, and cost criteria to varying degrees. Therefore, mode choice is critical to efficient relief operations.

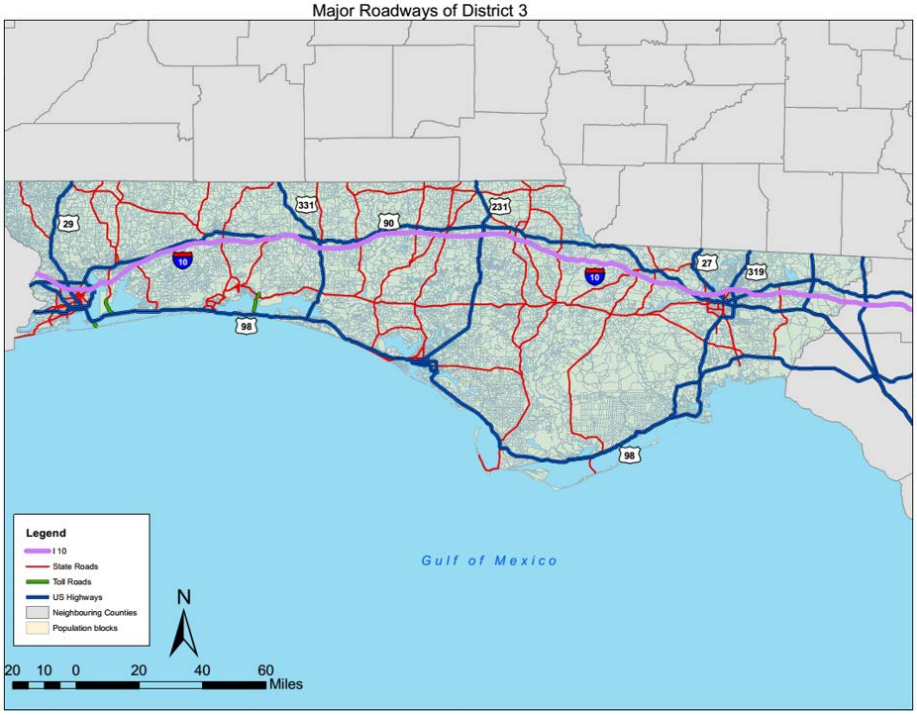
## 5.2 Evaluation of the Multi-Modal Transportation Network in District 3

Based on the knowledge base being created as a part of Step 1, the knowledge and literature reviewed in the prior step is processed in Step 2 in order to add value to the knowledge acquired.

Location, accessibility and capacity attributes for each intermodal facility in the affected region are critical. This information should be accessible either via GIS-based maps or compatible database formats to allow planners to make appropriate decisions regarding aging populations. Roadway transportation is found to be integral for emergency transportation operations in District 3, and therefore it becomes critical to determine the routes that could be used to move aging people and emergency supplies from their origins to their destinations.

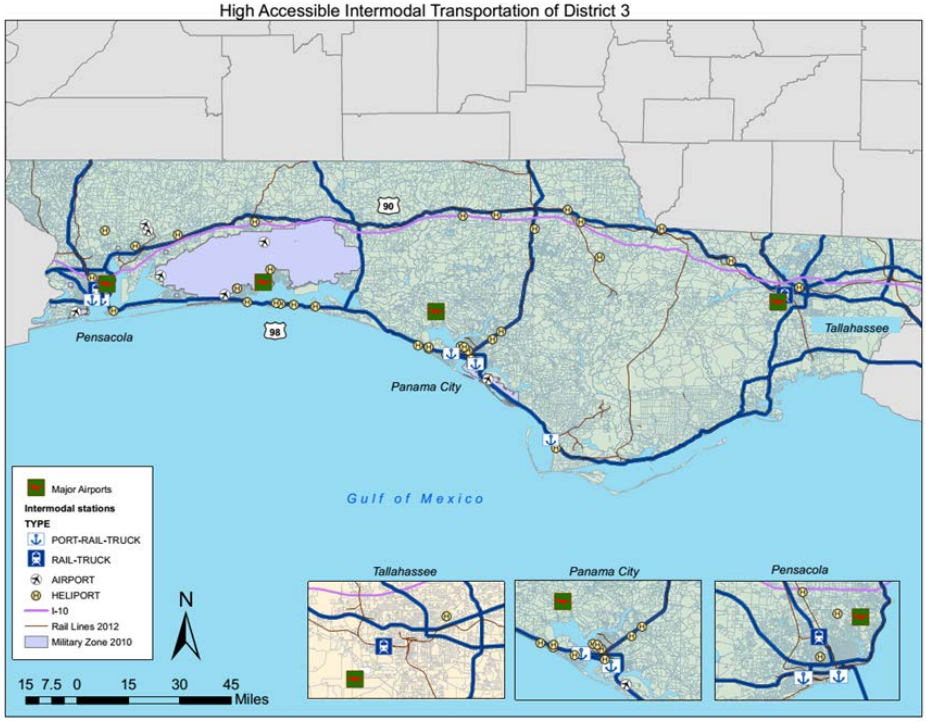
Figure 5.2 shows the major roadways based on evaluating available data as well as the locations of all airports, ports, and railway terminals in District 3. Here, several locations (such as small heliports) are eliminated from the database based on their vulnerability to disasters, and their limited functionalities such as lack of control towers. As shown in Figure 5.2, state roadways comprise a significant portion of the District 3's major urban highway network, particularly around larger cities such as Tallahassee in Leon County, Panama City in Bay County and Pensacola in Escambia County. Figure 5.2 also shows the aging population by District 3 counties, flood hazard risk levels, and the demand for common shelters in District 3.

Major Roadways of District 3

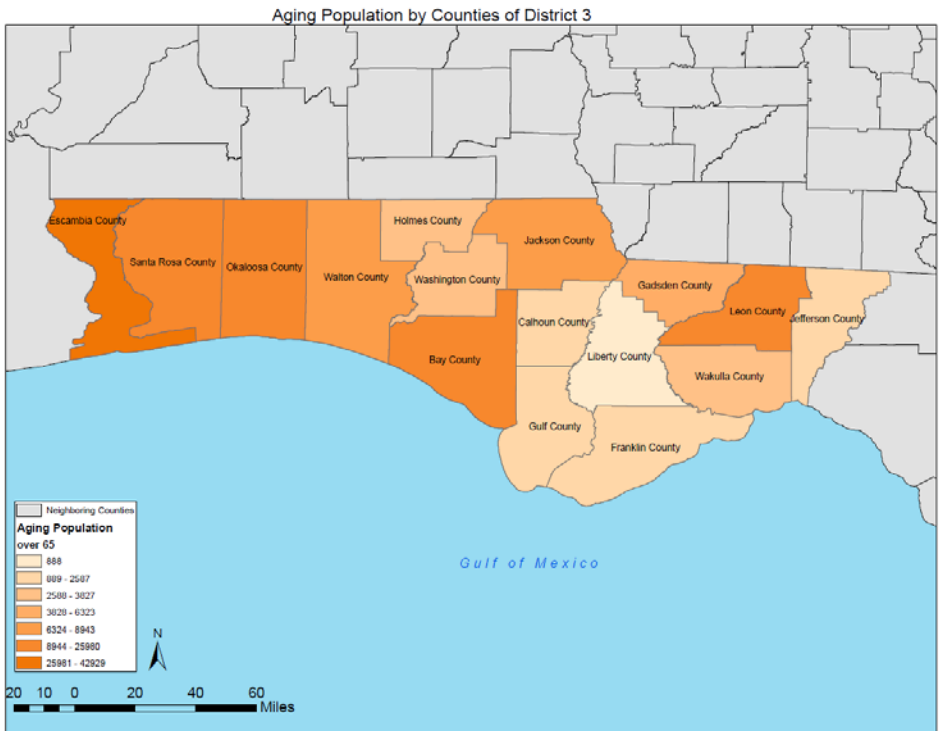



- (a)

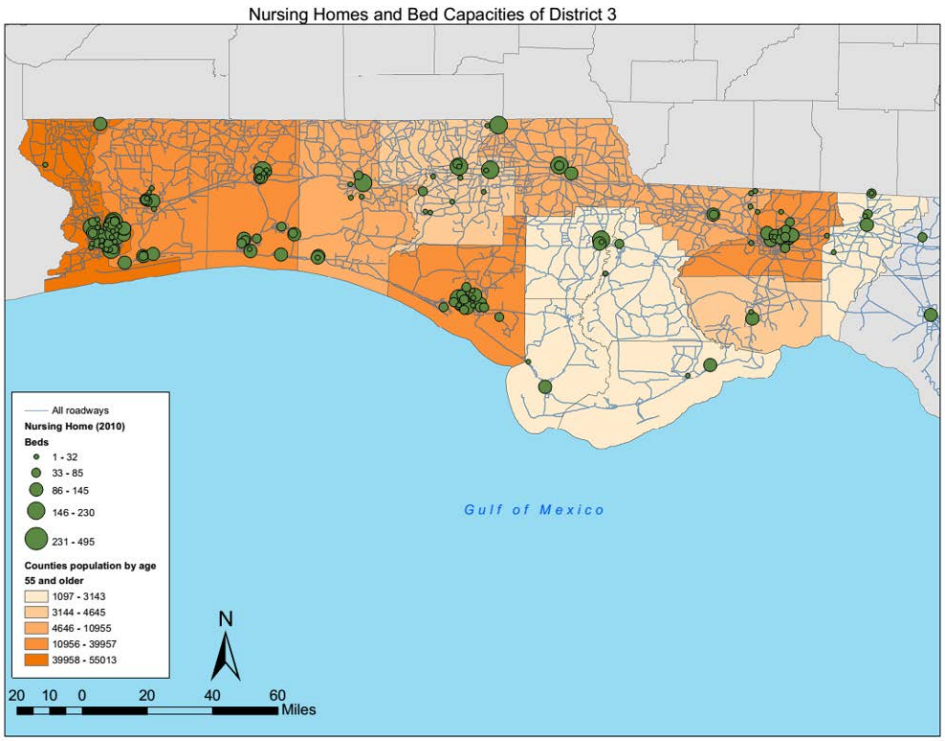
High Accessible Intermodal Transportation of District 3



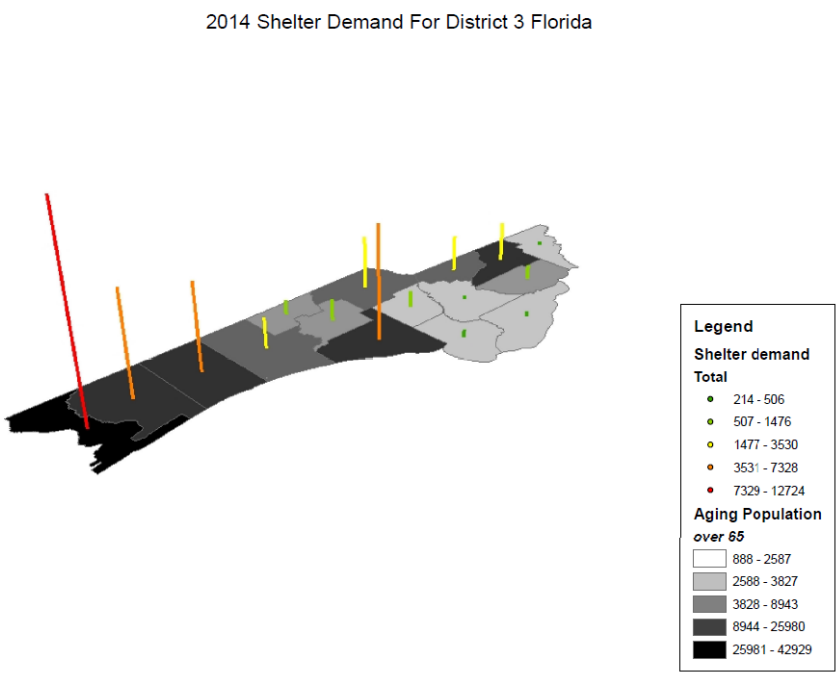

- (b)


Aging Population by Counties of District 3
Escambia County
Santa Rosa County
Okaloosa County
Walton County
Holmes County
Washington County
Jackson County
Bay County
Calhoun County
Gadsden County
Liberty County
Leon County
Jefferson County
Wakulla County
Gulf County
Franklin County
Gulf of Mexico
Neighboring Counties
Aging Population
over 65
888
889 - 2587
2588 - 3827
3828 - 6323
6324 - 8943
8944 - 25980
25981 - 42929
N
20 10 0 20 40 60
Miles

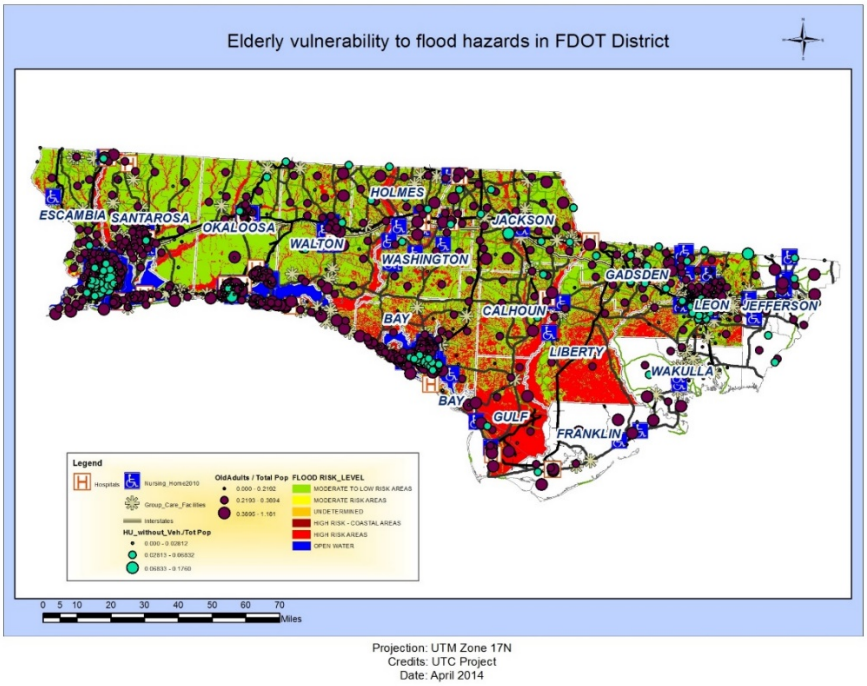
(c)


Nursing Homes and Bed Capacities of District 3
All roadways
Nursing Home (2010)
Beds
1 - 32
33 - 85
86 - 145
146 - 230
231 - 495
Counties population by age
55 and older
1097 - 3143
3144 - 4645
4646 - 10955
10956 - 39957
39958 - 55013
Gulf of Mexico
N
20 10 0 20 40 60
Miles

(d)




(e)

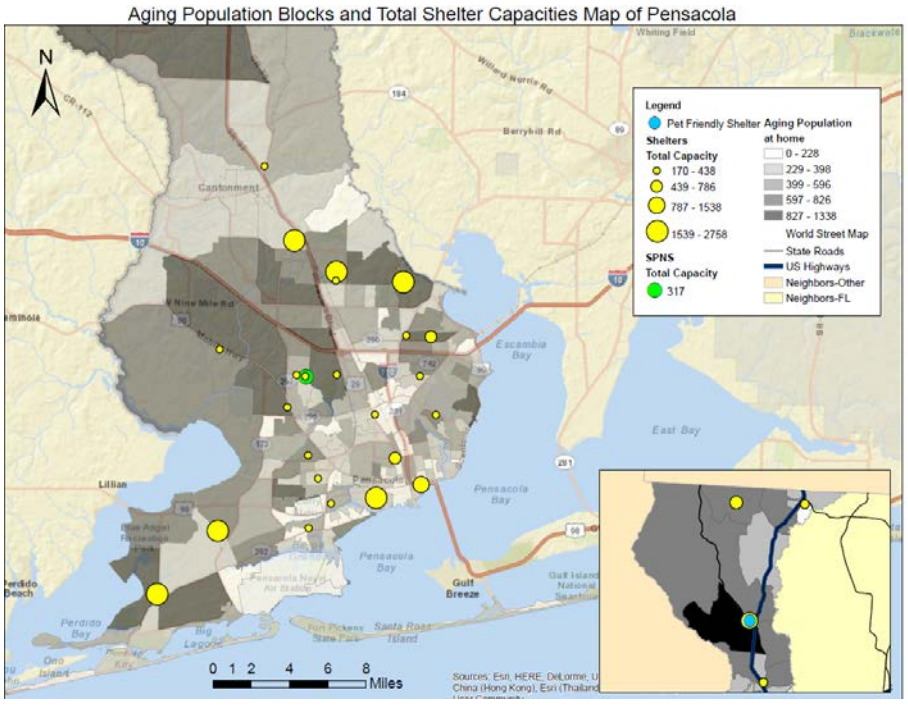



(f)

**Figure 5.2.** Multi-modal GIS-based Representation of District 3 with a Focus on an Aging Population (a) Major Roadways (b) Multi-modal Locations (c) Aging Population (65+) by County (d) Nursing Homes and their Capacities (e) Demand for Shelters and Aging Population (f) Flood Hazard Risk Levels for District 3

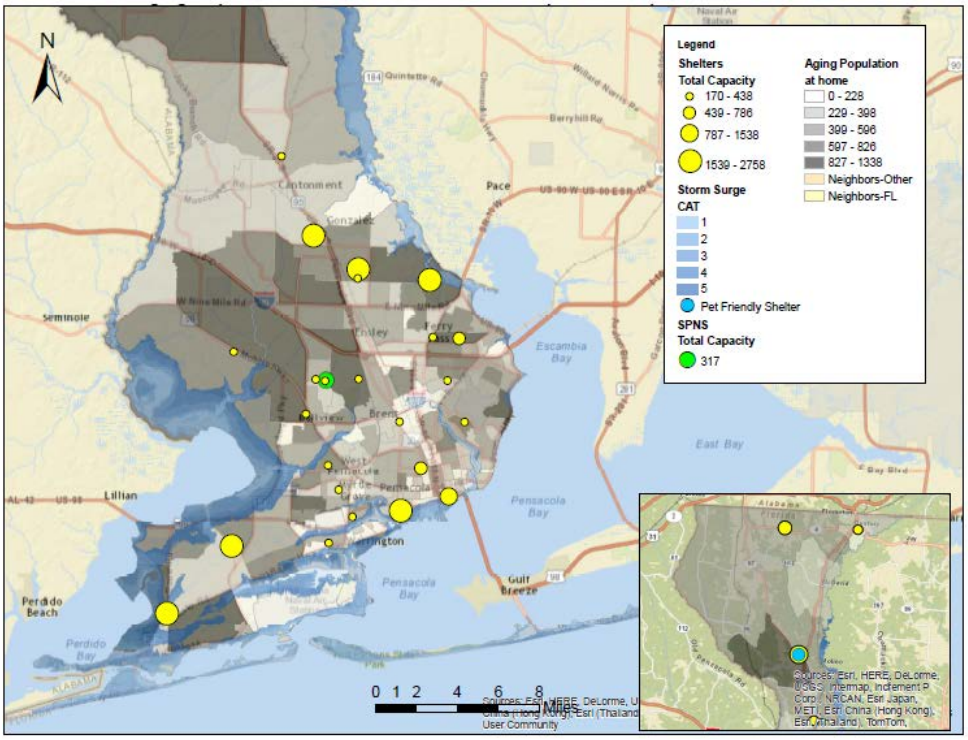
## 5.3 Disruption (Hazard) Analysis

Hurricanes and floods, being the most frequent hazardous events in Florida, are continuing to be the major focus areas. Thus, this step discusses potential issues resulting from disruption of highways in District 3 due to disasters, with a more detailed focus on the affected counties and cities. For this analysis, storm surge and flood zones were used to assess the vulnerability of the roadways due to tropical storms, hurricanes and heavy rains. Figure 5.3 presents such an analysis focusing on Escambia County, where the highest aging population in District 3 is located. Figure 5.3 presents a substantial amount of data including the aging population blocks, available shelters including special needs and pet friendly, storm surge and flooding zones, and roadway closures to due to flooding. The GIS-based maps (especially the proximity of the closed roadways to the aging population blocks) can help facilitate decision making for planners and emergency officials.



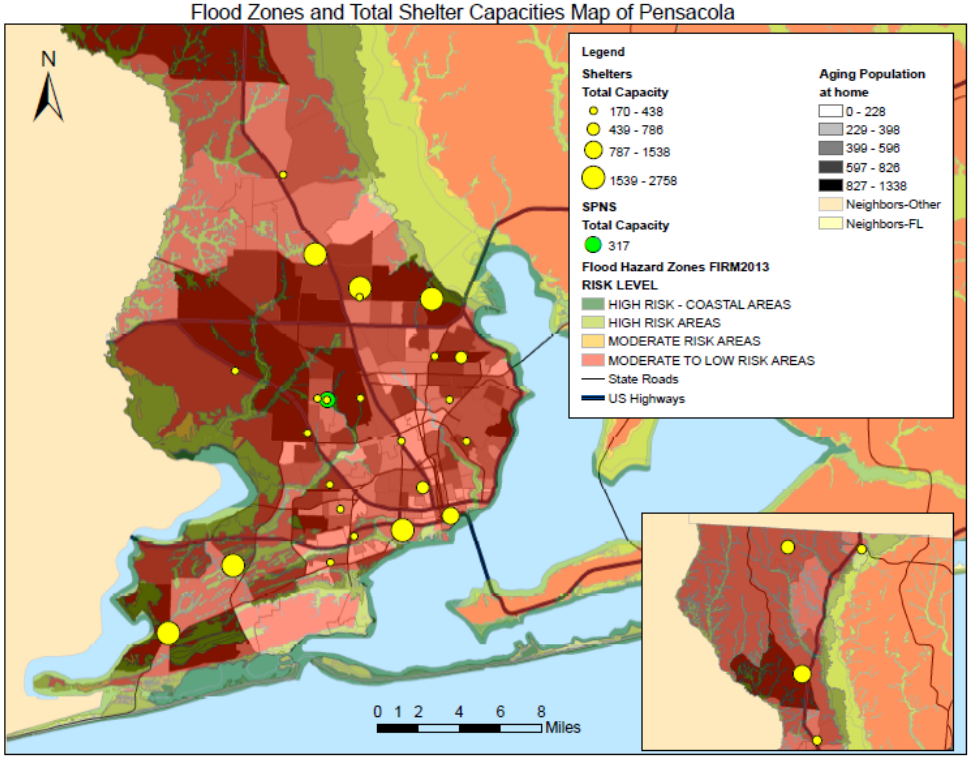

(a)

Storm Surge Zones and Total Shelter Capacities of Pensacola

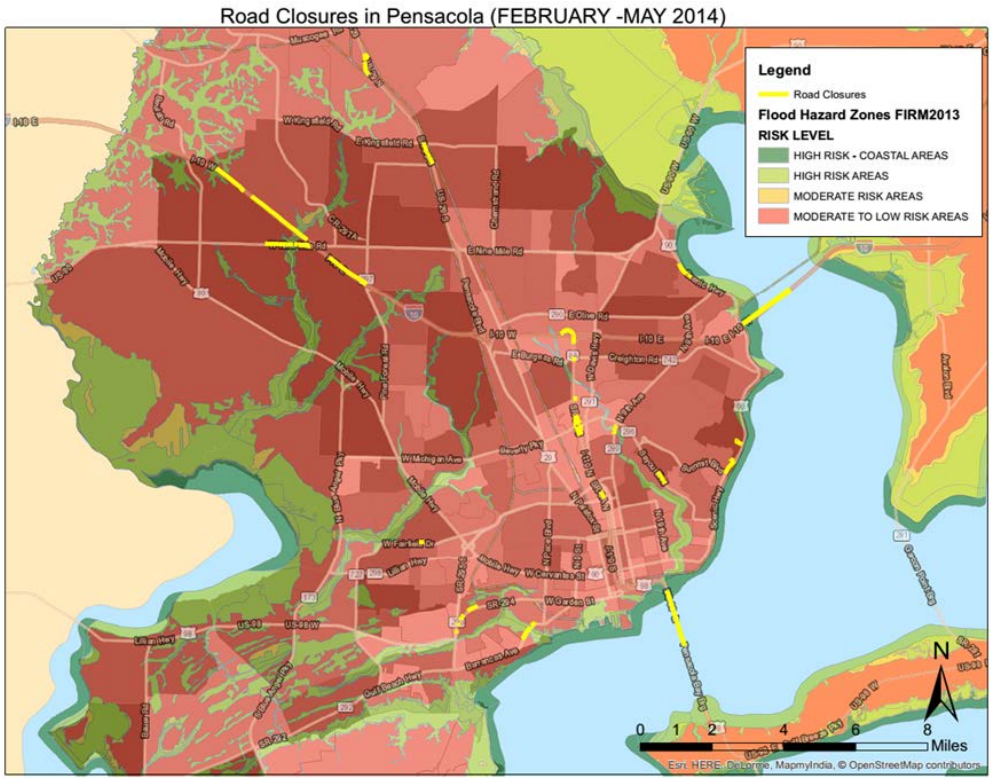



(b)

Flood Zones and Total Shelter Capacities Map of Pensacola



(c)




(d)

**Figure 5.3.** Multi-modal GIS-based Representation of Escambia County with a Focus on an Aging Population (The map on the bottom right shows the northern Escambia) (a) Major Roadways, Shelters and Aging Population (65+) (b) Shelters, Aging Population (65+) and Storm Surge (Category 5) (c) Shelters, Aging Population (65+) and Flood Hazard Zones (d) Road Closures, Aging Population (65+) and Flood Hazard Zones in Pensacola of Escambia County

## 5.4 Assessment of Network Characteristics for Evacuation Operations

This section presents an evaluation of evacuation operations that can help planners/emergency personnel decide how to transport aging people in the aftermath of an extreme event. After a review of evacuation studies that focus on aging people, vast amount of knowledge has been extracted from available resources and data sets in order to conduct a thorough assessment of the multi-modal transportation infrastructure for the District 3 region. A GIS database including highways, airport, port, and railway terminal locations was created to

present the locations of these facilities, and their proximities to roadways and aging-populated locations. With a focus on the challenges at the airports, ports, and railway terminals, this database will be extremely useful for supporting the emergency evacuation operations.

### *5.4.1 Study Approach and Methodology*

Emergency evacuation usually starts at designated distribution centers/hubs within the affected region, which have access to the transportation modes needed to evacuate the aging victims. Under usual conditions, aging victims can be transferred by air, rail, waterway, or roadway modes (individual vehicles or buses), and through intermodal terminals and other hubs, they can be transported to their final destinations. Depending on their limitations and mobility restrictions, emergency officials may need to evacuate the aging people directly from their houses. Efficiency of the multi-modal transportation depends on identifying the needs of aging populations in the affected region via the available transportation network to facilitate an evacuation. Following the determination of available modes given the disaster conditions, available routes should be identified to facilitate the emergency evacuation.

Since all disasters differ from one another in some respect, it becomes necessary to set forth clear assumptions about disaster characteristics and aging evacuees' expected response. A disaster varies not only in its track, intensity, and size, but also how it is perceived by aging residents in potentially vulnerable areas. Based on the U.S. Army Corps of Engineers and Federal Emergency Management Agency evacuation modeling approach (104), several basic assumptions should be made regarding the disaster scenarios, such as aging population-at-risk and the available transportation network in order to develop an efficient evacuation methodology.

Therefore, the first step is to determine the number and location of aging people living in the affected area using available resources such as state agency databases, and CENSUS data including surveys. Then, the available transportation network databases are processed to identify the following: (a) available roadway and railway transportation networks, (b) location and accessibility attributes for multi-modal origins (airports, water ports, railway terminals, and intermodal connection terminals) and destinations (staging areas, distribution centers, shelters) in the affected region. This information is presented as compatible GIS-based visual illustrations using the ArcGIS tool. Next, evacuation scenarios are created focusing on the transportation of aging victims safely out of the affected region. The literature suggests that there are two critical outputs of evacuation scenarios: clearance times and critical locations (38, 104, 105, 106). Therefore, the disaster scenario outputs will be evaluated based on the travel time needed to evacuate aging people, and the condition of critical roadways and bridges.

In the following section, we present a case study application on District 3 of Florida where we utilize the available data in order to represent this knowledge in terms of visual illustrations that can be vital for decision making in the aftermath of disasters.

### *5.4.2 Study Site (District 3) Characteristics for Emergency Evacuations with a Focus on Aging*

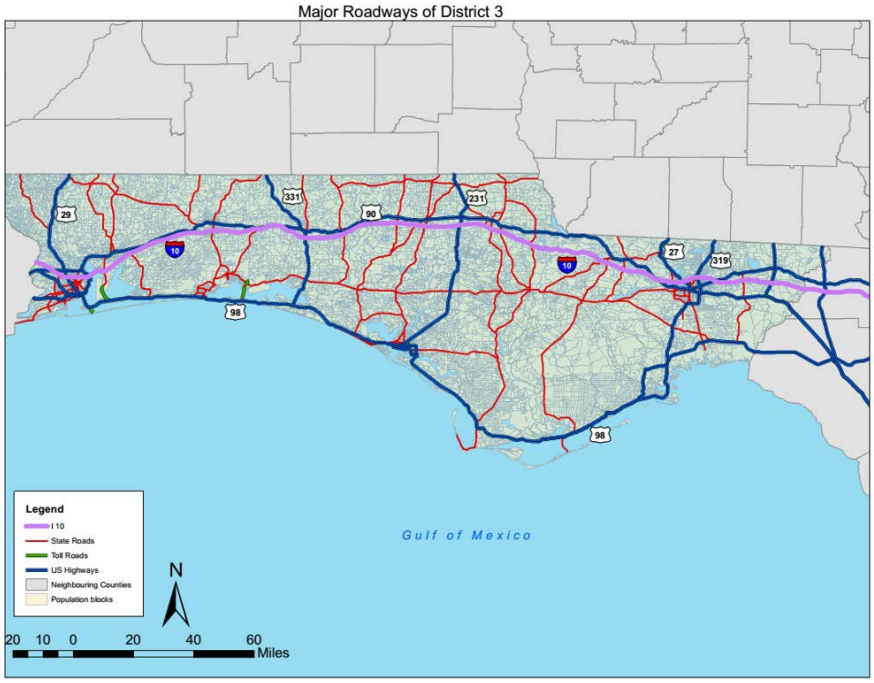
The aging population considered in this analysis comprises those over 65, which is consistent with the aging road user priority assessment by Florida Department of Transportation and Safe Mobility for Coalition (107). Based on 2010 US Census data, the aging population (65+) of District 3 is 181,984, which makes 13% of the total population. Based on 2010 US Census and Florida Healthcare Association data, and American Community Survey results, 26% of the aging people live alone, and approximately 3% live in nursing homes, group charters and assisted facilities in District 3 (108, 109). Moreover, if we focus only on the aging people living

in rural areas, they comprise 20% of the total aging population in District 3 based on the 2011 population estimates by Florida Department of Elderly Affairs (110). Moreover, there are counties such as Liberty and Jefferson, where this rural aging population percentage goes over 90%. These statistics clearly show that there is a need for specifically focusing on the needs of aging people during emergency evacuations, especially for those located in rural areas and who live independently. Urban counties like Escambia, Bay, and Leon counties have the highest percentage of aging residents as well as shelter demand, and they also include the major cities of District 3, which are Pensacola, Panama City, and Tallahassee, respectively.

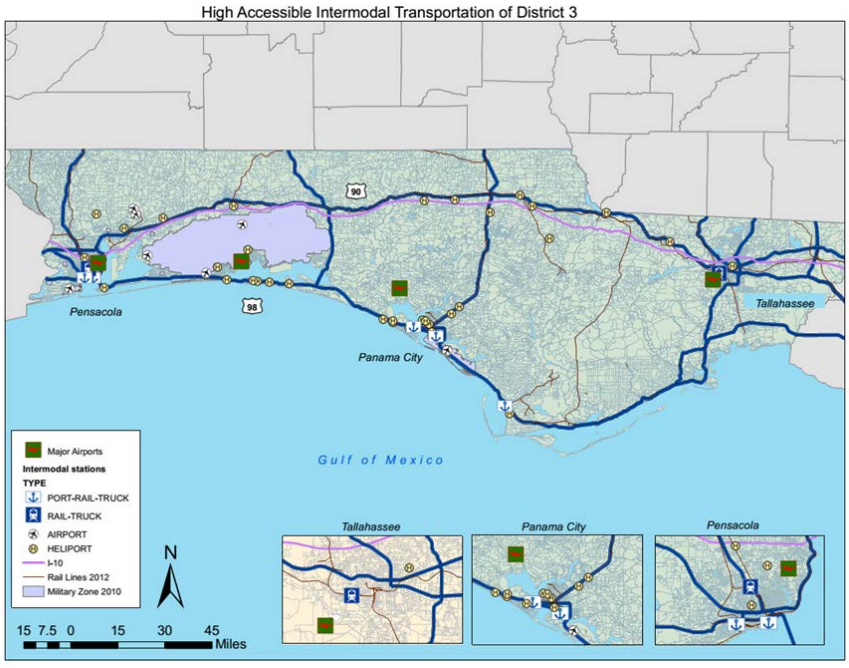
### *5.4.3 GIS-based Analysis of the Multi-modal Transportation Network of District 3 for Evacuations*

Figure 5.4 shows the major roadway network, the railway network, The Department of Defense Strategic Highway Network (STRAHNET) Routes (111) and evacuation routes (112) identified by the Florida Department of Transportation as well as the locations of all airports, heliports, sea ports, and railway terminals in District 3. In order to obtain Figure 5.4, several facilities (such as small heliports) are eliminated from the database based on their vulnerability to disasters, and their limited functionalities such as lack of control towers. As shown in Figure 5.4, state roadways comprise a significant portion of the District 3's major urban highway network, particularly around larger cities such as Tallahassee in Leon County, Panama City in Bay County, and Pensacola in Escambia County, whereas the railway network is very limited. Based on this information, roadways are found to be integral for evacuating aging victims in District 3. Since transportation of aging requires the availability and accessibility of sufficient roadway infrastructure, it becomes critical to determine and disseminate the roadways that could be used to move aging people from their origin to their destination. Based on this evaluation, if

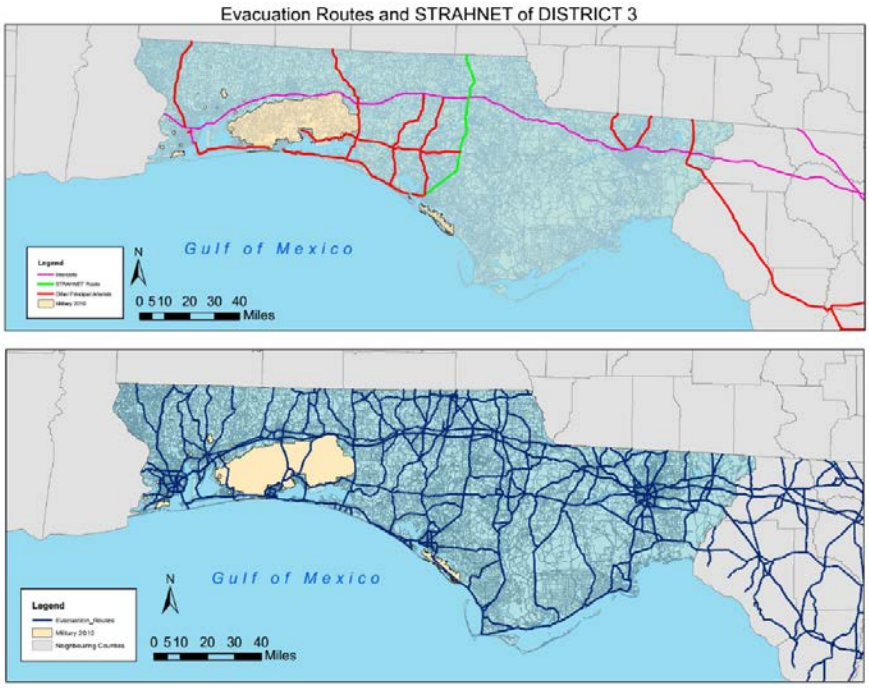
disruptions such as road closures (i.e., due to flooding) occur in the aftermath of disasters, the planner/official can make decisions on how to optimally select the mode/route, and safely transport the aging population.




(a)




(b)




(c)

**Figure 5.4.** Multi-modal GIS-based Representation of District 3 with a Focus on Evacuations (a) Major Roadways (b) Multi-modal Network and Locations (c) The Department of Defense Strategic Highway Network (STRAHNET) Routes (111) and Evacuation Routes (112) identified by Florida Department of Transportation

*5.4.4 Evaluation of Roadways*

The focus of emergency relief studies has evolved due to changes in the frequency and types of incidents and the characteristics/needs of evacuees. Storm surges due to hurricanes and floods have been the most frequent and dangerous hazardous events in the USA and continue to be one of the major focus areas that affect emergency transportation operations. On the other hand, providing accessible transportation to aging people also has utmost importance for secure and efficient evacuations. Thus, this step evaluates the risk involved in using the major roadways of District 3 in the aftermath of disasters such as hurricanes and plant failures based on their proximities to the aging population living in urban and rural areas as well as their vulnerability to those disasters.

Since there is no formal index or model to assess the proximity of roadways with respect to aging populations, urban/rural areas, multi-modal facilities, and subjective judgment need to be used to assess the vulnerability of roadways. This evaluation criteria can be changed depending on the type of disaster, the population characteristics of the area focused on and the available transportation network. For the plant-focused proximity assessment, an evaluation criteria based on the radii needed to create the impact buffer zones is used. On the other hand, GIS-based maps offer a more comprehensive evaluation for storm surges and flooding in terms of visually identifying their adverse effects on the available transportation network, and making decisions based on network vulnerabilities in the aftermath of such a disaster.

*Proximity to Aging Populations*

In order to improve the safety and efficiency of aging-focused emergency evacuations, accessibility of the locations where aging people are living to the transportation network is of critical importance. Location specific rating criterion for highways is given as follows (Table 5.2):

- **High:** Highway passes within 10 miles of a highly populated aging population block.
- **Medium:** Highway passes 10–50 miles from a highly populated aging population block.
- **Low:** All others.

*Proximity to Urban/Rural Areas*

Similar to the previous criterion, this one focuses on the proximity of the roadways to urban and rural areas. This is to assess the vulnerability of the roadway based on highly populated locations, and can be used to identify the risk associated with man-made disasters (Table 5.2):

- **High:** Highway passes within 10 miles of an urban area.

- **Medium:** Highway passes 10–50 miles from an urban area.
- **Low:** All others.

*Proximity to Multi-modal Transportation Facilities*

This criterion focuses on the proximity of the roadways to multi-modal transportation facilities such as airports, ports, and intermodal terminals. This is to identify the accessibility of the roadways with respect to other transportation modes (Table 5.2):

- **High:** Highway passes within 10 miles of a multi-modal transportation facility.
- **Medium:** Highway passes 10–50 miles from a multi-modal transportation facility.
- **Low:** All others.

*Storm Surges and Flooding*

For the flooding analysis, the hazard analysis procedure assesses the potential impact on the roadway if such an event did occur, rather than addressing the probability of an event. Within this effort, each major highway is ranked as high, medium, or low in terms of vulnerability for storm surge and flooding. Storm surge and FEMA flooding data for the GIS maps and assessment analysis are obtained from the Florida Division of Emergency Management (113) and the Florida Geographic Data Library (FGDL) (114), respectively. These maps are used to estimate storm surges and flooding resulting from tropical storms and assess the vulnerability of each facility to a storm surge with the following categorization as presented in Table 5.2:

- **High:** Highway is vulnerable to a storm surge or flooding from a Category I or II storm.
- **Medium:** Highway is vulnerable to a storm surge or flooding from a Category III or higher storm.
- **Low:** Highway is not vulnerable to a storm surge or flooding.

*Plant Failures/Accidents*

There is only one plant (Farley Nuclear Plant) which is of interest since the plant impact zone includes several counties of District 3 (38). Location specific rating criterion is as follows (Table 5.2):

- **High:** Highway passes within 10 miles of a plant.
- **Medium:** Highway passes 10–50 miles from a plant.
- **Low:** All others.

**Table 5.2.** Evaluation of Major Highways in District 3

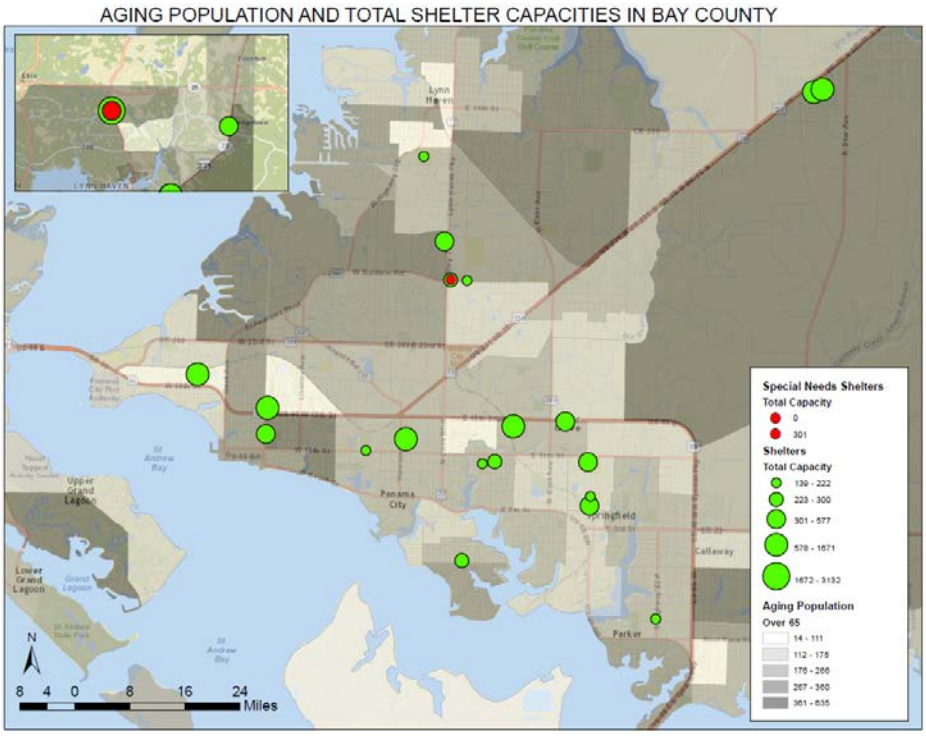
| Analysis of Major Highways in District 3 | Escambia County | | | | | | Bay County | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Proximity to Aging Population | Flooding Risk | Storm Surge Risk | Urban/Rural | Proximity to Nuclear Plant | Proximity to Multimodal Transportation | Proximity to Aging Population | Flooding Risk | Storm Surge Risk | Urban/Rural | Proximity to Nuclear Plant | Proximity to Multimodal Transportation |
| I-10 | High | High | Low | Urban | Low | Med | | | | | | |
| US-29 | High | Med | Low | Urban | Low | High | | | | | | |
| US-98 | Med | High | High | Urban | Low | High | High | Med | High | Urban | Low | High |
| US-90 | High | High | High | Urban | Low | High | | | | | | |
| US-231 | | | | | | | High | High | Med | Urban/ Rural | Low | High |

| Analysis of Major Highways in District 3 | Leon County | | | | | |
|---|---|---|---|---|---|---|
| | Proximity to Aging Population | Flooding Risk | Storm Surge Risk | Urban/Rural | Proximity to Nuclear Plant | Proximity to Multimodal Transportation |
| I-10 | High | Med | Low | Urban/ Rural | Med | Low |
| US-29 | | | | | | |
| US-98 | | | | | | |
| US-90 | High | Med | Low | Urban/ Rural | Low | High |
| US-231 | | | | | | |
| US-27 | Med | Med | Low | Urban/ Rural | Med | Med |
| US-319 | High | Med | High | Urban/ Rural | Low | High |

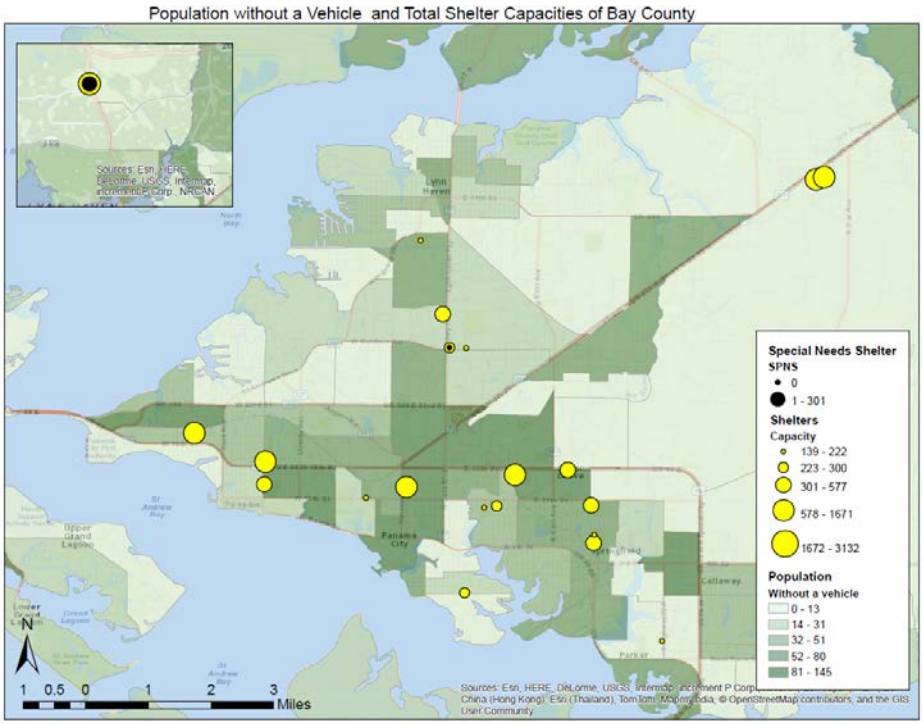
Following this evaluation, in the following sections, we will present two scenarios that focus on evacuating aging people in District 3.

*5.4.5 Scenario 1: Application to Panama City, Bay County*

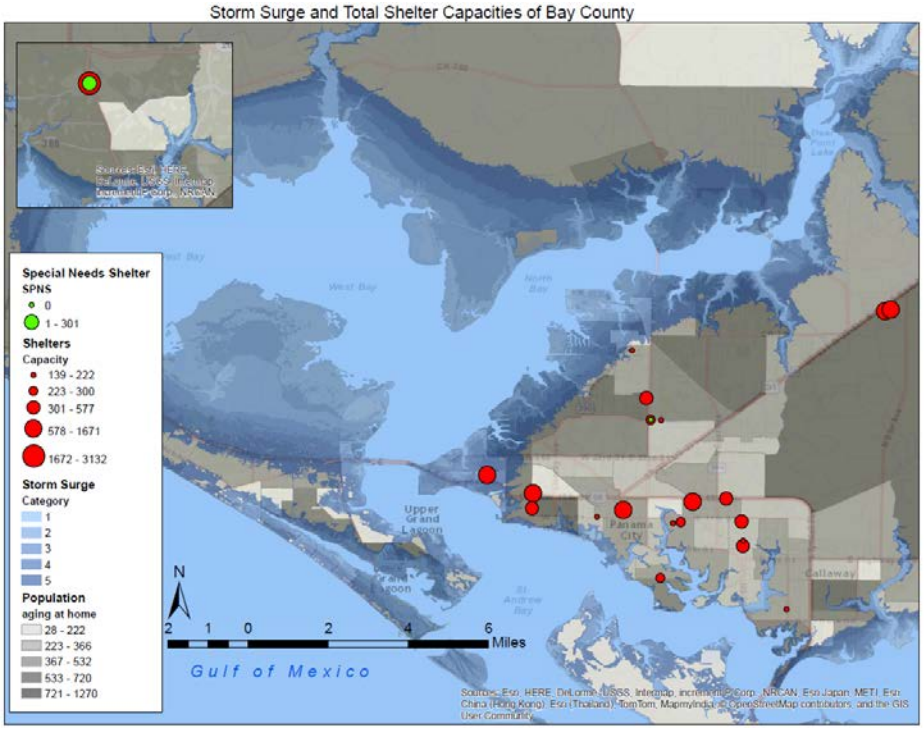
The evacuation area considered in this scenario includes one of the largest cities of District 3, namely Panama City. For Panama City, Figure 5.5 shows the major roadways and aging population blocks as well as the emergency shelters available in the region based on the evaluation of the available data. Note that the shaded parts of the maps show the highest concentration of aging populations. As seen in Figure 5.5, the critical roadway and bridge closures due to heavy rain show that the aging population that need special assistance or do not have vehicles will have trouble evacuating given the flood and storm surge-prone areas. The small map on the left top corner shows the remaining shelters available to the north of Panama City.



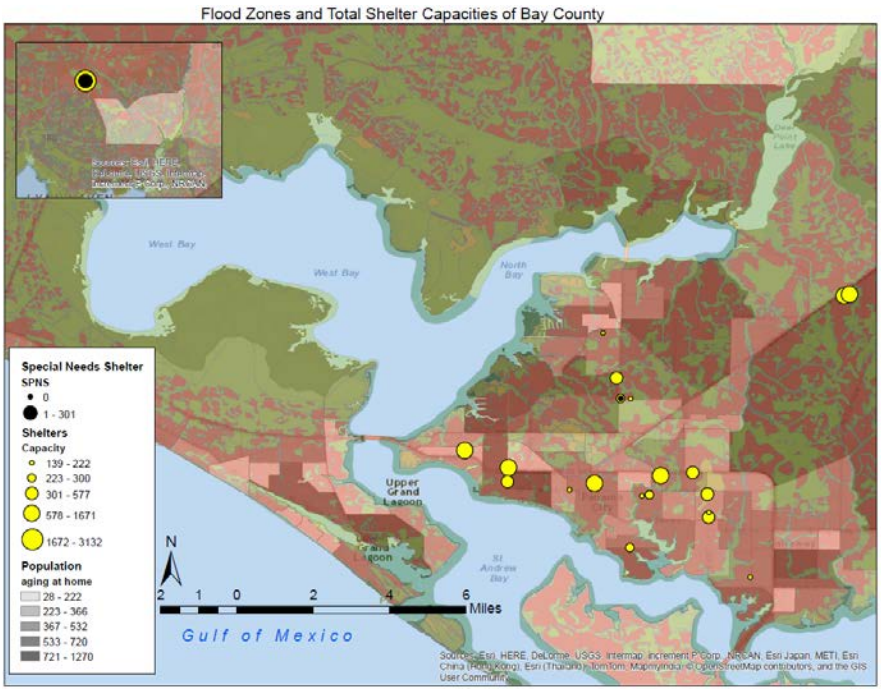

(a)


Population without a Vehicle and Total Shelter Capacities of Bay County
Special Needs Shelter
SPNS
0
1 - 301
Shelters
Capacity
139 - 222
223 - 300
301 - 577
578 - 1671
1672 - 3132
Population
Without a vehicle
0 - 13
14 - 31
32 - 51
52 - 80
81 - 145
N
1 0.5 0 1 2 3
Miles

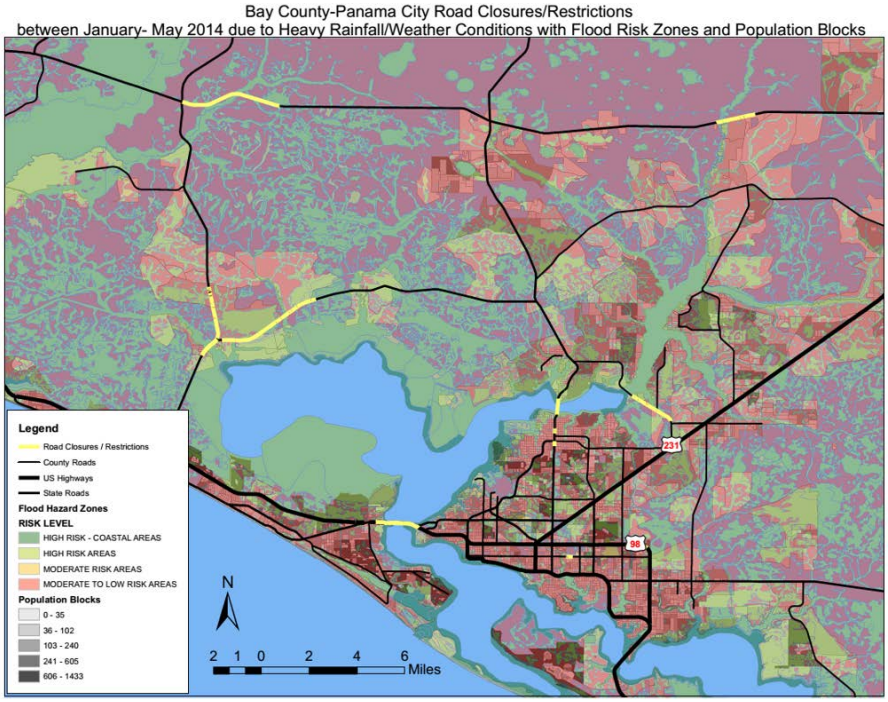
(b)


Storm Surge and Total Shelter Capacities of Bay County
Special Needs Shelter
SPNS
0
1 - 301
Shelters
Capacity
139 - 222
223 - 300
301 - 577
578 - 1671
1672 - 3132
Storm Surge
Category
1
2
3
4
5
Population
aging at home
28 - 222
223 - 366
367 - 532
533 - 720
721 - 1270
N
2 1 0 2 4 6
Miles
Gulf of Mexico

(c)




(d)



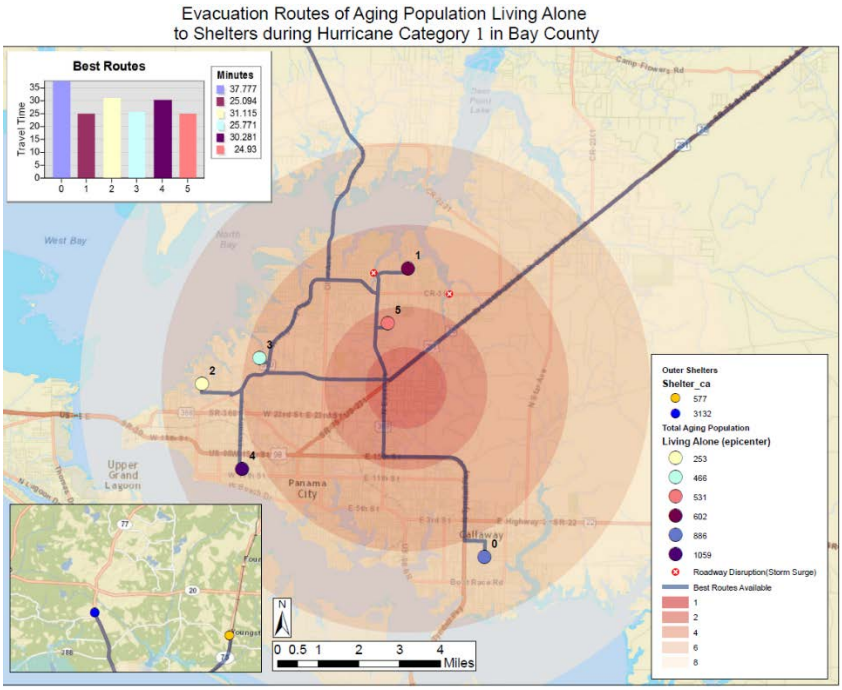

(e)

**Figure 5.5.** GIS-based Representation of Panama City/Bay County with a Focus on Aging Populations (a) Major Roadways, Shelters and Aging Population (65+) (b) Major Roadways, Shelters and Population without a Vehicle (c) Shelters, Aging Population (65+) and Storm Surge (Category 5) (d) Shelters, Aging Population (65+) and Flood Hazard Zones (e) Critical Locations, Aging Population (65+) and Flood Hazard Zones in Pensacola of Escambia County

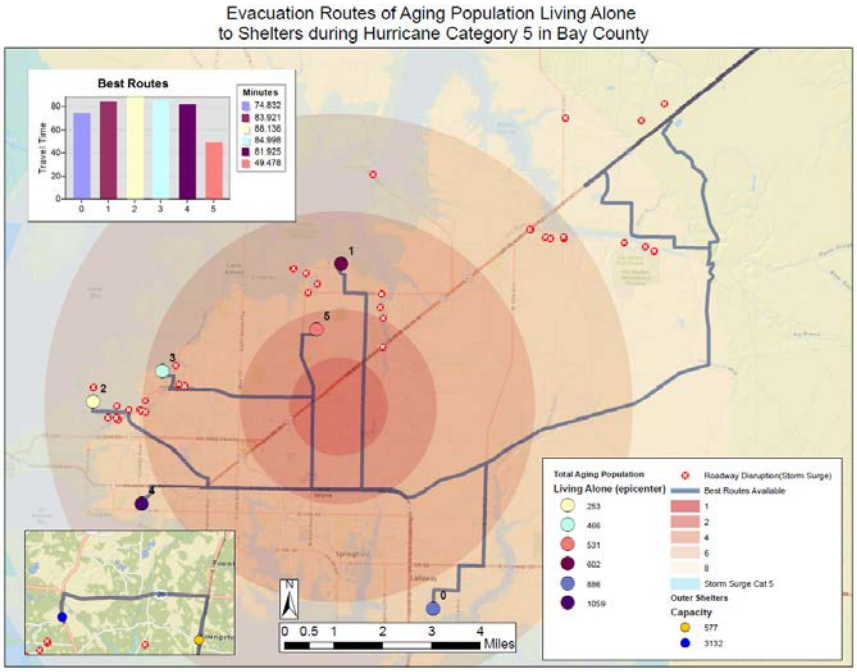
For the scenario, we focus only on the aging people living alone in Panama City of Bay County, for which data is obtained through American Community Survey results (109). During an emergency situation, the aging population can be evacuated from the affected region via roadway (individual vehicles or transit services), or by air, rail and sea, and transported to their final destinations, such as shelters. Therefore, origins for evacuation are usually located within or near their homes. However, destinations could be within the region or anywhere outside the affected region. Based on the impact zone shown in Figure 5.6, we assume that all the aging population living alone is evacuated from the designated origins (centroids of the population blocks) to shelters outside the affected region, and we consider two cases: with (Category 5 hurricane where critical locations such as north-bound bridges and major roadways are closed to the storm surge) and without disruptions (Category 1 hurricane with minimal roadway disruptions, north-bound bridges are open). The map on the left bottom corner represents the available shelters outside the affected area to the north.

We also assume that all aging people living alone need help to be able to evacuate, therefore we create a scenario based on the use of transit services (buses) for transporting people from the affected region to the shelters located outside the impact zone. The carrying capacity of each bus is identified as 45 aging people per trip. Based on these assumptions, to assess the anticipated impact of roadway disruptions on travel times, GIS and planning model-based output is used to measure bus evacuation travel times using the shortest path given all available roadways, and four cases are considered: free flow and model-estimated congested (daily background travel included) travels with or without any roadway disruptions. ArcGIS and the Northwest Florida Regional Planning Model (115) are used to compare the travel times (

Table **5.3**) where names of the origins (airports/ports/intermodal railway terminals) and destinations (shelters) are provided at the end of the table.




(a)




(b)

**Figure 5.6.** Evacuation Scenarios for Panama City with a Focus on Aging Populations Living Alone (a) Category 1 Case (b) Category 5 Case

**Table 5.3.** Travel Time Comparison with and without Roadway Disruptions

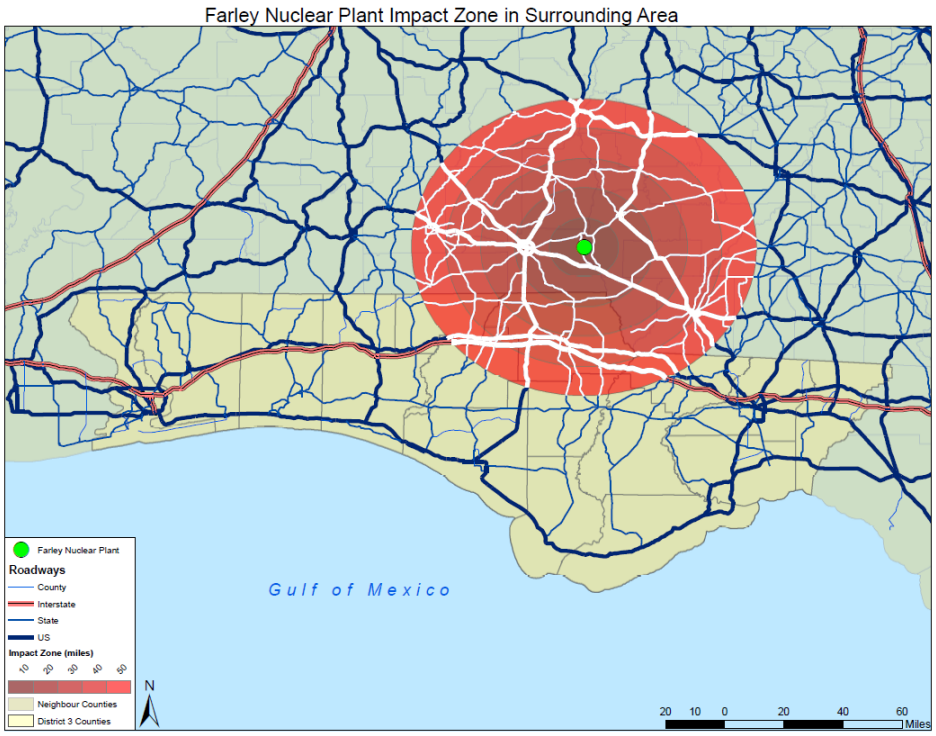
| Travel Times (One-way) from Population Block Centroids to Selected Shelters Outside the Affected Region | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Bus Evacuation Times without Roadway Disruptions (min) | | Bus Evacuation Times with Roadway Disruptions (min) | | | |
| Origins (Centroids of Aging Population - Living Alone-Blocks) | Aging Population Living Alone for Each Block | Destination | Free Flow Travel Time (min) | Congested Travel Time (min) | Free Flow Travel Time (min) | Congested Travel Time (min) | Delay based on the Congested Travel Time (min) | Number of Buses Needed |
| 0 | 886 | Shelter O1 | 37.8 | 39.2 | 74.8 | 111.2 | 72.0 | 20 |
| 1 | 602 | Shelter O1 | 25.1 | 25.1 | 83.9 | 115.2 | 90.1 | 13 |
| 2 | 253 | Shelter O2 | 29.6 | 43.5 | 85.3 | 120.4 | 77.0 | 6 |
| 3 | 466 | Shelter O1 | 25.8 | 27.7 | 85.0 | 118.2 | 90.5 | 10 |
| 4 | 1059 | Shelter O1 | 30.3 | 33.4 | 81.9 | 121.8 | 88.3 | 24 |
| 5 | 531 | Shelter O1 | 24.9 | 25.0 | 49.5 | 80.9 | 55.9 | 12 |
| **Travel Times from Intermodal Terminals to Selected Shelters Outside the Affected Region** | | | | | | | | |
| Airport | | Shelter O1 | 19.9 | 21.0 | 19.9* | 23.7 | 2.7 | |
| Airport | | Shelter O2 | 29.6 | 34.1 | 107.2 | 134.5 | 100.4 | |
| Intermodal Terminal (Port/Rail) | | Shelter O1 | 29.9 | 39.6 | 90.6 | 118.3 | 78.7 | |
| Intermodal Terminal (Port/Rail) | | Shelter O2 | 11.2* | 15.6* | 11.2* | 15.6* | 0* | |
| **Centroids are listed in order as follows: 0, 1, 2, 3, 4, 5. Please see FIGURE 4 for locations.** | | | | | | | | |
| **Selected shelters outside the affected region include the following:** | | | | | | | | |
| Shelter O1 (Special Needs (SPNS) Shelter): Bozeman Learning Center | | | | | | | | |
| Shelter O2: Waller Elementary School | | | | | | | | |
| Airport: Northwest Florida Beaches International Airport (ECP) | | | | | | | | |
| Intermodal Terminal (Port/Rail): Port Panama City | | | | | | | | |
| *(Roadway closure do not affect the optimal route and travel time) | | | | | | | | |
| Note: Loading/unloading times can vary between 5 to 15 minutes depending on the case and should be considered as additional time needed. | | | | | | | | |

During a natural disaster such as a hurricane, which can be relatively predictable in terms of its likelihood of occurrence and area of impact, evacuees generally have enough time to consider different options, including whether or not to evacuate, and when and where to evacuate. This may not be the case for aging evacuees who may need special assistance and help in order to evacuate. Time can be vital for their survival and this analysis clearly shows the importance of considering the roadway disruptions while evacuating aging people focusing on the evacuation times. The importance of these travel time estimation can be summarized as follows:

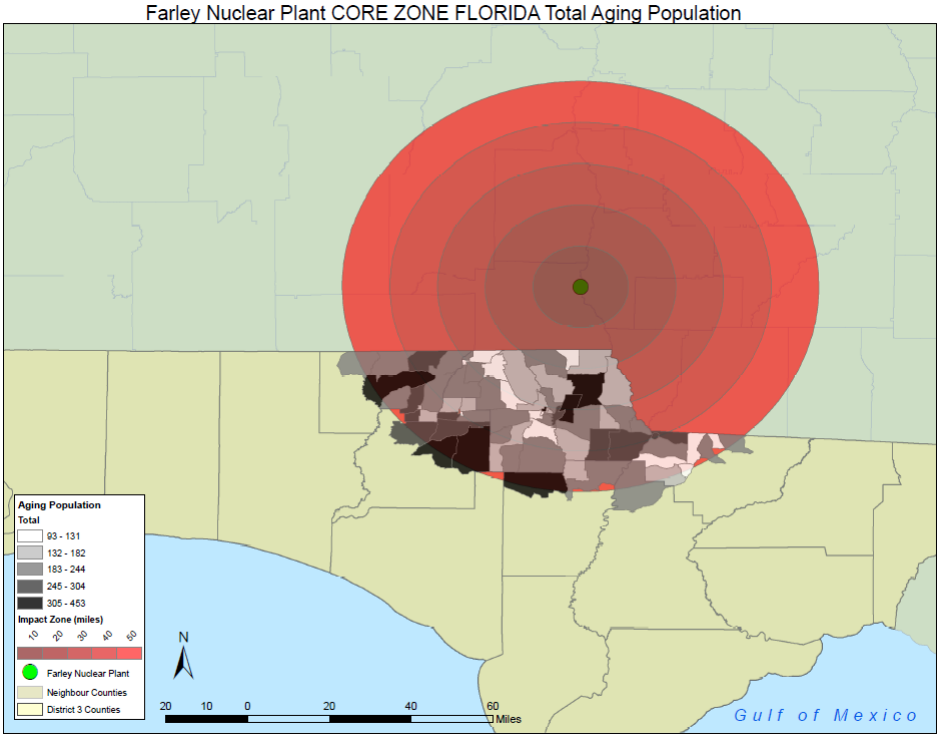
- Roadway disruptions have a vital effect on evacuation times for Panama City. Especially when the bridges that connect Panama City to the northern part of Bay County get flooded (having a high probability of getting flooded based on previous data) (Figure 5.5), congested travel times are almost tripled for some routes (up-to 90 minutes more than the one without any disruptions for the farthest epicenter). This indicates that a comprehensive evacuation plan should have a decision component to start evacuating people earlier based on the disaster conditions/characteristics.
- These travel time calculations also cover possible intermodal origins such as the airports and sea ports in the region with or without roadway disruptions.
- Destinations (shelters) selected outside of the impact zone represent outside locations that can serve the aging residents evacuated from the affected region.
- Planners/officials may not know where a disaster will strike, nor do they know to where exactly victims will be evacuated. Although these estimations would not be directly used for real-time emergency management operations, a widely dispersed group of aging-population origins and outside destinations would provide more choices to the emergency planners while evacuating aging victims. In addition, it would also help in understanding the feasibility of certain routes and the use of transit services.
- Before conducting the optimal evacuation routing analysis, officials could be aware of the estimated travel times between origins and destinations with and without including daily congestion, and number of buses needed to evacuate the aging people. This information can help decision making related to the allocation of the resources (in this case, buses) so that other options can be considered if the resources are not sufficient. This may include the use of other transportation modes.

### *5.4.6 Scenario 2: Farley Nuclear Plant Failure*

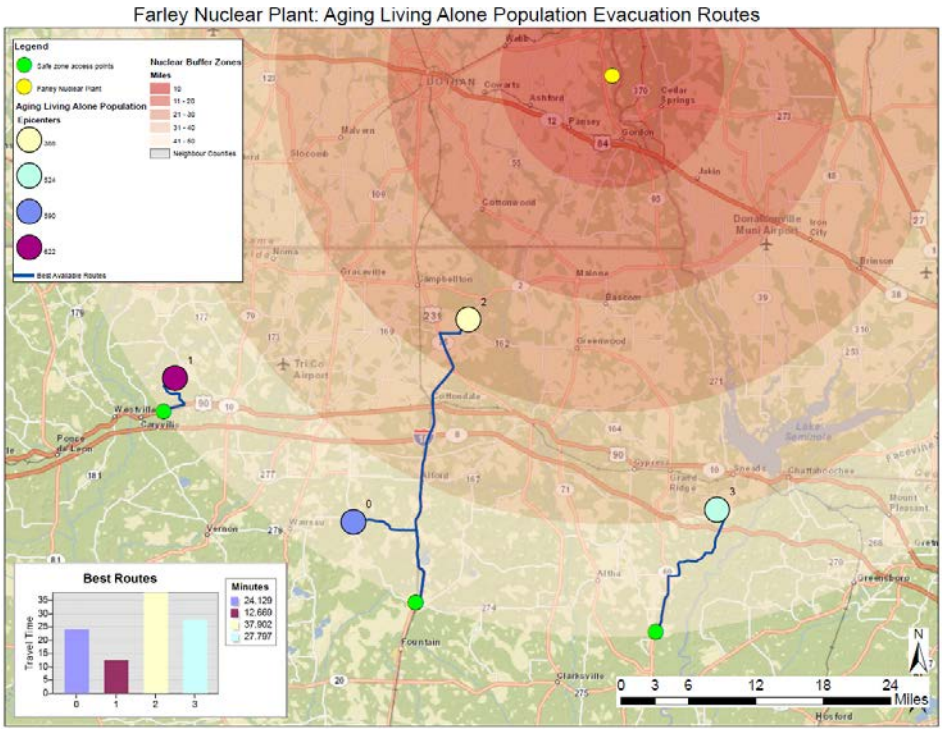
For this scenario, we focus only on the aging people living alone in the counties residing in the impact zone of Farley Nuclear Plant, for which population data is obtained through American Community Survey results (109). Figure 5.7 shows the counties and roadways that pass through the high risk areas within the plant impact zone. During a nuclear power plant evacuation, there may be no widespread loss of transportation infrastructure (e.g., major decrease in the capacity of the transportation network due to flooding in the case of a hurricane). In such cases where disasters do not have an impact on the highway infrastructure, the rapid evacuation of aging evacuees from the impact zone should be considered rather than a destination-based approach (38). For such disasters, the evacuation process also has to start immediately without any time to make for individual decision making (105). Therefore, in this section, the vulnerability of the aging population located in the impact zone is studied with an evacuation scenario that determines the travel times to the impacted zone border identified by the Florida State Emergency Response Team (38). As seen in Figure 5.7, four epicenters are selected as evacuation origins, for which the number of aging people being evacuated and optimal routes/travel times are presented. This type of travel time analysis will give planners and emergency officials an idea of the expected evacuation times to the border of the impacted zone for an aging population, which can help emergency planning due to such a plant failure.


Farley Nuclear Plant Impact Zone in Surrounding Area
Farley Nuclear Plant
Roadways
County
Interstate
State
US
Impact Zone (miles)
10 20 30 40 50
Neighbour Counties
District 3 Counties
N
Gulf of Mexico
20 10 0 20 40 60
Miles

(a)


Farley Nuclear Plant CORE ZONE FLORIDA Total Aging Population
Aging Population
Total
93 - 131
132 - 182
183 - 244
245 - 304
305 - 453
Impact Zone (miles)
10 20 30 40 50
Farley Nuclear Plant
Neighbour Counties
District 3 Counties
N
20 10 0 20 40 60
Miles
Gulf of Mexico

(b)




(c)

**Figure 5.7.** FDOT District 3 Region Roadway Vulnerability Map with a Focus on Aging Population (65+) (a) Farley Nuclear Plant Impact Zone (b) Farley Nuclear Plant Core Zone with Aging Population (65+) Blocks (c) Scenario Results for Evacuation Aging People Living Alone: Best (Optimal) Routes and Evacuation Times to the Impact Zone Border

## 5.5 Spatial Network Optimization Modeling for Special Needs Hurricane Shelter Placement Serving the Aging Population

Providing critical services to vulnerable populations is essential in the event of disasters. Recent experience with hurricane damages and impacts particularly in the Southeastern U.S. has heightened awareness of the multifaceted nature and challenges of effective disaster relief planning (91-118). One key element of hurricane disaster relief planning is providing adequate shelter space at secure locations so that people who choose to evacuate their home may have safe refuge available (78).

The populations who wish to evacuate their residences for shelters to flee an oncoming storm are not heterogeneous. They may consist of the young, the old, people with transportation limitations, and those with weak housing infrastructure (119). Among these evacuees will be those known as having 'special needs.' So-called special needs populations consist of the aging people, people with disabilities and health problems, certain children, and other groups (120-122). As the requirements for accommodating special needs populations are more substantial than those of the general population, planners must designate dedicated shelter space for them. Site characteristics such as the amount of floor space are key to the designation of special needs centers (123), though we would also argue that spatial proximity and accessibility are also important to selecting shelter locations (120, 124, 76). Strategic selection of locations for special needs shelters that maximize accessibility to these vulnerable populations is one way to promote safe and effective utilization of these facilities, thereby helping to minimize risk.

In this section, we design and implement a geographic information systems (GIS) based network optimization methodology to site special needs hurricane relief shelters focusing on the transportation component. We look to find new locations for special needs shelters that maximize accessibility to vulnerable populations all while accounting for the capacity constraints on special needs facilities. The central focus here is on the aging component of the special needs population. Our framework is implemented in a medium-sized Florida metropolitan statistical area where published reports show there currently exists a deficit in the available special needs shelter space relative to demand (37). Thus, our work has implications for informing future policy development in our study area and beyond. In sum, our contribution is the adaptation of spatial optimization models to the problem of siting special needs shelter locations, while controlling for several key real-world considerations, including the capacity limits of such

shelters along with the potential for the roadway infrastructure that would be used for transportation to fail during extreme events.

### *5.5.1 Study Area and Modeling Approach*

Our study region is that of Leon County, FL. It contains Florida's capital city and according to the 2010 U.S. Census, it had a population of about 275,000 people. According to the Florida State Plan on Aging 2013-2016, Leon County has nearly 39,000 people aged 60 and older. It is an economically diverse region that boasts a large number of education and health-oriented employment options, along with a substantial contingent of state government employees. Its southernmost point is approximately a 20-30 minute drive to the Gulf of Mexico coast, and it has been subject to a number of previous studies on emergency management issues (87, 90). Leon County, FL is shown in Figure 5.8 along with some key data items used in our analysis.

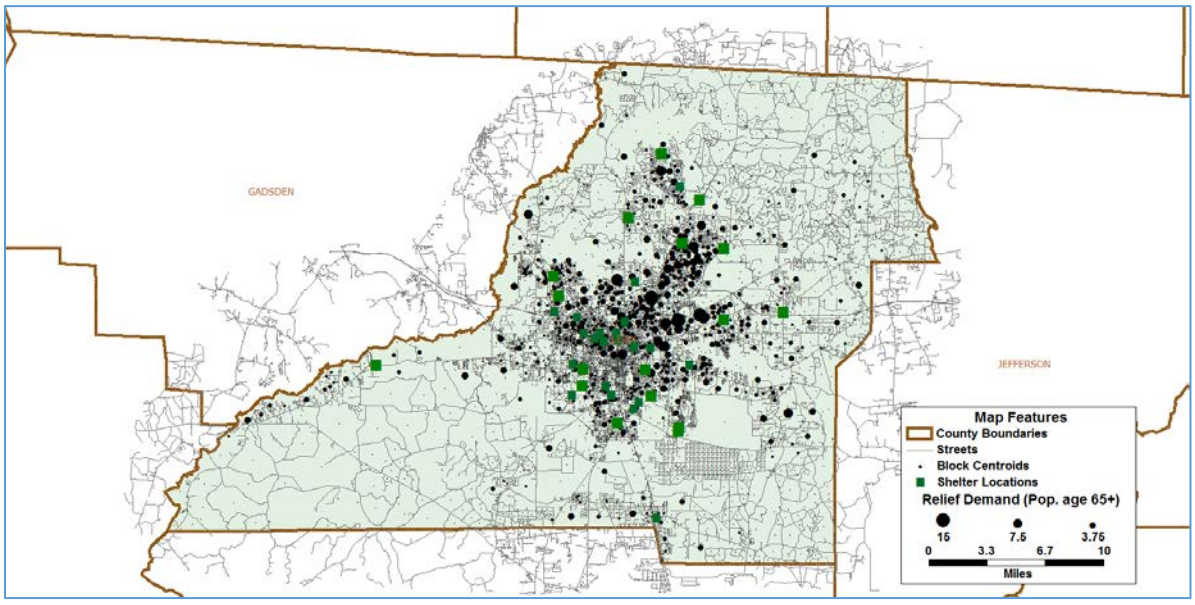



**Figure 5.8.** Leon County, FL Study Area

*5.5.2 Scenario Overview and Assumptions*

Shelter planning is done at the County Level in Florida as a part of each County's Emergency Plan (37). Shelters are typically used when a category 4 or 5 storm is threatening. The situation is such that Leon County, Florida has documented special needs of approximately 1,425 shelter spaces (2014), and we know from the literature that those with special needs are among the most vulnerable populations. However, recent documentation suggests Leon County does not have the shelter capacity to meet these needs, as it has a current deficit of 720 spaces (37). Although its inland location is such that it is likely at a lower risk for hurricane damage than other Florida counties, the capacity shortage seemingly would need to be addressed. As special needs populations require additional care above and beyond traditional populations, excessive dispersion of special needs populations across a large number of shelters would not be a wise use of staffing and other resources, if possible at all. Thus, our approach is to concentrate new special needs shelter spaces in a few targeted existing regular shelter locations. Taking a more strategic approach, we look to open these new special needs spaces in locations that maximize their accessibility to specific special needs populations; those of the aging. This means attempting to minimize the travel costs of people reaching new special needs shelter space. To motivate this scenario, we detail a number of considerations and assumptions that underpin our work.

The approach taken is to assume that existing population shelter space at current Leon County shelters can be 'repurposed' into special needs population shelter space. Shelters in Leon County are either American Red Cross (ARC) compliant or not, and those that are ARC compliant tend to be public schools (120, 37). Within the scenario, we work with the ARC approved regular shelter sites (18 of 40 published shelters in Leon County) and assume that they

can be partially converted to supporting special needs populations (see Figure 1). Shelter location data were obtained from the 2014 State Shelter Plan (37). Special needs shelters are subject to a number of criteria including having sufficient emergency power, electrical capacity to operate medical equipment, potable water and plumbing, space for children to play, and many more. Readers interested in the specific guidelines that govern shelter site compliance and characteristics are referred elsewhere (120, 37) as our focus is on determining spatially accessible site locations which meet other macro constraints. Currently there is a single existing ARC compliant special needs shelter in Leon County – the Florida State University (FSU) Charter School near Southwood in the southeastern portion of the County. It has a capacity of 705 persons. The Kate Sullivan School located more centrally in Leon County is also listed in planning documentation as a possible special needs center, but its space has not been certified by the ARC and is therefore not considered as an option in our modeling effort. Thus, again, there is a deficit of 720 special needs shelter spaces that need to be added.

In all modeling scenarios, the FSU Charter School Special Needs Shelter is automatically opened and its unaltered capacity is available for use. For the other 17 candidate shelters, we compute their potential special needs shelter capacity by taking their existing regular population shelter capacity and assuming some fraction of that could be converted to serving special needs. This is done by assessing the physical space available at a given shelter and applying a series of conversions. For example, suppose an existing shelter had 6,000 square feet available for serving the general population. We might assume that 50% of this space could be re-purposed to serve special needs people. We also know that approximately 60 square feet (sq.ft.) is needed to serve one special needs person (37). Thus, in this example, 50 special needs people could be served (50% of 6,000 sq.ft divided by 60 sq.ft per person) at this candidate location. As a point of

background, only 15 sq. ft. of shelter space is needed for each regular shelter occupant, and although re-purposing shelters does result in an overall drop in total shelter capacity, there is currently a surplus of 19,685 shelter spaces for the regular population (37).

According to the sources described above (13), there is special needs shelter demand in Leon County of 1,425 persons, however exact spatial distribution of these people and their composition are not known; data only provided the aggregate county total. Special needs populations include the aging people, people with disabilities, the sick, and others. While there has been some research on identifying special needs populations and their locations (6) here we take a more direct approach and use counts of the aging population (those age 65+) to proxy the spatial distribution of the special needs population, as they are a primary focus of our work. Though it could be preferable to have a more robust estimate of the special needs population distribution, the aging people would comprise a substantial share of it and if we assume that the remaining special needs population follows a similar spatial pattern, then the modeling results will be meaningful.

Operationalizing the special needs demand for the shelter modeling was done in GIS. A vector balancing algorithm was applied to distribute the 1,425 special needs shelter demand total across 2010 Census blocks in Leon County. The population was distributed proportionally based on each block's share of Leon County's county aging population. 2,880 of the 6,198 census blocks had nonzero aging populations in the initial data - of the 2,880 census blocks, as no fractional demand is permissible (i.e. we deal in whole persons) 727 of them were allocated some nonzero demand based on the algorithm. See Figure 5.8 for the distribution of relief demand.

*5.5.3 Spatial Modeling Approach*

We used a capacitated p-median problem to select potential special needs shelter sites. A capacitated p-median problem seeks to minimize the total (or average) travel costs of client demand locations reaching facilities. The user specifies some desired number of facilities (p) for the model to locate. Unlike the traditional p-median problem that does not account for the capacity limitations of sited facilities (125, 98), the capacitated version of the problem ensures that each sited facility cannot serve more than its limits. Capacitated models have been discussed in a number of studies (125, 126, 127). The formulation of our model is adapted from that of (128) and is:

Minimize (Z)

$$Z = \sum_{i \in N} \sum_{j \in M} a_i c_{ij} x_{ij} \tag{5.1}$$

Subject to

$$\sum_{j \in M} x_{ij} = 1, \qquad \forall i \in N \tag{5.2}$$

$$\sum_{j \in M} y_j = p \tag{5.3}$$

$$\sum_{i \in N} a_i x_{ij} \leq Q_j y_j \tag{5.4}$$

$$x_{ij} \in (0,1), \qquad \forall i \in N, \forall j \in M \tag{5.5}$$

$$y_j \in (0,1), \qquad \forall j \in M \tag{5.6}$$

*N* is the set of demand points indexed on *i* and *M* is the set of candidate facility locations (shelters) indexed on *j*. The objective function in Equation (5.1) minimizes total transportation costs between client demand locations and sited special needs center facilities. Transportation costs are captured by the variable $c_{ij}$ and may be measured in distance, time, or some other variable. Demand is captured by *a* and assignments between demand points and sited facilities are tracked by *x*. Constraints in Equation (5.2) ensure that each demand location is served by one and only one special needs facility. The total number of facilities to be sited is regulated by Equation (5.3) with the facility location variable y. Constraints in Equation (5.4) stipulate that demand is assigned to sited facilities and does not exceed their capacity, captured by *Q*. Binary integer decision variables are required for both the decision of the facilities to be sited (*y*) and the allocation of demand location to sited facilities (*x*).

Besides the census block data being used as demand points, and the point locations of regular and special needs shelters, we also needed data on the likely transportation costs connecting these origins and destinations. To accomplish this task we obtained a Census TIGER/Line GIS file from 2010 and inferred speed limits based on functional class codes. From there we computed free-flow travel times for each network linkage (33, 20) and applied a congestion factor of 30% to account for possible stoppages and other normal delays (129). As this travel time assessment is closer to what might be witnessed during 'normal' everyday conditions closer to free-flow, we also computed a separate estimate of travel time that tried to account for the possible delays that could happen during a hurricane emergency. Research has

shown that transportation network failure has the potential to influence the accessibility of facility locations (88).

This second approach taken looked to add realistic possible delays to the road network. As Leon County and Tallahassee are famous for their 'canopy roads' where beautiful trees cover certain roadways, there is potential for these trees to fall down during a major storm, hence resulting in debris and heavy plant material possibly blocking or slowing travel on major roads. Thus we obtained a GIS file depicting the canopy roads geography in Leon County and used them to select out 1,174 road segments from our network. From these we randomly selected 50% (587 segments) and applied an additional 50% delay. As this is a relatively small share of the total roads in Leon County, we looked at the remaining 32,026 of roads and randomly selected 10% of them, or about (3,202), and added an additional delay factor of 50% to their travel times. These ranges are consistent with previously published simulation strategies from the literature (88). This serves to simulate extra delays associated with an emergency and will allow us to explore whether the choice of facilities to re-purpose are sensitive to the travel costs used to select them.

The spatial model was implemented using a combination of GIS, custom programming scripts and an external optimization engine. TransCAD GIS was used to manage the spatial data including the aging special needs demand points, candidate shelter locations and their capacities, and the road networks used to compute travel costs. Data on the travel costs, demand levels, and capacity are exported from the GIS as text files and read into a custom written C++ script that formats them according to the model equations in (91-119). Known as a linear programming file, or LP file, this is then read into the optimization engine CPLEX. As all of these problems were relatively modestly sized, each of the scenarios was solved to less than a 0.01% optimality gap,

and many fully to optimality in no more than about 30 seconds of computing time each. These problems were solved on a standard Windows Pentium 4 32-bit PC running the Windows XP operating system. Although this class of spatial models is difficult to solve for larger problem instances, we would expect that the approach could be applied in larger problem scenarios with more demand points and/or candidate locations.

*5.5.3 Results and Evaluation of Free-Flow and Disrupted Network Solutions*

Results of the model runs are shown in Table 5.4. It contains the outputs from a series of capacity scenarios where we increase the special needs space at candidate locations from 30% up to 50% in increments of 5 percent. Then, for each scenario we run models for a range of values of p, the number of special needs shelters to be sited. We provide three feasible/optimal solutions for each capacity scenario. Table 5.5 gives the names of the specific schools and other facilities that correspond to the shelter numbers listed in Table 5.4.

The left portion of Table 5.4 shows the solutions for models based on uninterrupted network free-flow conditions. Initially, with the one special needs center sited at location 11 (the FSU school), the average travel time to reach this facility is almost 21 minutes for the special needs/aging population. However, as we know, there is not enough ARC approved capacity at this location to handle the total estimated shelter demand, and as such, this cannot be considered a viable solution and therefore additional facilities must be added.

**Table 5.4.** Results of Shelter Placement Modeling

| Base Network Case | | | | | Disrupted Road Network Case | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Current Situation with Unimpeded Road Network:* | | | | | *Current Situation with Disrupted Road Network:* | | | | | |
| Tot.Trav. Costs (mins) | SNS Demand | Avg. Trav. Costs (mins) | Fac. Sited | Sel. Shelters | Tot.Trav. Costs (mins) | SNS Demand | Avg. Trav. Costs (mins) | Pct. Time Inc. | Fac. Sited | Sel. Shelters |
| 29,848.45 | 1425 | 20.95 | 1 | 11 | 31,787.25 | 1,425 | 22.31 | 6.50% | 1 | 11 |
| *30% Capacity Increase* | | | | | *30% Capacity Increase* | | | | | |
| Tot.Trav. Costs (mins) | SNS Demand | Avg. Trav. Costs (mins) | Fac. Sited | Sel. Shelters | Tot.Trav. Costs (mins) | SNS Demand | Avg. Trav. Costs (mins) | Pct. Time Inc. | Fac. Sited | Sel. Shelters |
| - | - | - | 1 | - | - | - | - | - | 1 | - |
| - | - | - | 2 | - | - | - | - | - | 2 | - |
| - | - | - | 3 | - | - | - | - | - | 3 | - |
| - | - | - | 4 | - | - | - | - | - | 4 | - |
| - | - | - | 5 | - | - | - | - | - | 5 | - |
| 17,089.40 | 1,425 | 11.99 | 6 | 1,2,9,11,14,17 | 18,061.54 | 1,425 | 12.67 | 5.69% | 6 | 1,2,9,11,14,17 |
| 16,017.99 | 1,425 | 11.24 | 7 | 1,2,9,11,13,14,17 | 16,916.48 | 1,425 | 11.87 | 5.61% | 7 | **1,2,9,11,14,17,18*** |
| 15,039.70 | 1,425 | 10.55 | 8 | 1,2,4,9,11,14,17,18 | 15,850.85 | 1,425 | 11.12 | 5.39% | 8 | 1,2,4,9,11,14,17,18 |
| *35% Capacity Increase* | | | | | *35% Capacity Increase* | | | | | |
| Tot.Trav. Costs (mins) | SNS Demand | Avg. Trav. Costs (mins) | Fac. Sited | Sel. Shelters | Tot.Trav. Costs (mins) | SNS Demand | Avg. Trav. Costs (mins) | Pct. Time Inc. | Fac. Sited | Sel. Shelters |
| - | - | - | 1 | - | - | - | - | - | 1 | - |
| - | - | - | 2 | - | - | - | - | - | 2 | - |
| - | - | - | 3 | - | - | - | - | - | 3 | - |
| - | - | - | 4 | - | - | - | - | - | 4 | - |
| 17,616.14 | 1,425 | 12.36 | 5 | 1,2,11,14,17 | 18,571.32 | 1,425 | 13.03 | 5.42% | 5 | 1,2,11,14,17 |
| 16,231.73 | 1,425 | 11.39 | 6 | 1,2,9,11,14,17 | 17,133.68 | 1,425 | 12.02 | 5.56% | 6 | 1,2,9,11,14,17 |
| 15,296.01 | 1,425 | 10.73 | 7 | 1,2,9,11,14,17,18 | 16,118.76 | 1,425 | 11.31 | 5.38% | 7 | 1,2,9,11,14,17,18 |
| *40% Capacity Increase* | | | | | *40% Capacity Increase* | | | | | |
| Tot.Trav. Costs (mins) | SNS Demand | Avg. Trav. Costs (mins) | Fac. Sited | Sel. Shelters | Tot.Trav. Costs (mins) | SNS Demand | Avg. Trav. Costs (mins) | Pct. Time Inc. | Fac. Sited | Sel. Shelters |
| - | - | - | 1 | - | - | - | - | - | 1 | - |
| - | - | - | 2 | - | - | - | - | - | 2 | - |
| - | - | - | 3 | - | - | - | - | - | 3 | - |
| 18,623.08 | 1,425 | 13.069 | 4 | 1, 2, 11, 14 | 19,616.94 | 1,425 | 13.77 | 5.34% | 4 | 1, 2, 11, 14 |
| 16,995.35 | 1,425 | 11.927 | 5 | 1,2,11,14,17 | 17,934.91 | 1,425 | 12.59 | 5.53% | 5 | 1,2,11,14,17 |
| 15,739.00 | 1,425 | 11.045 | 6 | 1,2,9,11,14,17 | 16,627.74 | 1,425 | 11.67 | 5.65% | 6 | 1,2,9,11,14,17 |
| *45% Capacity Increase* | | | | | *45% Capacity Increase* | | | | | |
| Tot.Trav. Costs (mins) | SNS Demand | Avg. Trav. Costs (mins) | Fac. Sited | Sel. Shelters | Tot.Trav. Costs (mins) | SNS Demand | Avg. Trav. Costs (mins) | Pct. Time Inc. | Fac. Sited | Sel. Shelters |
| - | - | - | 1 | - | - | - | - | - | 1 | - |
| - | - | - | 2 | - | - | - | - | - | 2 | - |
| - | - | - | 3 | - | - | - | - | - | 3 | - |
| 17,936.07 | 1,425 | 12.587 | 4 | 1, 2, 11, 14 | 18,894.42 | 1,425 | 13.26 | 5.34% | 4 | 1,2,11,14 |
| 16,623.56 | 1,425 | 11.666 | 5 | 1,2,11,14,17 | 17,470.10 | 1,425 | 12.26 | 5.09% | 5 | **1,2,11,14,18*** |
| 15,436.99 | 1,425 | 10.833 | 6 | 1,2,9,11,14,17 | 16,340.40 | 1,425 | 11.47 | 5.85% | 6 | 1,2,9,11,14,17 |
| *50% Capacity Increase* | | | | | *50% Capacity Increase* | | | | | |
| Tot.Trav. Costs (mins) | SNS Demand | Avg. Trav. Costs (mins) | Fac. Sited | Sel. Shelters | Tot.Trav. Costs (mins) | SNS Demand | Avg. Trav. Costs (mins) | Pct. Time Inc. | Fac. Sited | Sel. Shelters |
| - | - | - | 1 | - | - | - | - | - | 1 | - |
| - | - | - | 2 | - | - | - | - | - | 2 | - |
| 19,758.00 | 1,425 | 13.865 | 3 | 2, 11, 14 | 20,742.23 | 1,425 | 14.56 | 4.98% | 3 | 2, 11, 14 |
| 17,463.23 | 1,425 | 12.255 | 4 | 1, 2, 11, 14 | 18,374.96 | 1,425 | 12.89 | 5.22% | 4 | 1, 2, 11, 14 |
| 16,307.14 | 1,425 | 11.444 | 5 | 1,2,11,14,17 | 17,168.80 | 1,425 | 12.05 | 5.28% | 5 | **1, 2, 9, 11, 14*** |

***Indicates shelter configuration that differs from its corresponding undisrupted Increase**

Under the first capacity increase of 30%, we attempt to solve the model for p=2-5 and find that these amounts of facilities cannot provide enough capacity to meet total shelter demand and therefore the optimization software is unable find a feasible solution. At p=6 the software finds its feasible solution, siting facilities at locations 1,2,9,11,14, and 17. Per our prior

discussion, we 'force' the model to use the FSU School's existing special needs shelter (location 11). In this case the model selected 5 other facilities for opening. If these were opened, the average costs of an aging resident reaching a special needs facility in Leon County would be about 12 minutes, a substantial decrease from the base case of about 21 minutes, which we note again did not satisfy basic capacity needs.

Looking further at the results for the 30% capacity scenario, we run models for p=7 and 8 to explore how additional facilities might affect shelter access time. Adding the two additional facilities reduces the travel access times by more than a minute. If we look at the configurations of facilities selected in these scenarios, we can see that facility 13 is added as a consequence of increasing *p* from 6 to 7. However facility 18 and 4 are added due to moving *p* from 7 to 8 facilities and facility 13 drops out of the final solution. This shows that the results of the shelter selection decision are sensitive to the choice of p.

As the capacity is increased in each scenario, generally the model can find 'feasible' shelter solutions that satisfy demand using fewer facilities. If we look at the 50% capacity increase scenario, the model is able to fully satisfy shelter demand using 3 facilities with locations at 2, 11, and 14. The average time needed to reach shelters is about 14 minutes in this case, which is about two minutes more than the previously discussed 30% capacity scenario which utilized 6 facilities. This comparison illustrates a useful trade-off in the provision of special needs shelters in terms of outlining the interplay between capacity addition, facility location selection, and overall travel time. In general, as the number of facilities sited or capacity is increased, typically overall transportation costs decrease as accessibility is improved. Of course, adding facilities and/ or capacity to the system will generate costs. For instance, planners wishing to minimize the total number of facilities opened may gravitate towards future strategies

which increase shelter capacity at a few targeted locations. The results demonstrate that this reduction in new facility changes can be achieved while still maintaining a relatively low average access time in comparison to other alternatives.

**Table 5.5.** List of Candidate Shelter Locations in Leon County, FL

| Shelter Number | School/Shelter Name |
|---|---|
| 1 | Bucklake Elementary |
| 2 | Canopy Oaks Elementary |
| 3 | Carolyn Brevard Elementary |
| 4 | Chaires Elementary |
| 5 | Conley Elementary |
| 6 | Dearlake Middle |
| 7 | Desoto Trail Ememtary |
| 8 | FAMU/FSU Engineering Building 77 |
| 9 | Fort Braden Elementary |
| 10 | FSU School Regular Shelter |
| 11 | FSU School Special Needs |
| 12 | Hartsfield Elementary |
| 13 | Hawks Rise |
| 14 | Lawton Chiles High |
| 15 | Montford Middle |
| 16 | Oak Ridge Elementary |
| 17 | Roberts Elementary |
| 18 | Springwood Elementary |

We also ran capacitated *p*-median models under impeded/disrupted network conditions subject to the previously described parameters. This was done to test the sensitivity of the model results to changes in network conditions. In this way, we are able to evaluate whether network disruptions result in additional substantial travel time increases, as well as if the specific facilities selected in a given scenario persist when the network is further congested.

The overall trend is that this extra level of congestion present in the network tends to add anywhere from about 5-7% more travel time to the average trip to a shelter, and the impacts tend to be greater at lower capacity scenarios (30% vs. 50%) (see right side of Table 5.4). At the higher capacity scenarios, the model has more flexibility to work around the congested network and better allocate demand. On an individualized level, this additional travel time does not seem especially onerous, but as it is an average masking variation (i.e. each census block will have its

own time to its assigned facility, which will vary from block to block), some individual census blocks could see much higher travel times under congested conditions, particularly if they are located in the vicinity of one of the affected roads. Moreover, any extra time incurred for special needs populations and the aging people can be especially dangerous in light of health and other safety concerns.

A second useful exercise is to determine if the facilities selected in the uncongested state persist when the network is impeded. In three specific cases (shown in bold on Table 5.4) there were changes in the facilities selected. Focusing on one of these outcomes, for p=5 under the 50% capacity increase scenario, facility 17 is selected in the base case, but not when the network is congested. Facility 17 (Roberts Elementary) is located in the area of some of the densest 'canopy roads' and is likely being affected by their impedances. Thus the solver selected Facility 9 (Fort Braden Elementary) as a replacement. In sum, the results do suggest that some road network changes can have significant impacts on the provision of special needs shelters, although these are not consistent across all scenarios.

## 5.6 A Spatial Network Optimization Analysis of Hurricane Relief Facility Locations

Relief distribution transportation has become more pressing in emergency planning. Forecasts for more intense and destructive future hurricanes will undoubtedly affect more people. Research has looked to maximize the effectiveness and equity in disaster relief provision efforts, particularly exploring the needs of various socioeconomic groups. Besides income, age of the population can also be an important metric of equity, as evidenced by the disproportionate death toll in New Orleans' aging population caused by Hurricane Katrina. Yet no consideration has been given so far to the impacts of age-based demand on the provision of disaster relief. This research compares the service needs of aging vs. other populations in terms of the strategic siting

of relief distribution centers. Through a case study in Leon County, Florida, we explore the influence of the age of potential hurricane survivors on the decision of where to site relief distribution facilities. A p-median based modeling framework linked to a geographic information system (GIS) is employed to explore the extent to which configurations of relief facilities adequately serve aging populations. It was found that the average travel time between neighborhoods and sited nearest facilities varies as a function of relief demand specifications with the population age 65 and over tending to bear the higher relative burden of the access time, which may limit their accessibility to post-disaster relief. Such burden is even more substantial when the associated road network is the subject of random delay congestion. Changing the specified demand populations results in overall minor changes in the sited relief facilities' spatial layouts with the rare alternative facility configurations observed being driven by the spatial distribution of the population age 65 and over (when specified as relief demand). Our results suggest the need for emergency planners to better incorporate aging populations through priority integration of their disaster-related special needs into existing and future emergency planning efforts at all administrative levels to ensure a more equitable disaster relief distribution system.

*5.6.1 Modeling Approach*

The *p*-median model seeks to minimize the total transportation costs of providing services to populations by siting accessible facilities on networks (97). Favoring conditions of efficiency, the p-median model has enjoyed a wide range of applications from locating medical centers (130) to vehicle refueling facilities (131). In the disaster realm, for instance, the p-median model is extended to design the multilevel goods assignment problem (96), MGAP used to produce a generalized distribution network. This modes is adapted in the formulation of their Distribution and Relief Transport for hurricanes (90), DART model to explore the effects of

alternate goods distribution strategies on the provision of disaster relief. The p-median and the p-center respective models are combined with socio-demographic data to site hurricane relief centers in Florida (97). Finally, the p-median (and the capacitated-median problem) is employed to propose a model capable of producing a facility distribution that is both efficient in minimizing travel costs and hierarchical in nature (98). The p-median model is useful for the task at hand for allowing siting facilities such that they are maximally accessible to the population they are intended to serve (96). The below presented formulation is borrowed from (71), and 97 as follows:

Minimize

$$\sum_{i \in I} \sum_{j \in J} a_i c_{ij} x_{ij} \tag{5.7}$$

Subject to

$$\sum_{j \in J} x_{ij} = 1 \; \forall \; i \in I \tag{5.8}$$

$$\sum_{j \in J} x_j = p \tag{5.9}$$

$$x_{ij} - x_j \geq 0 \; \forall \; i \in I \; , \forall j \in J \tag{5.10}$$

$$x_{ij}, x_j \in (0,1) \;\; \forall i \in I \; , \forall j \in J \tag{5.11}$$

where

$i$ = index of all neighborhood locations in $I$

$j$ = index of all distribution center candidate locations in $J$

$a_i$ = demand for relief services at neighborhood $i$

$c_{ij}$ = transportation costs between neighborhood *i* and distribution candidate site *j*

$p$ = user defined number of distribution facilities to be sited

$x_{ij}$ = 1 if neighborhood *i* is served by distribution facility *j*, 0 otherwise

$x_j$ = 1 if a distribution facility is sited at candidate site *j*, 0 otherwise

Equation (5.7) (the objective function) minimizes the total demand-weighted costs (e.g. time, distance, etc.) between each neighborhood and the nearest relief facility. This optimal total time may be divided by the total number of interactions ($\sum_i \sum_j x_{ij}$) to obtain the *average* demand-weighted time between neighborhoods and sited relief facilities. Equation (5.8) requires that each neighborhood is assigned to be served exactly by one distribution facility. Equation (5.9) requires that exactly *p* distribution facilities are to be sited. Per equation (5.10) neighborhoods are only able to be serviced by sited distribution centers. Equation (5.11) ensures that the location variables ($x_{ij}$) and allocation variables ($x_j$) are binary.

### *5.6.2 Study Area and Material*

Leon County, Florida, which contains the Florida state capital city: Tallahassee, constitutes the study area presented in Figure 5.9. Neighborhoods considered as the basis for service demand are represented by Leon County's 6,198 census blocks (in 2010) of which only those with at least two (2) persons as population counts were considered for analysis. Through this filtering, only 3,657 census blocks remained for further analysis. The census block population data from the 2010 census produced by the US Census Bureau were obtained from the Florida Geographic Data Library, FGDL. The census blocks represented by their centroids (population centers) serve as the starting point for computing demand for relief services.

A database of 40 (general-need and special-need) hurricane shelter locations in Leon County was used to help determine candidate locations for siting relief distribution facilities. Those shelters were published by the Florida Division of Emergency Management, FDEM as being fully effective for the county's population during 2014. Each census block containing a shelter was considered a candidate location for receiving a relief distribution facility. This resulted in 40 of the census blocks being considered as candidate locations.

A street network was obtained from the Census Topologically Integrated Geographic Encoding and Referencing, TIGER/Line files and speed limits were inferred based on functional class codes present in the database. A base travel time was computed for every network link with a uniform 30% delay assumed to allow for stoppages, normal system delays and congestion. The base travel time was used in the first scenario. For a second scenario to reflect uncertain, disaster-related movement possibilities, a random travel time was computed for each network link assuming a random delay in the congested travel time. This was done to account for more hazardous movement and congestion conditions that might be associated with weather conditions, fallen trees, debris, excessive vehicles, and other possibilities. Each link's base travel time was randomly increased between 0 to 100% effectively meaning that travel times were doubled on the worst-case linkages.

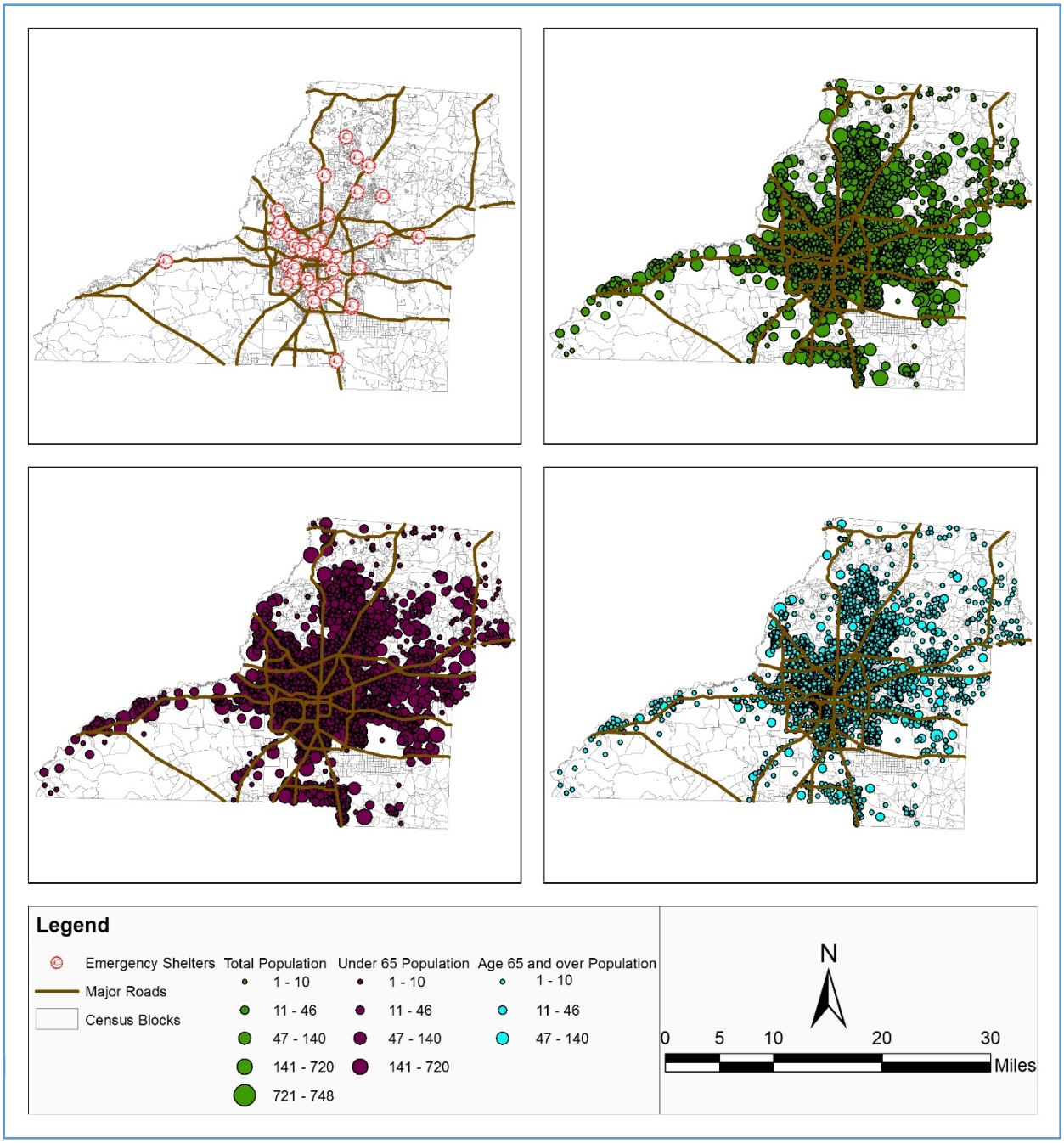



**Figure 5.9.** Leon County's major roads and census blocks with 4 panes showing respectively: the spatial location of the 40 local hurricane shelters published for 2014 by Florida Division of Emergency Management (a), and the distribution of Total Population (b), Under 65 Population (c), and Age 65 and over Population (d).

*5.6.2 Scenarios and Computational Environment*

The relief distribution protocol adopted in this study is identical to that assumed by (88) and refers to the placement of relief distribution centers in pre-determined locations where disaster survivors will pick up needed relief goods and services following the passage of a hurricane. Relief demand, the number of people who do not evacuate but stay behind and need relief service, is an important uncertainty affecting the quality of pre-determined locations to site relief distribution facilities. Consistent with (87, 88, 98), we assume a uniform evacuation rate of 50%; meaning that 50% of the local population will shelter in-home (132), will stay behind with associated relief needs. As only the census blocks with total population count of at least 2 were considered, the total demand for relief assistance explored in this study was based on the following: Total population: 136,834; Under 65 Population: 123,867; and Population age 65 and over: 12,206.

We solve *p*-median models for a range of facility placement scenarios locating 5-15 relief distribution centers. These models are also solved for the mentioned three different demand specifications – one for each of the three corresponding populations namely; the total population, the population under 65 and those 65 and older. We first solved the models using what is essentially near free-flow or limited congestion conditions (the base travel time with 30% delay). Then we solved the models again using the previously described random congestion travel time.

The costs to minimize are measured in average travel time (in minutes) over the network between the census blocks / neighborhoods and the sited facilities. They deal with assignment of neighborhoods to disaster relief facilities weighted by the population at each of these neighborhoods similar to a related protocol followed by 96. The 2010 population at each census

block / neighborhood is used to weight the network travel times between neighborhood and potential relief distribution facility location.

Dell OptiPlex 9010 workstations equipped with 3.30 GHz Intel (R) Core(TM) processors and 8.00 GB of installed RAM with Windows 7 Professional (64-bit) were used to perform the data processing. ArcGIS 10.2 and TransCAD 6.0 were used to manage the data and to create the final maps for this study. TransCAD was further used to create cost matrices, and solve the p-median problems.

*5.6.3 Results*

In this section, we first focus on the costs of serving the various populations based on the number of facilities sited. Then we turn our attention to the configuration of facilities.

For the facility evaluation, two distinct sets of thirty-three (33) spatial models associated each with one of the three levels of specified demand were run to site p facilities varying from 5 to 15. Table 5.6 reports the motorized average time it takes disaster survivors in neighborhoods to reach their closest sited facilities in search of relief. In this way, the analysis truly assumes a 'worst-case' scenario where it might be assumed that populations had to access relief centers themselves, hence the focus on minimizing the amount of effort spent on people potentially having to reach them.

With sited facilities varying (incrementally by 1) from 5 to 15, and the near free-flow or limited congestion conditions (the base travel time with 30% delay), the average times modeled between the sited facilities and their associated neighborhoods vary from 7.26 to 4.86 minutes, 7.21 to 4.82 minutes, and from 7.68 to 4.95 minutes with relief demands specified respectively as: Total Population, Population under 65, and Population age 65 and over. Under a random delay in the congestion conditions, with all other conditions being unchanged, access times from

neighborhoods to nearest sited facilities ranging from 10.82 to 7.29 minutes; 10.75 to 7.25; and from 11.41 to 7.40 minutes respectively are modeled for relief demands specified as: Total Population, Population under 65, and Population age 65 and over. In both travel time scenarios, all client nodes (3,657 block centroids) require service when Total Population was specified as relief demand. However, when demand is changed from the total population, the number of nodes to be served decreases slightly., In these cases, forty-seven (47), and a thousand and twenty-two (1,122) nodes are not in need of service when relief demands are specified as Population under 65, and Population age 65 and over respectively. These sets of blocks simply contain none of the respective population groups.

Depending on the scenario in question, the average motorized travel time a neighborhood needs to reach its closest sited relief distribution center ranges from 7.68 to a low 4.82 minutes; and from 11.41 to 7.25 minutes under near free-flow and random delay respective congestion conditions. Under both network congestion scenarios, the average motorized travel times between given neighborhoods and their closest sited facilities were found to systematically reach their maximum values when Population age 65 and over is used as the relief demand. By contrast, the minimum values were obtained when demand is defined as Population under 65; the intermediary travel time values being observed when Total Population is specified as relief demand (Table 5.6).

Furthermore and as seen in Figure 5.10, adding additional relief facility units results in a reduction in the average time a neighborhood needs to reach its nearest facility but only at a decreasing rate. Such marginal reduction decreases from 6.06% to 2.41%, 6.10% to 2.36%, and from 6.52% to 1.98% (under the base travel time); and from 6.01% to 2.28%, 6.05% to 2.36%, and from 6.40% to 1.86% (under the random delay travel time) with relief demands specified

respectively as Total Population, Population under 65, and Population age 65 and over. Rare instances of increasing marginal reduction in access time are among those observed with Population age 65 and over at p6+1 and p8+1 (under the base and the random travel time congestions) and with Population under 65 at p14+1 (under the two travel time scenarios).

**Table 5.6.** Results for Demand Relief Scenario for Linkages from Relief Distribution Facilities to Neighborhoods.

| *p* | **50% Total Pop 2010** *Total demand: 136,834* | | | | **50% Pop age under 65** *Total demand: 123,867* | | | | **50% Pop age 65 and over** *Total demand: 12,206* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Travel Time 30pct | | Random Travel Time | | Travel Time 30pct | | Random Travel Time | | Travel Time 30pct | | Random Trav. Time | |
| | Avg. | Total | Avg. | Total | Avg. | Total | Avg. | Total | Avg. | Total | Avg. | Total |
| 5 | 7.26 | 993,659.60 | 10.82 | 1,480,658.68 | 7.21 | 892,577.30 | 10.75 | 1,331,119.11 | 7.68 | 93,712.00 | 11.41 | 139,227.63 |
| 6 | 6.82 | 933,108.90 | 10.17 | 1,391,660.32 | 6.77 | 837,959.30 | 10.10 | 1,250,745.65 | 7.21 | 88,051.80 | 10.68 | 130,349.69 |
| 7 | 6.49 | 887,946.80 | 9.65 | 1,320,799.86 | 6.43 | 796,730.50 | 9.58 | 1,186,010.05 | 6.74 | 82,284.70 | 10.05 | 122,603.78 |
| 8 | 6.16 | 842,813.70 | 9.16 | 1,253,693.58 | 6.12 | 757,511.80 | 9.10 | 1,127,694.62 | 6.41 | 78,219.90 | 9.57 | 116,852.12 |
| 9 | 5.91 | 808,568.80 | 8.76 | 1,198,769.15 | 5.85 | 724,542.30 | 8.70 | 1,077,314.56 | 6.10 | 74,484.30 | 9.06 | 110,547.70 |
| 10 | 5.67 | 776,172.70 | 8.42 | 1,151,714.90 | 5.62 | 695,744.30 | 8.36 | 1,035,499.11 | 5.83 | 71,163.70 | 8.66 | 105,714.92 |
| 11 | 5.44 | 744,125.90 | 8.12 | 1,111,083.71 | 5.41 | 670,649.90 | 8.08 | 1,001,300.29 | 5.58 | 68,143.80 | 8.29 | 101,165.01 |
| 12 | 5.26 | 719,494.50 | 7.87 | 1,077,410.14 | 5.22 | 645,969.70 | 7.82 | 968,586.91 | 5.38 | 65,636.00 | 8.00 | 97,688.13 |
| 13 | 5.12 | 700,213.40 | 7.66 | 1,047,775.96 | 5.08 | 629,792.50 | 7.62 | 943,587.48 | 5.20 | 63,491.20 | 7.76 | 94,669.37 |
| 14 | 4.98 | 681,943.80 | 7.46 | 1,021,362.77 | 4.96 | 614,067.90 | 7.44 | 921,317.40 | 5.05 | 61,681.30 | 7.54 | 92,063.54 |
| 15 | 4.86 | 665,212.10 | 7.29 | 997,832.62 | 4.82 | 597,144.00 | 7.25 | 898,499.64 | 4.95 | 60,449.60 | 7.40 | 90,282.11 |

NOTE: Avg. = Average; Travel Time 30pct = 30% of delay imposed to travel time to adjust for congestion. This is the base travel time.

Random Travel Time = Random increase in the base travel time obtained through multiplying Travel Time 30pct by a random number; Time is in minutes

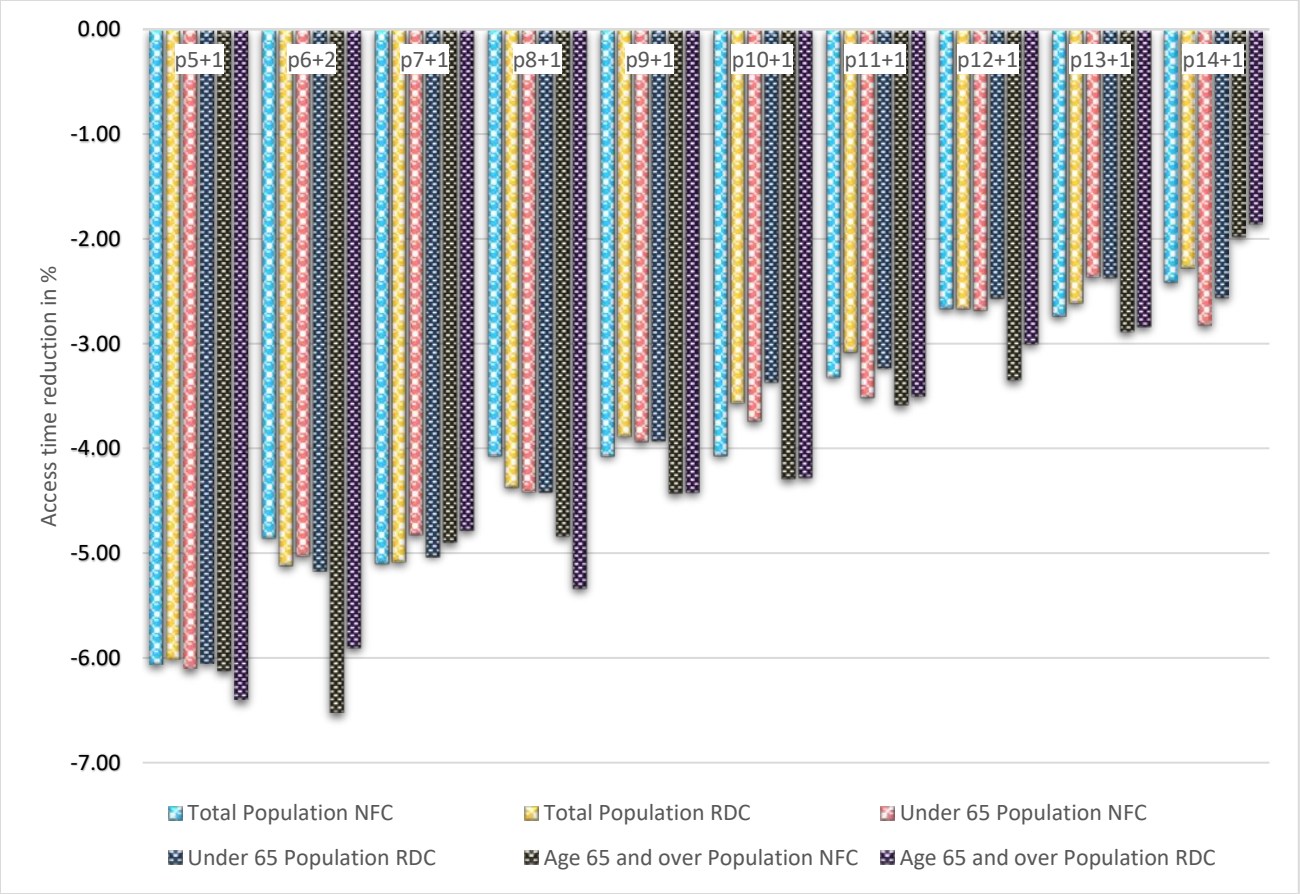



**Figure 5.10.** Marginal reduction of access time from neighborhoods to sited facilities as unit facilities are added to the model (in %) under network near free-flow conditions, NFC (sphere pattern with light colors), and under random time delay in network conditions, RDC (trellis pattern with dark colors).

With -6.52% (base travel time) and -6.40% (random delay travel time), Population age 65 and over enjoys the study's highest rate of marginal reduction of the access time as a function of additional facility units sited. Moreover, it systematically shows the comparatively higher decreases in the travel time reduction of the study except at p14+1 for both congestion scenarios.

Figure 5.11 and Figure 5.12 show the comparative spatial locations of the relief facilities sited under 33 different models run in two travel time scenarios. It shows that for a given travel time scenario, the facilities tend to be co-located for relief demand specified

as *Total Population* and *Population under 65* (under any value of *p*). Facilities sited under demand specified *as Population age 65 and over* tend to be in very distinct locations for a given *p*. For any given travel scenario and across the three specified demands, the location of previously sited facilities does not vary substantially as new facilities are added in the models' subsequent runs. It is also apparent that as more facilities are added to the model, the census blocks located in Leon County's central area tend to receive higher relative service coverage than those located at the periphery.

Comparing the 33 models across travel time scenarios shows that the facilities selected in the uncongested state (base travel time) persist when the network is impeded (under the random delay) in most cases. For instance, the spatial distribution layout of the modeled facilities was found to be fairly close under both travel time scenarios for *p*=11-15. By contrast, the facilities sited for *p*=5-10 presented slightly different spatial distribution layouts across travel time scenarios. Such differences are in the fact that the *Population age 65 and over* facilities tend to fall in stand-alone locations distinct from those of facilities sited under other specified demands.


**Figure 5.11.** *p*-median solutions comparing changes in spatial configuration of relief facilities as a function of specified demands with 11 panes respectively represented by: p = 5 (a); p = 6 (b); p = 7 (c); p = 8 (d); p = 9 (e); p = 10 (f); p = 11 (g); p = 12 (h); p = 13 (i); p = 14 (j); and p = 15 (k). Each pane presents a pair-wise comparison between optimization solutions obtained under near free-flow conditions (top) and random delay congestion conditions (bottom) affecting the distribution network.


**Figure 5.12.** *p*-median solutions comparing changes in spatial configuration of relief facilities as a function of specified demands with 11 panes respectively represented by: p = 5 (a); p = 6 (b); p = 7 (c); p = 8 (d); p = 9 (e); p = 10 (f); p = 11 (g); p = 12 (h); p = 13 (i); p = 14 (j); and p = 15 (k). Each pane presents a pair-wise comparison between optimization solutions obtained under near free-flow conditions (top) and random delay congestion conditions (bottom) affecting the distribution network.

*5.6.4 Discussion*

We found that how demand is specified results in a change both in response time between sited nearest facilities and their associated neighborhoods and the spatial configuration of the sited facilities. Under both travel time scenarios, the average travel times modeled between the sited facilities and their associated neighborhoods decrease as the number of facilities sited increases. Our method of adding additional congestion leads to increasing access times (between neighborhood and sited facilities) but with less drastic changes in facility configuration. Among the three demographic groups tested, *Population age 65 and over* is associated with the lowest disaster relief accessibility translated in a longer time to reach the sited nearest facilities. Similar to past literature (particularly (96)), the addition of new facilities (to the models) results in a decrease in motorized travel time from neighborhoods to their sited nearest facility. Substantially, alternative demand specifications produce measurable impacts on *Population age 65 and over* for which average travel time to the nearest facilities for $p$=5-15 is relatively higher: 7.68 to 4.95; and 11.41 to 7.40 minutes (against 7.21 to 4.86; and 10.75 to 7.25 minutes for *Under 65 Population* for instance under the near free-flow and the congested respective network conditions (Table 5.6). *Population age 65 and over* has comparatively lower accessibility to the sited relief facilities.

Unlike for (96), and (90) where average times increase as more individuals are taken into consideration as needing relief, our modeled results show an inverse pattern which varies more or less randomly. In fact, the average access travel time between neighborhood and sited facilities reaches its minimum values (7.21 to 4.82 in near free flow network; and 10.75 to 7.25 minutes in random congested network) with *Under 65*

*Population* specified as relief demand (123,867). Intermediary values of access travel time (7.26 to 4.86 minutes, and 10.82 to 7.29 minutes) are obtained when *Total Population* associated with the highest relief demand of the study: 136,834) is specified. The average travel time between neighborhood and sited facilities reaches its maximum values (7.68 to 4.95 and 11.41 to 7.40 minutes) under *Population age 65 and over* with a demand of 12,206 (see Table 5.6).

On the basis of the map of Leon County (Figure 5.9) the comparatively higher access time to relief facilities observed in the *Population age 65 and over* suggests that important clusters of aging adults generally live away from the central locations of the county. By contrast most of the *Total Population* as well as the associated *Population under 65* group (representing 90.5 of the total) tend to be clustered in the central areas of the county's urban area (of Tallahassee) resulting in their improved accessibility. Furthermore, the fact that the *p*-median model tends to favor the communities located in the central locations at the expense of those located in the periphery justifies the differentially higher travel time between neighborhoods and sited relief facilities observed with the *Population age 65 and over* group. The overall trend of the marginal reduction in access time is decreasing for all three specified relief demands under both congestion conditions of the network. *Population under 65 and over* however systematically shows the comparatively higher values of decreases in the travel time reduction of the study. This suggests the higher sensitivity of the aging population demand specification to increases in the number of sited facilities.

The most populated neighborhoods (those located in and at close proximity of the central study area (per Figure 5.9) tend to receive higher levels of relief facility coverage

(see Figure 5.11 and Figure 5.12). By contrast, the larger census blocks located at the peripheral northeastern, southern and southwestern areas of Leon County with relatively lower population counts tend to receive mediocre service coverage. As the *p*-median problem is weighted to account for the number of people in an area, changes in the population size of the served neighborhoods influence the spatial layout of the sited relief distribution facilities which consequently tend to cluster in the most populated neighborhoods.

A change in the population specified as the relief demand results in minor changes of the relief facilities' spatial layout as evidenced by the high number of facility (geographical) co-locations observed on Figure 5.11 and Figure 5.12. It is however apparent that the spatial distribution of the *Population age 65 and over* (when specified as relief demand) drives alternative facility configurations. Results suggest planners should give weight to the aging adults as an age-based distinct group, which would ensure a more equitable disaster relief distribution system. Consistent with (87), our research shows that the demand and its location impacts the averaged time to relief facilities while accessibility can be improved through augmenting existing facilities with alternative ones.

Solving the models for the random congested network results in substantial increase in the average time neighborhoods would take to reach the nearest facilities. The associated changes in spatial layout are less obvious. In fact, the shortest average travel times between neighborhoods and nearest facilities modeled for the random congested network (7.40 to 7.25 minutes) reveals about a 50% higher time than those obtained with the near free flow network (4.95 to 4.82 minutes). That is any random perturbation of the network is susceptible to substantially increasing the travel time separating neighborhoods from their

nearest relief distribution facilities. Using an alternative congestion strategy based on random elements, service times are found to be very sensitive to the least case of network disturbance as they examined the impacts of simulated network failures on hurricane disaster relief planning strategies (88). Clearly, alternative measures of accounting for disaster-related delays could produce alternative outcomes.

## Chapter 6 Validation and Verification

Validation and verification are an essential step in creating a knowledge base because judging the overall quality of the "knowledge" contained therein determines its overall utility. Ideally, this step provides a means for improving the content, aims, and goals of the aging-focused knowledge base, as needed. In this project, as different steps of the proposed methodology were executed, materials were evaluated by the research team to assess accuracy and appropriateness with regard to designing better aging-focused emergency transportation logistics. Much of the information reviewed was highly technical and procedural in nature, emanating from sources that span multiple perspectives, disciplines and governmental levels. Continuously refining our framework is important for maintaining and augmenting its future utility.

Relatedly, several presentations of the research project have been given to various groups. These include governmental entities (FDOT [Traffic Operations, Roadway Maintenance and Emergency Management Offices], Safe Mobility for Life Coalition, Florida Department of Emergency Management and the Florida Department of Elderly Affairs), private companies (CITILABS), and university groups (Florida Agricultural and Mechanical University, University of North Florida, and Florida State University (FSU), including the FSU Institute for Successful Longevity and Disaster Incident Research Team). Project presentations were helpful in terms of generating feedback with regard to our ongoing work, particularly with respect to issues that would be of most interest to practitioners and that of the project's real-world applicability.

Based on the results of the four-step knowledge base methodology, the PIs identified critical research needs towards obtaining better humanitarian logistics during emergency situations with a focus on aging populations. These needs are extensively evaluated in the following chapter.

## Chapter 7 Metadata-based Research Needs Assessment

Based on the evaluation of the knowledge base in the previous chapters, this chapter provides a metadata-based research needs assessment focusing on the emergency assistance that should be provided to the aging population supported by real-life experiences and practices. It is important to note that there are a number of objectives pursued by researchers to obtain efficient commercial transportation management methodologies. The majority of studies focuses on the minimization of transportation and inventory costs (11). However, emergency transportation management for aging, in nature and characteristics, is primarily concerned with the welfare of the aging disaster victims. Unique objectives for this problem, therefore, are ranked in order as follows, starting with the most important:

- Minimization of suffering and maximization of survival for aging victims.
- Optimizing the emergency evacuation operations, and maximization of the available vital supplies for the aging victims.
- Ensuring the flexibility of the emergency transportation operations in the presence of uncertain demand and supply, and a dynamically changing environment.
- Cost minimization (transportation, supplies, inventory costs, etc.).

Constraints for the problem, on the other hand, include the following:

- behavioral, disability and health constraints (effects of physical, mental and psychological limitations or disabilities of the aging population),
- minimum tolerable disruption level constraints (due to transportation network characteristics, extreme demand, communication and supplier related disruptions),

- technological constraints (i.e., technological obsolescence for the stocked equipment such as medical apparatuses, inexperience or lack of knowledge while implementing new technologies),
- space and budget constraints (roadway, inventory and shelter service limits, monetary issues)
- military, local and political constraints (i.e., limited communication between different agencies, security related limitations on evacuation and delivery of supplies, etc.)

To accomplish these objectives with the given constraints, emergency planning and relief operations needs for the aging population require the involvement of different disciplines. Figure 7.1 represents such an inter-disciplinary action plan with an operational perspective that clearly requires the joint work of public, private, military and humanitarian agencies as well as research institutes and universities.

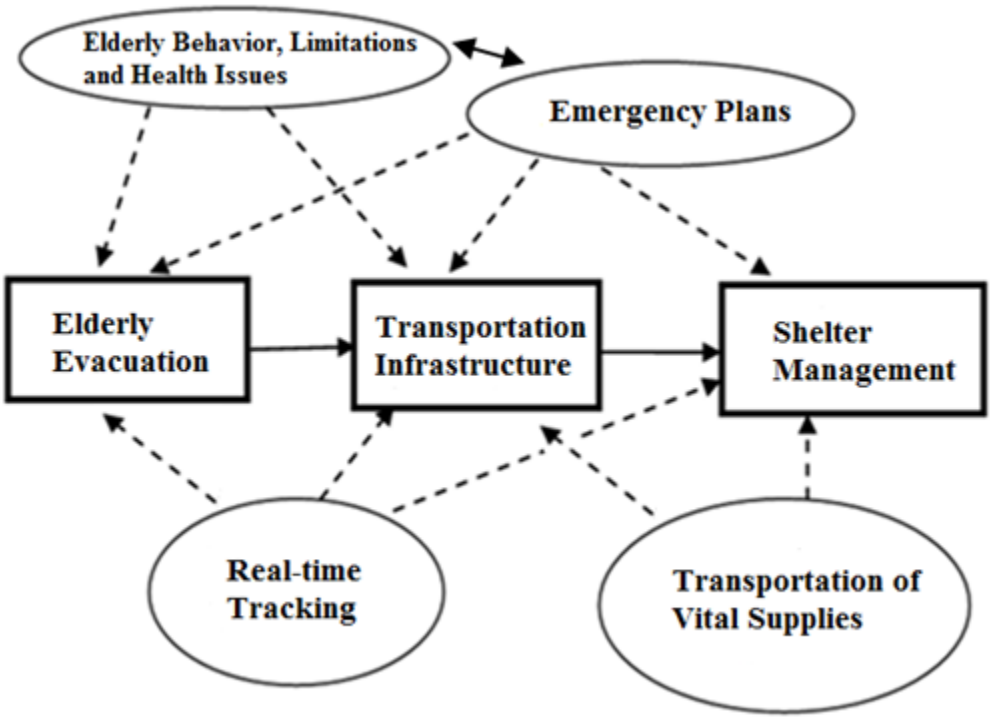


**Figure 7.1.** Interdisciplinary Components of the Aging Population-focused Emergency Transportation Problem

In order to ensure that the aforementioned objectives are realized satisfactorily in the decade ahead, there is a need to investigate the following problems thoroughly and develop solutions that seek to minimize their effects on the aging population:

7.1 Research Need 1: Improving State and Local Emergency/Disaster Transportation Plans

The needs of the aging population should be clearly defined in the emergency management plans developed by federal, state and local agencies, and private humanitarian organizations. Many agencies have been trying to include the needs of the whole population including the aging in their plans and operations. However, it is critical to develop and back up plans based on (a) practices that have been proven to be working in actual disaster situations and ones that need improvement, and (b) pros and cons of the individual components of emergency practices that address the specific needs of the aging. Data collected from previous experiences during emergency relief operations should be analyzed carefully, possibly with statistical techniques, to identify the strengths and weaknesses. Lessons learned from these analyses and best practices should be provided for future reference in the disaster plans.

There is also a clear need for easily understood and applicable plans and models that provide decision support and emergency assistance focusing on the following issues critical for the survival of the aging victims in the aftermath of disasters:

1. **Safety:** Safety measures should be taken into account at every phase of the relief operations for the aging population since the aging people are more likely to be

vulnerable at any time during the disasters due to their functional limitations, sensory, physical and cognitive disabilities.

2. **Accessibility:** Accessibility should be provided to the aging population by any means necessary regardless of their limitations, how they live (independent/dependent), and where they live (rural/urban).
3. **Speed and Reliability:** For emergency transportation operations focusing on aging populations, speed and reliability become critical as their survival could directly depend on sufficient and timely assistance/treatment. For different prevailing disaster conditions with distinct characteristics, different transportation modes can meet the speed and reliability criteria to varying degrees.
4. **Fulfillment:** Another important issue is fulfilling the vital needs of the aging victims, which may be gathered in shelters or that shelter-in-place, efficiently throughout the entire pre- and post-disaster period even when disruptions such as transportation network unavailability and power outages are experienced.

Moreover, as a part of emergency planning, educating officials and personnel is a must to efficiently respond to transportation-related problems of aging in the aftermath of a disaster. Educating the aging population is also critical for emergency operations. Providing clear instructions, indicating the locations and dates/times for pickups, locations and features of shelters (special needs, pet friendly, etc.), and what they can carry with them, will enhance the overall efficiency of the operations. In order to support the widely used registries, a robust and resilient emergency management system should also have a way to keep track of aging people and vital supply movement during the emergency operations. For example, use of RFID technologies will enable the officials to track aging

population and supplies, and therefore locate the problems and disruptions within the disaster supply chain, reaching the major causes faster (115).

### 7.2 Research Need 2: Location, Allocation, Accessibility and Design of Emergency Shelters

Physical location, design and purpose of potential emergency shelters is of interest in terms of both creating accessible and safe evacuation/sheltering and also for the logistical aspects of transporting emergency supplies. For example, there is a need for special needs oriented shelters (SPNS) that provide medical care for aging population (i.e., medical support units in the shelter that can withstand power outages). Current data suggests a lack of SPNS shelters in Leon County, where a substantial amount of aging population that have special needs live (37). In addition to the design aspects, the proximity of shelters to the populated areas and their accessibility to the roadway network are also critical to their effective utilization. Whether shelters are provided by public agencies or humanitarian organizations like American Red Cross, emergency operations cannot be successful without identifying their optimal locations and designs. Mapping systems and transportation network analysis software should be used to identify shelter locations (including special needs and pet friendly) based on the population characteristics/features of the affected region and the accessibility of the shelters via different modes of transportation. This requires the involvement and integration of mathematical models (such as distance-based clustering) that can determine the optimal location and allocation of the shelters (87, 88).

### 7.3 Research Need 3: Creating Accessible Emergency Evacuations for Aging Populations

There is a need for research that investigates the effects of transportation infrastructure availability, multi-modal origins and destinations, roadway disruptions, shelter locations/allocations with a focus on aging people. This will also require the extensive use of mapping and transportation network models. Therefore, an efficient disaster plan should also include emergency evacuation strategies to minimize the impacts of unforeseen disruptions, or at least to address the problem at hand as quickly as possible to create accessible evacuation for the aging population. To have such a robust plan, there is a need for research studies that focus on real-time control and management of the emergency disaster operations using IT-based strategies. A Dynamic Traffic Assignment (DTA)-based research can provide capabilities that can help planners grasp the dynamic realities of evacuation more clearly in terms of delays and queues, and help them formulate better decisions (38). With the help of previous data on actual emergencies, this IT-based strategies can be applied to different kinds of extreme events, possibly as part of emergency plans and mechanisms. There may also be a lack of availability for medical assistance and emergency vehicles for evacuation. Therefore, evacuation plans should also include a strategy for optimally allocating vehicles for emergency use, and also should have an emergency plan for unavailability/loss of the vehicles or designated drivers.

### 7.4 Research Need 4: Transportation of Vital Supplies and Emergency Inventory Management

An efficient inventory planning and supply transportation system becomes a must to ensure the survival of aging people since their needs can drastically change during disaster relief operations. Even if the safety stocks for emergency commodities are planned

individually beforehand, the delivery process can be problematic. During the recovery period after the disaster, the emergency, rescue and commodity supply activities should be able to satisfy the basic needs of the aging people even if the transportation network is heavily damaged/degraded. Therefore, there is a need for research that investigates the effects of stochastic real-life conditions, availability of resources, single/multiple suppliers, deterministic/stochastic demand and supply, and perishable commodities, possibly using GIS-based mapping and transportation analysis software. Communications and infrastructure network has also utmost importance for a reliable information transfer between the agencies and personnel, therefore studies that focus on IT solutions are needed.

# Chapter 8 Conclusions and Future Work

This research provides a detailed transportation needs assessment and knowledge base focusing on the emergency assistance that should be provided to the aging population. It is supported by real-life experiences and practices. Based on the knowledge base, the project presents future research needs and challenges with a focus on the aging evacuations. Since aging victims need special assistance in the aftermath of disasters, public and/or private humanitarian agencies will clearly benefit by including the assessment results of this research in their disaster plans specifically on how these needs can be addressed and how related problems can be solved. Evaluation of the multi-modal capabilities in District 3 of FDOT will also provide suggestions on the usage of different transportation modes to create safe, accessible and fast emergency operations for the aging population.

## 8.1 Emergency Evacuations

Evaluation results of the evacuation operations in FDOT District 3 can help planners/emergency personnel decide how to transport aging people in the aftermath of an extreme event. After a review of evacuation studies that focus on aging people, vast amount of knowledge has been extracted from available resources and data sets in order to conduct a thorough assessment of the multi-modal transportation infrastructure for the District 3 region. A GIS database including highways, airport, port, and railway terminal locations was created to present the locations of these facilities, and their proximities to roadways and aging-populated locations. With a focus on the challenges at the airports, ports, and railway terminals, this database will be extremely useful for supporting the emergency evacuation operations.

Roadway network and infrastructure in District 3 are found to be capable of facilitating the optimal multi-modal transportation of aging people which would significantly contribute to emergency plans. Despite this capability, the existing network might not be sufficiently utilized for the emergency transportation operations during and/or after the disasters due to the possible disruptions or capacity degradations that can occur (Closure of roadways, bridges and tunnels) in the aftermath of extreme events such as hurricanes and storms.

Since District 3 poses serious challenges due to its vulnerability to flooding and storm surges, which are magnified under emergency conditions, it is significant to focus on the hazard analysis of the roadways. Almost all evacuation routes have some percentage of vulnerability to the disasters which should definitely be included as supplementary information in planning. The proposed evaluation methodology can help emergency officials identify the unexpected disruptions likely to happen during emergency evacuation operations such as the road closures due to storm surges or flooding. Travel time analysis results could also provide the planners with a measure of how long it would take to transport aging people from representative origins to destinations selected outside the impact zone given the roadway network.

The scope of this study is also limited to evacuating aging people from the affected region. This type of study can be extended to include other types of vulnerable populations including mobile home residents, and seasonal populations (such as people travel with recreational vehicles). The model can be expanded towards a dynamic traffic assignment and transit-based solution that can help emergency officials and planners with a more detailed view of emergency evacuation performance. The authors would also like to note

that these results will be mostly helpful to the local or state agencies in the District 3 region. However, this type of this research can be successfully extended to other areas of Florida, and then for elsewhere in the U.S.

## 8.2 Sheltering

The approach used for sheltering analysis in this project is hypothetical as it takes a possible problem scenario and adapts a spatial model to assist with solving it. The intention of this work is not to make a specific policy recommendation in our study area, or to critique current shelter plans. Rather, the intent here is to design a generic approach which can be used to help address this and related shelter placement problems. Our work contributes ideas showing how such a problem might be approached but is in no way intended as a ready to implement recommendation for where to place facilities. Its contribution is the framework it builds describing how this problem can be tackled.

There are a number of caveats and limitations associated with this sheltering effort that may suggest areas for future work. First, as our focus here is on transportation and accessibility considerations in site selection, we made assumptions that all shelter facilities could be ‘repurposed’ in order to facilitate a series of hypothetical scenarios. At a finer level of planning it may be the case that cost or infrastructure constraints would prevent this from happening. Thus, good alternatives identified from a spatial modeling perspective may have difficulty being implemented, particularly if costs and other constraints are accounted for. However, this is a dimension which could be built into future modeling efforts. Secondly, it is worth pointing out that there is no absolute 'nearest center assignment rule' inherent to the capacitated p-median model in the sense that people are automatically assumed to go to their nearest located facility, which is the case in the

traditional *p*-median problem. Such a constraint can be added to this model, which will increase the computational complexity of generating solutions, but also allow for perhaps a more simplified means of routing people to the appropriate special needs shelter. Thirdly, and related to this point, the routing issue of how people get to shelters is not specifically a part of this research – the assumption is that shortest paths would be taken, and means of transportation would be available. However, we did not account for the modal splits and resource allocation of transportation assets that could be deployed as a part of helping aging and special needs populations, including questions of how they would reach shelters given that some live alone, in retirement facilities, etc. Our modeling was at a more 'sketch' level of planning and future work could consider some of the ways facility location might interact with transportation resource deployment, including other representations of travel costs, such as those output from advanced traffic assignment models. Related to this, it is well known that certain special needs populations may need additional time to evacuate and reach facilities, thus suggesting future work could account for this possibility, perhaps by further differentiation in the demand for relief services. Knowing where the most in need special needs people to be evacuated are located could be used to guide future siting decisions. Fourthly, our way of disrupting the network to assess whether any impacts would be realized was fairly straightforward and simplistic. Although our method was helpful in highlighting where difficulties might arise, future work could look at more sophisticated ways of simulating disruptions, including assuming even higher levels of impedance could result from storm effects, or possibly including additional ancillary data such as flood zone information to target possibly problematic roads. Another area of work could be in measuring shelter utilization directly through tracking people's

movement with RFID or other similar technologies which would lead to data that could be used to improve shelter allocation in the spatial modeling. Lastly, and as previously stated, we made several assumptions to focus our efforts on the aging people, and did not work with detailed info on other components of 'special needs' populations. Were we to alter this data component, using other assessments of the aging and/or special needs populations it no doubt could change the results. In sum, this effort has demonstrated a strategy that can be used to address the needs of siting special needs shelters for hurricane disasters.

8.3 Relief Goods Distribution

The relief goods transportation model has explored the relationship between age status and various strategies for providing people hurricane disaster relief. It was found that average access travel time varies as a function of relief demand specifications with *Population age 65 and over* tending to bear the higher relative burden of the response time which limits their accessibility to disaster relief. Applying a random delay to the near free flow network results in a significant and visible increase of the average travel time (1.5 times as much as the base travel time) neighborhoods would take to reach their nearest relief facilities. Changing the population as specified relief demand results in overall minor changes in the sited relief facilities' spatial layouts. The rare alternative facility configurations observed are definitely driven by the spatial distribution of the *Population age 65 and over* (when specified as relief demand). Results suggest emergency planners and managers should give weight to the aging adults as an age-based distinct group, which would ensure a more equitable disaster relief distribution system.

Future work should consider experiment with relief demands assessed from non-uniform but variable age-based and/or spatially-aware evacuation rates. Another open

avenue for further research resides in modeling efforts using the 3657 selected neighborhoods as candidate locations to siting the relief distribution facilities in place of the 40 hurricane shelter locations used in this study. Future work should also consider alternative site modeling strategies, such as equity approaches like the p-center spatial optimization. Also, future research may wish to explore if these results persist at alternative spatial scales such as the traffic analysis zone or census tract level. Additionally, alternative solution tools, such as the CPLEX optimization library can be applied to these spatial models, which may improve our ability to identify the most optimal distribution configurations. Lastly, and more broadly, we focus only on the distribution center to neighborhood linkage in this research and not on the movement of goods per se throughout the entire supply chain. Were future research to venture into this area, a number of issues would be raised, including that of 'material convergence', which gets at the collection and distribution challenges associated with relief goods from multiple public and private sources. Recent research by (9) state that material convergence-related problems should be handled carefully using innovative mathematical models especially as part of post-disaster humanitarian logistics. However, as the complexity of the disaster increases (especially right after the disaster hits), it may be very difficult to handle and manage diverse goods flows. Material convergence and the potential delays are especially critical for vulnerable populations such as aging people, as their needs should be met immediately. Identifying strategic facility locations before the onset of a disaster can help mediate these problems and future research can take a more integrative approach to the management of goods flows for aging people.

## 8.4 Discussion on the Research Needs and Future Work

In order to ensure and promote the long-term usage of this knowledge base by state/federal agencies and other organizations, it is important to conduct a scenario-based implementation study that should address the following major goals: (a) to extend the developed methodology to other Districts of Florida, (b) to create and evaluate new aging-focused emergency evacuation, shelter allocation, and supply transportation scenarios and case studies using GIS-based transportation network models such as CUBE and TransCAD, and (c) to leverage these tools and findings to inform emergency plans.

The research needs identified in project indicate that it is critical to develop and analyze novel dynamic traffic assignment-based evacuation and supply transportation models as well as shelter location/allocation optimization approaches to serve the aging. Dynamic traffic assignment (DTA)-based approaches that depart from static models in order to provide solutions based on time-varying traffic volume should be implemented for emergency transportation operations. Uncertainty involved in the disaster relief operations (due to disruptions in the transportation network, fluctuating demand, unavailability of the personnel and vehicles, drastic changes in the disaster strength, etc.) should also be accounted for by carefully selecting the relevant scenario parameters, boundaries and conditions. The future needs of aging populations should also be identified using the forecasted demand figures for aging populations (based on forecasted Census population data) in the transportation network models and shelter optimization methodologies.

It is important to note that there is still a significant gap between theory and practice which has to be eliminated to obtain an efficient action plan. Elimination of this gap requires the involvement of different disciplines with an action plan that should focus on

the following components: health, behavioral and mobility limitations of aging population; emergency planning; multi-modal transportation infrastructure and evacuation; transportation of vital supplies; shelter management and real-time tracking of aging people and supplies. There should also be detailed studies focusing on the use of IT, which can cover both computing and communications capabilities to enhance the operational management of disasters for the aging people. One critical IT-based research direction is to make use of the real-time information regarding the movement of aging people and supplies to dynamically adjust emergency management decisions. Investment on better information technologies such as RFID systems and their integration with theoretical models will definitely enhance the emergency management of disasters.

The approach used in this research can be extended to other districts of Florida and then to other locations. Qualitatively, however, the effectiveness of the methodology in a particular country/region for a given disaster can be affected by the following critical variables: (a) economic system; (b) cultural traditions; (e) country/nation characteristics. This research does not address a discussion of these variables on the efficiency of the aging-focused emergency transportation operations, which is an interesting area of future work.

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# Appendix A Metadata Tables

**Table A.1** Metadata-based Assessment Table 1

| METADATA TABLE | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Criteria** | Sorensen et al (2004) | McGlown (2001) | Blanchard et al (2009) | Dosa et al (2012) | Li et al (2012) | Pekovic et al (2008) | Burnett et al (2008) |
| Scope | Planning for Protective Action decision Making : Evacuate or Shelter-in-Place | Evacuation of Health Care Facilities: A new Twist to a Classic Model | A Comparison of the Nursing Home Evacuation Experience between Katrina and Gustav | To Evacuate or Shelter in Place : Implications of Universal Hurricane Evacuation Policies on Nursing Home Residents | Population Aging, Gender, and the Transportation system | Planning for and Responding to Special Needs of Elders in Natural Disasters | Rapid Needs Assessments for Older Adults in Disasters |
| Objective | Provide a framework for decision making during an emergency especially hazardous chemicals. | Compares two models from studies related to evacuation process : Vogt`s adaptation and McGlown`s model by examining variables of decision making | Examine whether nursing home administrative directors were more prepared with the experience of Katrina before Gustav. | Examines the differential morbidity/mortality associated with evacuation versus sheltering in place for nursing home residents exposed to the 4 most recent Gulf hurricanes. | Reviews the nature of older people`s interaction with the transport system by gender, older people`s attitude to travel and involvement of aging as road traffic casualties | Explores the special needs of healthy and frail elders in relation to planning for and responding to natural disasters,including hurricanes, tornadoes, ice storms etc. | Lessons learned in the Astrodome, Houston . |
| Methodology | Decision trees / Padre | Data collection/ Cluster grouping | Data collection / Surveys | Data collection / Surveys / modelling | Data collection / Surveys | NONE | NONE |
| Spatial Coverage | USA | USA | Gulf States | Gulf States | UK | India, Gulf States | NONE |
| Temporal Coverage | 1987-2002 | 1969-1999 | 2005-2009 | 1982-2011 | 1995-2011 | 1985-2006 | 1996-2006 |
| Data Analysis | No | Yes | Yes | Yes | Yes | No | Partial |
| Type of Source / Media | Academic journals | Academic journals, books, reports | Academic journals, reports, websites | Academic journals,reports, websites | Academic journals,reports, websites | Academic journals. Practitioners journals, guidebooks, reports | Academic journals, websites, guidebooks. |
| Contribution | Describes a model for detailed analysis of specific emergency scenarios | Data collected from the source-managers and decision makers.Issues of importance to managers were ascertained. | Is the first of its kind to compare the hurricane preparedness and evacuation experiences of nursing home administrators. | Although there is significant increased morbidity and mortality related to exposure, there is added risk in evacuation. | Involvement of older women increases in transportation system and population structure day by day. More research and policy changes needed for aging. | Emphasis on planning, identifying and coordination among agencies. | Introduction and emphasis on SWIFT(senior without family triage) tool |

**Table A.2** Metadata-based Assessment Table 2

| Criteria | Hyer et al (2010) | Langan et al (2012) | Chung et al (2010) | Mando et al(2011) | Golmohammadi et al (2011) | Manley et al (2012) | Christensen et al (2008) |
|---|---|---|---|---|---|---|---|
| Scope | Improving Relations Between Emergency Management Offices and Nursing Homes during Hurricane-related Disasters | Factors Influencing the Decision to Evacuate or Shelter in Place : Follow-up of Hurricane Katrina | Location and Analysis of Emergency Management Points of Distributions for Hurricane Ike | Hurricane Preparedness and Sheltering Preferences of Muslims Living in Florida | Estimation of the Evacuation time in an Emergency Situation in Hospitals | Modeling Emergency Evacuation of Individuals with Disabilities (exitus): An Agent-based Public Decision Support system | Agent-Based Emergency Evacuation Simulation with Individuals with Disabilities in the Population |
| Objective | To document the importance of the relationship of NHs and EM entities before,during and after hurricanes. | To determine barriers and facilitators for evacuation | To describe the development and sue of the software package POD locator. Analyzing the PODs of Hurricane Ike and suggesting alternatives. | Given the increasing diversity of the US population and hurricane threats, to adress different cultural or religious groups and their hurricane preparedness attittudes. | A prediction model is presented that estimates evacuation time. | Presenting a model that is designed to safely evacuate individuals with disabilities during emergency situations | This manuscript describes the BUMMPEE model, an agent-based simulation |
| Methodology | Data collection / Surveys | Data collection / Surveys | Data collection / POD locator software / GIS | Data collection / Cross-sectional Seurvey | Data collection / Model design | Simulation modelling | Simulation Modelling |
| Spatial Coverage | Florida | Mississippi | Harris County, TX | Tampa,Florida | NONE | Utah | NONE |
| Temporal Coverage | 2006-2009 | 2002-2011 | 2005-2010 | 1997-2010 | 1991-2009 | 1966-2009 | 1989-2007 |
| Data Analysis | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Type of Source | Academic journals, Practitioner journals, guidebooks | Academic journals, Practitioner journals, websites. | Academic journals, Practitioner journals, websites. | Academic journals, Practitioner journals,websites | Academic journals | Academic journals | Academic journals, websites,books |
| Differentiation | Emphasis on an effective working relationship between nursing homes and EM offices during all phases of disaster preparedness. | A unique finding is that those with less means were more likely to evacuate that those with greater means. ($20000=annual household income) | Suggests mobile PODs as future work. Significant finding is that rather than additional PODs, one should increase the capabilities of existing ones. | First study on different religious or cultural groups and their behaviour and needs during hurricanes. | The major advantage of the prediction model is that the computation time is short and the model does not need a costly design.But also that model considers one-floor hospitals. | System reveals that people using wheelchairs and those with lower stamina such as elderly are at the greatest risk. | Indicates that the BUMMPEE model is a reasonable approach for simulating evacuations representing the disability in the population |

**Table A.3** Metadata-based Assessment Table 3

| Criteria | Fernandez et al (2002) | Rosenkoetter et al (2007) | Mitchell (2003) | Adams et al (2011) | Enarson (1999) | McGuire et al (2007) | Cocanour et al (2002) |
|---|---|---|---|---|---|---|---|
| Scope | Frail Elderly as Disaster Victims : Emergency Management Strategies | Perceptions of Older Adults Regarding Evacuation in the Event of aNatural Disaster | Prayer in Disaster : Case Study of Christian Clergy | Aging Disaster: Mortality, Vulnerability, and Long-term Recovery Among Katrina Survivors | Women and Housing Issues in Two U.S Disasters: Hurrican Andrew and the Red River Valley Flood | Natural Disasters and older US adults with disabilities : Implications for evacuations | Lessons learned from the evacuation of an Urban Teaching Hospital |
| Objective | Identifying the vulnerabilities of elderly to disasters, and to develop strategies to address these vulnerabilities. | To investigate the evacuation need and beliefs of older adults in Georgia, to identify heatlh risk factors | To investigate the role of faith and prayer in hazards adjustment | Offers insight on how older adults copes with disasters and illustrates that long-term catastrophes `age` in specific ways. | Examines root causes reproducing women`s disaster vulnerability in developed nations, among them economic dependency,male violence etc. | To estimate the number of community dwwlling people aged 65 years or older with a disability and requiring special equipment by BRFSS. | To investigate the lessons learned after Tropical Storm Allison |
| Methodology | A relevant literature search. | Data collection / Surveys | Data collection / Survey / Questionnaire | A relevant literature search. | Data collection / Surveys / Interviews / Group Sessions | Data collection / Surveys | A Case study |
| Spatial Coverage | USA | Richmond&Columbia , Georgia | South Carolina | New Orleans | Florida, Minnesota, North Dakota | Louisiana | |
| Temporal Coverage | 1988-2001 | 1991-2005 | 1961-2000 | 1976-2009 | 1982-1998 | 1992-2005 | 1982-2002 |
| Data Analysis | No | Yes | Yes | No | Yes | Yes | No |
| Type of source / media | Academic journals, government materials, news reports | Academic journals, government materials, news reports | Academic journals, government materials, news reports | Academic journals, government materials, news reports | Academic journals, government materials, news | Academic journals, government materials, news reports | Academic journals |
| Contribution | Addresses `insurance`problems of aging evacuees. | Addresses `memories/photos` of evacuees and their look for trust. | Demonstrates that the people of different religious groups hold contrary beliefs on prayers. Secondly, addresses the main reason to evacuate NHs as flooding. | Emphasis on the lack of recovery support, before and after catastrophes, is tied in the US to larger social structural relationships. | Provides a framework for women in disaster housing. | Baseline data of older adults with needs of special equipment is crucial.Many older adults requires assistance. | Provides a framework for hospital evacuation and offers maximization of use of volunteers. |

**Table A.4** Metadata-based Assessment Table 4

| Criteria | Hayunga et al (2006) | FEMA (2013) | FDOT(2010) | FHCA (2012) | AHRQ (2011) | Cahalan et al (2007) | Florida Seaport Transportation and Economic Development Council (2013) |
|---|---|---|---|---|---|---|---|
| Scope | We can do better : Lessons learned for Protecting Older Persons in Disasters | Emergency Procedures for Employees with Disabilities in Office Occupancies | Investment Element of the 2010 Florida Rail System Plan | Facts about Long Term Care in Florida | Hospital Evacuation Decision Guide (Chapter 2) | Safeguarding Independent Living - Emergency Evacuation of the Elderly and Disabled | The Five-year Florida Seaport Mission Plan |
| Objective | Reporting the proceedings of the AARP conference held on December 1, 2005. | Providing information such as equipments,procedures,comments for facilities managers | Describing 15 Florida Rail railroads by profiling,examining movements and trends | Providing key facts | Provides guidance pre-disaster and evacuation | Providing a general examination over latest experiences | Highlighting operational and economic numbers,information of seaports |
| Methodology | NONE | NONE | NONE | NONE | Case Studies | Case Studies | Data Collection |
| Spatial Coverage | Gulf States | NONE | Florida | Florida | USA | Louisiana | Florida |
| Temporal Coverage | NONE | NONE | NONE | 2012 | 2011 | -2007 | 2013-2017 |
| Data Analysis | No | No | Yes | No | Partial | No | Partial |
| Type of source / media | Conference speakers | NONE | NONE | NONE | News , articles | News / Articles / Interviews | NONE |
| Contribution | Provide wide range of ideas, thoughts from different disciplines,people regarding aging population. | Provides evac equipments and highlights the importance of understanding the needy. | Provides exclusive information for supply operations aftermath of a disaster as multimodal | 85% occupancy at any given time | Provides definitions for evacuation times, historical examples of hospital evacuations | Provides extensive information on hurricanes focusing on elderly cases. | Extensive information on Seaport development |

**Table A.5** Metadata-based Assessment Table 5

| Criteria | Brachman et al (2014) | Simkins (2005) | Spearpoint et al (2012) | Florida Department of Elderly Affairs (2010) | Florida Justice Institute | Florida Department of Elderly Affairs (2012) | Florida Department of Elderly Affairs (2010) |
|---|---|---|---|---|---|---|---|
| Scope | A spatially explicit network science model for emergency evacuations in an urban context | High-Rise evacuation of elderly during fire alarmas | The effect of an aging and less fit population on the ability of people to egress buildings. | Florida Dementia Friendly Transportation Research Project | Older Floridians Handbook | Assessing the Needs of Elderly Floridians:PSA1 | Assessing the Needs of Elderly Floridians:PSA1 |
| Objective | The objective is to design and implement Network Science Emergency Evacuation Model (Netseem) | To identify current behaviour of residents during fire alarms while evaluating methods that could improve the evacuation. | To examine the possible effects of of gender, age , and obesity and using a Monte-Carlo evac model to see if changes would affect evac time of high-rise buildings. | To analyze surveys and develop conclusions and recommendations on dementia friendly transportation | It contains useful legal and program information on topics of special interest to persons over sixty years of age. | A needs assessment conducted by FDEA to determine the needs of elders residing in the community | A needs assessment conducted by FDEA to determine the needs of elders residing in the community |
| Methodology | Modelling | Data Collection / Surveys | Data Collection / Modelling | Surveying / Discussion | NONE | Surveying | Surveying |
| Spatial Coverage | Burnaby, Canada | Illinois | Canada , New Zealand | Florida, USA | Florida | Escambia, Okaloosa, Santa Rosa, Walton counties of Florida | Bay, Calhoun, Franklin, Gadsden, Gulf, Holmes, Jackson, Jefferson, Leon, Liberty, Madison, Taylor, Wakulla, Washington Counties of Florida |
| Temporal Coverage | 1990-2013 | 1972-2005 | None | 1990-2010 | None | 2002-2012 | 2002-2012 |
| Data Analysis | No | Yes | Yes | Yes/No | No | Yes | Yes |
| Type of source / media | Academic papers, guidelines, news articles | Academic papers, guidelines | Academic papers, guidelines, news articles | Academic papers, guidelines, news articles,reports | NONE | Academic journals, reports | Academic journals,reports |
| Differentiation | NetSEEm provides an exploratory tool that can be used to examine what-if types of scenarios in emergency planning and management | The study shows there is a need for fire officials and building managers to cooperate in developing much needed fire safety and evacaution plans. | Results suggest that total evacuation times may increase by up to 20% when comparing historical data from Canada in 1971 with a future New Zealand scenario for 2031 | Results indicate particular focus as seniors living alone and extensive information and quotes regarding transportation and demographic data. | Provides answers to challenges that older people usually have regarding legal and fiscal issues. | Provides statistical data regarding minority,rural and low income elders of mentioned counties. | Provides statistical data regarding minority,rural and low income elders of mentioned counties. |

**Table A.6** Metadata-based Assessment Table 6

| Criteria | Renne et al (2009) | Elmore et al (2008) | Sullivan et al (2006) | Hebert (1993) | Gray et al (1992) | US Government (2006) | Brunkard (2008) |
|---|---|---|---|---|---|---|---|
| Scope | The Challenge of Evacuating the Carless in Five Major U.S. Cities. | Emergency Preparedness and Response : Health and Social Policy Implications for Older Adults | Disaster Preparedness for Vulnerable Populations : Determining Effective Strategies for Communicating Risk,Warning, Response | Freezes and Hurricanes in Florida | African Rainfall as a Precursor of Hurricane-related Destructionon the US East Coast | The Federal Response to Hurricane Katrina : Lessons Learned | Hurricane Katrina Deaths,Louisiana,2005 |
| Objective | Paper examines the carless and special needs evacuation planning for five selected U.S Metropolitan Areas. | Focusing on the policies and what can be done to improve policies for older adults | The paper explores the challenges faced by vulnerable populations and discusses strategies that may prove effective in providing information | Examines the occurences of freezes and hurricanes | Describes a predictive relationship between West African rainfall and US Hurricane-spawned which is based on 1949-1990 | To identify and establish a road map on how to do better in the future. | To verify, document, and characterize Katrina-related minority in Louisiana and help identify strategies to reduce mortality in future disasters. |
| Methodology | Focus groups | Data Collection | Data Collection / Review | Data Collection | Data collection | Data collection | Data Collection |
| Spatial Coverage | New Orleans, Miami, Chicago, New York City, San Francisco | USA | Southeastern Asia | Florida | West Africa , Gulf Coast | Gulf Coast region especially Katrina zone | Louisiana, generally Mississippi |
| Temporal Coverage | 2000-2008 | 1995-2007 | 1961-2005 | 1970-1992 | 1971-1991 | 1906-2005 | 2000-2007 |
| Data Analysis | Yes | No | No | Yes | Yes | Yes | Yes |
| Type of source / media | Academic journals, governmental materials, | Academic journals, governmental materials, | Academic journals, governmental materials,reports, guidelines,news articles | Academic Journals, government reports, publications | Academic journals, government reports,publications | Academic journals, governmental materials,reports, guidelines,web articles | Academic journals, government reports,publications |
| Contribution | States the fact that New Orleans was a success regarding carless and special needs evacuation. | Emphasizes on the needs of 'diversed' aging population. | Provides an Far East aspect on elderly evacuation planning. | Classifies hurricanes according to Saffir/Simpson scale | States that category 3,4 and 5 hurricanes are responsible for 80% the damages associated with US hurricane landfalls. | 71 % of the victims were older than | Strongly emphasizes on the fact that there is an vulnerable population that needs to be evacuated.(with statistical facts) |

**Table A.7** Metadata-based Assessment Table 7

| Criteria | Florida Department of Elderly Affairs (2013) | Transportation Research Board of the National Academies(2008) | Transportation Research Board of the National Academies(2013) | Ye et al (2010) | Florida Department of Elderly Affairs (2009) | US Government Accountability Office (2004) | The Federal Interagency Forum on Aging-Related Statistics (2012) |
|---|---|---|---|---|---|---|---|
| Scope | Assessing the Needs of Elder Floridians | The Role of Transit in Emergency Evacuation | A Transportation Guide for All-Hazards Emergency Evacuation | Use of Rural Transportation Infrastructure in Evacuations | Florida Master Plan on Aging 2007-2009 | Transportation - Disadvantaged Seniors- Efforts to Enhance Senior Mobility Could Benefit from Additional Guidance and Information | Older Americans 2012 - Key Indicators of Well-Being |
| Objective | This report assess the needs of Floridians age 60 or older. | To evaluate the potential role of transit systems in times of emergency focuses on 38 urbanized area in US. | Focuses on transportation aspects of evacuation, particularly large scale, multi-jurisdictional evacuation | To evaluate the use of transportation infrastructure in evacuation operations through the investigation of current practices in rural Northern Gulf of Mexico | The purpose of this plan is to establish a set of policy recommendations that will serve to enhance and improve the services that state provides to the aging population. | A review of the mobility needs of transportation-disadvantaged seniors. | To provide a comprehensive,easy-to-understand picture of older populations's health, finances and well-being. |
| Methodology | Surveying | Data collection | Framework | Data Collection | Data Collection / Framework | Survey / Data Collection / Literature Review | Survey / Data Collection |
| Spatial Coverage | Florida State | 38 urbanized area in US | USA | Northern Gulf of Mexico | Florida State | USA | USA |
| Temporal Coverage | 2002-2010 | 1993-2007 | 2007-2010 | 1991-2009 | None | 1997-2004 | 2000-2010 |
| Data Analysis | Yes | Yes | No | Yes | Yes | Yes | Yes |
| Type of source / media | Academic journals,reports, guidelines | Academic journals, government materials, news reports | Academic journals, government materials | Academic journals,reports, guidelines | None | Academic journals, government materials | Academic journals,reports, guidelines |
| Contribution | Assessment survey has found some key areas of need among elders age 60 or older, especially elders in historically underserved and disadvantaged group.In general, minority showed more pronounced needs. | Recommends inclusion of transit providers for emergency plans.Most of the plans do not include them. | Nationwide Evacuation Framework | Explore the similiarities, differences,and issues in rural evacuations.Lessons learned from past evacuation events. DMS found to be the most efficient device in evacs.Lack of budget is the main barrier. | Focuses on disaster preparedness and transportation services of the state with a framework. | While gathering information from local agencies, it emphasizes on Health Department's guidance and supervision. | Presents the key indicators for the well-beging of older Americans. |

**Table A.8** Metadata-based Assessment Table 8

| Criteria | Banks (2013) | Clary et al (2010) | Wilson (2004) | Campbell (2008) | Gray-Graves et al (2011) | Pielke (1997) | Nigg et al (2006) |
|---|---|---|---|---|---|---|---|
| Scope | Caring for Elderly Adults During Disasters: Improving Health Outcomes and Recovery | Changing the nature special needs : Utilizing a function-based approach to special needs planning | Frailty- and Its Dangerous Effects-Might be Preventable | On Belonging and Belongings : Older adults, Katrina, and Lessons Learned | The Level of Willingness to Evacuate Among Older Adults | Reframing the US Hurricane Problem | Hurricane Katrina and the Flooding of New Orleans : Emergent Issues in Sheltering and Temporary Housing |
| Objective | Provides a review on elderly people's health chalenges during disasters, identifies ways to improve | Advocating a function-based approach rather than "list of lists" approach for for special needs. | Examining frailty of the older people | Discussing what happened to the belongings of older adults how people reacts to what happened. | Examines the level of willingness to evacuate among older adults in the event of a disaster. | To stimulate constructive debate about how it is framed the problem of hurricanes and defining the problems in extraordinary events. | To review the disaster literature with respect to sheltering and temporary housing and contrasts. |
| Methodology | Review | Review / Discussion | Review / Discussion | Data Collection | Data collection / Survey | Data collection | Review / Discussion |
| Spatial Coverage | USA | Gulf Coast Hurricane Zones | USA | Hurricane Katrina zones | Hurricane Katrina zones | Gulf Coast , Atlantic Coast | New Orleans |
| Temporal Coverage | 2002-2012 | 2000-2010 | 2002-2004 | 2005-2006 | 1975-2010 | 1952-1997 | 2005 |
| Data Analysis | No | No | Yes | Partial | Yes | Yes | No |
| Type of source / media | Academic Journals, Government publications, agency reports | Academic Journals, Government publications, agency reports,news articles | Academic Journals | Academic Journals | Academic Journals, Government publications, agency reports, | Academic Journals, Government publications, agency reports,news articles | Academic Journals, Government publications, agency reports,news articles |
| Contribution | Identifies vulnerability problems or elderly people.Health outcomes and recovery should be improved for older adults during disasters | States that emergency plans should focus on function-based approaches more than list-of-lists approach | 20% of persons age 80 or older are frail,aside from any acute or chronic conditions they may have. | Emphasizes on older adults with pets. | Older adults are more likely to comply with a mandatory evacuation order | Strongly indicates the fact that hurricanes cannot be stopped so vulnerability of the nation should be decreased. | Increased attention must be paid to identifying refuges of last resort and emergency shelters |

**Table A.9** Metadata-based Assessment Table 9

| Criteria | National Council on Disability (2005) | Day et al (2010) | Comerio (1997) | US Government Accountability Office (2006) | Florida Health Care Education and Development Foundation (2008) | National Organization on Disability (2006) | Monroe County Website(2014) |
|---|---|---|---|---|---|---|---|
| Scope | Saving Lives : Including People With Disabilities In Emergency Planning | Aging and Disaster : Coping in the wake of Hurricane Katrina | Housing Issues after Disasters | Disaster Preparedness : Preliminary Observations on the Evacuation of Hospitals and Nursing Homes due to Hurricanes | National Criteria for Evacuation Decision - Making in Nursing Homes | Report on Special Needs Assessment for Katrina Evacuees (SNAKE) | Special Needs Registry Information |
| Objective | Provides an overview of steps the Federal Government should take to build a solid and resilient infrastructure that will enable them to include the diverse population with disabilities in emergency. | Examines the self-reported experiences, psychological effects, and evacuation behaviors of New Orleans people across age groups. | To document the housing losses and recovery problems in Northbridge earthquake and to compare the experiences to US urban disasters | To assess the evacuation of hospital and nursing home patients | To create a tool for decision making | To capture a snapshot in time through representative sampling of experience and observation for further reviews of Hurricane Katrina | Providing information on Monroe County special needs registry program |
| Methodology | Review / Data collection | Data Collection / Discussion | Data Collection | Survey / Data Collection | Discussion / Data Survey | Survey / Discussion | NONE |
| Spatial Coverage | USA | New Orleans | USA | USA | Gulf States | Hurrican Katrina zones | Monroe County |
| Temporal Coverage | 1983-2005 | 1978-2009 | 1986-1995 | NONE | NONE | NONE | NONE |
| Data Analysis | No | Yes | Yes | Preliminary | No | No | No |
| Type of source / media | Academic journals, government publications,reports, magazines | Academic Journals | Academic journals, government reports, publications, agency reports | NONE | NONE | NONE | NONE |
| Contribution | Provides planning steps for disaster relief, emergency preparedness. | Older people less likely to report material losses and difficulties with some routine activities. | Housing problems after disaster are potential for major financial crisis. | States the legislation for hospitals and nursing homes to have emergency plans. | States the fact that nursing homes and hospital are responsible for deciding whether to evacuate patients or to "shelter-in-place" | States the need of wheelchairs for evacuation operations. | Shelter registry program example is provided |

**Table A.10** Metadata-based Assessment Table 10

| Criteria | US House Committee on Homeland Security Democratic Staff (2006) | American Red Cross (2005) | Moore, *USA TODAY* (2005) | Castle (2008) | Hyer et al (2009) | Zane et al (2010) | Hansen (2006) |
|---|---|---|---|---|---|---|---|
| Scope | Trouble Exposed : Katrina, Rita, and the Red Cross: Familiar History | Shelter Operations : Participant's Workbook | States Review Evacuation Plans for Elderly | Nursing Home Evacuation Plans | Weathering the Storm : Challenges to Nurses providing Care to Nursing Home Residents During hurricanes | Hospital Evacuation Decision Guide | Through Hell and High Water : the Epic Struggle of Two Hospitals to Rescue the Abandoned, a Serial Narrative |
| Objective | Reviewing the experiences of Red Cross and Hurricanes | To present helpful information and specific shelter procedures that will guide you through the shelter process | To present an article about Gulf States programs for elderly evacuation | To examine evacuation plans of nursing homes and analyzing national data to determine the types of nursing homes cited for deficiencies | To document the experience of 291 Florida nursing homes during the 2004 hurricane season | To design a guidance for evacuation decision teams on how to consider different factors involved in hospital evacuation. | to offer lessons in disaster response |
| Methodology | Review | Framework | Review | Data Collection | Data Collection | Data Collection / Framework | Newspaper supplements |
| Spatial Coverage | Hurrican Rita and Katrina zones | NONE | Gulf States | USA | Florida | USA | Louisiana |
| Temporal Coverage | 1990-2005 | NONE | NONE | 1992-2006 | 1998-2008 | 2002-2009 | 2004-2005 |
| Data Analysis | No | No | No | Yes | Yes | Yes | No |
| Type of source / media | Academic journals, websites, government reports,publications,press releases | NONE | Legislations | Academic journals,legislations, codes,news articles, | Academic Journals,agency reports, | Academic journals,interviews, government reports,publications, news articles | News articles, interviews |
| Contribution | States the fact that in the aftermath of Hurricane Katrina, even the nurse volunteers had appropriate education and credentials, many were no allowed to provide a care due to "red tape" | States the fact that Red Cross cannot operate a facility during a disaster that would require licensure during non-disaster time | Casualties due to drowning in New Orleans and due to bus accident in Houston during evacuation | In USA, out of 2134 nursing homes, only 31% specified an evacuation route. | The decision to evacuate must be made long before a storm is projected strike | Presenting examples of intermodal evacuations of hospitals such as helicopters | Presenting evacuation examples such as Charity Hospital, moving patients by truckç |

**Table A.11** Metadata-based Assessment Table 11

| Criteria | Schultz et al (2003) | Kaisar et al (2012) | Strawderman et al (2010) | The Florida Senate (2013) | The Florida Senate (2011) | Fritz Institute (2006) | Taylor (2001) |
|---|---|---|---|---|---|---|---|
| Scope | Implications of Hospital Evacuation after the Northridge, California Earthquake. | An Emergency Evacuation Planning Model for Special Needs Populations using Public Transit Systems | The Role of Inter-modal Transportation in Humanitarian Supply Chains- Final report | Florida Statutes - Military Affairs and Related Matters | Florida Statutes - Military Affairs and Related Matters | Hurricane Katrina : Perceptions of the Affected | Many People Unprepared for Terrorist Attacks or Other Disasters |
| Objective | To examine the reasons for and methods of evacuation and the emergency-management strategies used. | To evaluate different evacuation procedures for special needs populations from large urban areas using current public transit systems | To identify the role of and impact of inter-modal transportation on the performance of response and recovery operations following a disaster | Emergency Management Chapter 252.34 Definitions | Emergency Management Chapter 252.36 Emergency Management Powers of the Governor | To present a summart of findings from research conducted among a total of 1089 adults affected by Hurrican Katrina | To investigate the the level of anxiety and people's preparedness for disasters or terrorist attacks. |
| Methodology | Survey / Questionnaire | Data collection / Modelling | Data Collection / Survey / | NONE | NONE | Data Collection / Survey | Survey |
| Spatial Coverage | California | Washington,DC | Gulf States | Florida | Florida | Alabama, Mississippi, Louisiana | NONE |
| Temporal Coverage | 1983-2002 | 2002-2010 | 1999-2008 | NONE | NONE | NONE | NONE |
| Data Analysis | Yes | Yes | Yes | No | No | Yes | Yes |
| Type of source / media | Academic journals, government publications, | Academic journals, agency manuals | Academic journals, Websites,agency reports | NONE | NONE | NONE | NONE |
| Contribution | With use of available resources and personnel evacuation of large numbers of inpatients from multiple hospitals can be accomplished quickly and safely. | Each bus stop scenario that contained a greater number of bus stop locations performed superior. | Relief organizations have limited use of modes with an emphasis on truck and air. | Definitions of Emergency Management | Emergency Management Powers of the Governor | Women,minorities, people living alone and persons with lower income or less education are more likely to need help. | Large numbers do not know who to contact or have no plans to evacuate their homes or their workplaces. |

**Table A.12** Metadata-based Assessment Table 12

| **Criteria** | The Federal Interagency Forum on Aging-Related Statistics (2010) | Simmons, *LA TIMES* (2006) | Salt, *TheGuardian* (2006) | FEMA(2007) | FEMA (2011) | EVACUSLED (2014) |
|---|---|---|---|---|---|---|
| Scope | Health Statues Detailed Tables | In New Orleans, Self Sufficiency is the Theme | Blood is Thicker that Floodwater | The Stafford Act | FEMA May Provide up to 18 months of Rental Assistance | NONE |
| Objective | Providing detailed tables on life expectancy,mortality,chronic conditions, sensory impairments and oral health, memory impairment etc. | To point out how people do not rely on government plannning | To point out in aftermath of disaster what happened. | By this act, to provide an orderly and continuing means of assistance by Federal Government to State and local governments in carrying out the responsbilities whic results from disasters | To provide information about rental assistance | Website to provide evacuation equipment |
| Methodology | NONE | Interviews | Interview | NONE | NONE | NONE |
| Spatial Coverage | NONE | New Orleans | New Orleans | NONE | NONE | NONE |
| Temporal Coverage | NONE | NONE | NONE | NONE | NONE | NONE |
| Data Analysis | NONE | NONE | NONE | NONE | NONE | NONE |
| Type of source / media | NONE | NONE | NONE | NONE | Website | NONE |
| Contribution | Providing numbers regarding aging population | Physical conditions can affect evacuation decisions. Also people do not rely on government planning anymore. | Superdome, New Orleans did not admit elderly and infirm back that time during Katrina. | FEMA may only provide assistance when a governor requests it and responds if it is beyond capabilities of the stae | 18 months rental assistance from FEMA | Providing evacuation equipment information |

**Table A.13** Metadata-based Assessment Table 13

| **Criteria** | Kamo, Y. Henderson, T. L. and Roberto, K. A., 2011 | Castro, C., Person, D., Bergstrom, N., & Cron, S. (2008). | Murray-Tuite, P. & Wolshon, B. (2013) | Rincon, E., Linares, M. Y-R, and Greenberg, B. (2000). | Aurbach. G. (2001) | Archibald and McNeil (2012) | Dow & Cutter. (2002) |
|---|---|---|---|---|---|---|---|
| Scope | Assessing the relationship between hurricane disaster displacement and psychological well-being of older adults | Emergency preparedness in nursing facilities | Evacuation Transport modeling | Effect of previous experience of a hurricane on preparedness for future hurricanes. | Access to transport systems for persons with reduced mobility | Traffic data value to understand hurricane evacuation | Hurricane evacuation |
| Objective | To characterize the effects of hurricane Katrina on the psychological well-being of displaced older adults and examine the factors that may worsen and/or mitigate such effects | To assess the preparedness of long-term care facilities in response to Hurricanes Katrina and Rita | Focuses on highway-based evacuation modeling and simulation and its evolution over time | To check whether or not experience with past hurricanes results in better disaster preparedness | To present recommendations bound to increase / improve barrier-free access to transport services for persons with reduced mobility; | To identify ways to use traffic data to better understand evacuation behavior and to explore ways to integrate traffic data into evacuation planning and response | To provide solutions for future evacuations |
| Methodology | Surveying | Data collection through mail-out survey | Literature review | Data Collection through survey and statistical analysis | Data collection Field survey | Analysis of traffic data collected at all phases of Hurricane Irene | Phone survey |
| Spatial Coverage | New Orleans, LA | Texas | USA | Dade County, FL | Europe | Delaware | South Carolina |
| Temporal Coverage | 2002-2010 | 2008 | 2000-2010 decade | 1999 | 2000 | 2001 | Oct. Nov. 1999 |
| Data Analysis | Yes | Yes | No | Yes | Yes | Yes | Yes |
| Type of source / media | Academic journals, reports, guidelines | Academic journals, government materials, news reports | Academic journals, government materials | Academic journals, reports, guidelines | Academic journal | Academic journals, | Academic journals |
| Contribution | The authors used the ecological framework and previous research on response to disasters to explain the coping strategies of older adults in situation of disaster | Reports a higher susceptibility of assisted facilities to [higher]financial losses than nursing facilities as a result of transportation and staff overtime;<br><br>Highlights the need for improved disaster preparedness training, better coordination and transportation; Recommends change in policy and practice as a way to satisfy the need for improved health outcomes during future public health disasters. | Suggests the following future directions to evacuation transportation modeling: attention to logistical difficulties; further interdisciplinary efforts, including the medical community; using new technologies for communication of warnings and traffic condition information, data collection, and increased modeling resolution and confidence; using real-time information; and further model refinements and validation. | Finds that experience with (past) major hurricanes doesn't promote better preparedness for the future ones | Provides recommendations for improving free access to transport services for reduced mobility persons in the four main transport modes (e.g. bus, taxi, air, and rail) with practical implementation suggestions;<br><br>Formulates certain guideline principles which may lead to further suggested improvement. | Suggests that the evacuation patterns of residents from beach communities are similar to traffic patterns experienced on summer weekends; Suggest such results may serve opportunistically to model evacuation for other (disaster) events in other communities | Provide important information about: evacuation rate (e.g. percent of evacuated households); number of cars taken per household; preferred evacuation time window; and the distance travelled by evacuees; |

| **Criteria** | McGlown, K. J. (2001) | Barratt, J. (2007) | Burnett, J., Dyer, C. B., & Pickins, S. (2007) | Jenkins, P., Laska, S., &Williamson, G. (2007) | Mayhorn, C. B. (2005) | McGuire, L. C., Ford, E.S., & Okoro, C. A. (2007) | Ngo, E. B. (2001) |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| Scope | Evacuation of Health care facilities | Identification and characterization of factors creating older adults vulnerability to disasters | Rapid needs assessment for old adults in disasters | Ways of increasing older adults' influence and safety in current and future disaster rebuilding effort | Cognitive aging and the processing of hazard information and disaster warnings | Disaster evacuation and older adults with disabilities | Elderly's perception and response to natural disasters from sociological, psychological, and medical standpoints |
| Objective | Comparing two models from study related to evacuation process: Vogt's adaptation and McGlown's model by examining variables of decision making;<br><br>Identification and analysis of variables significant in executive decision making involving disaster evacuation or sheltering-in-place of a health care facility | Differentially characterizing older adult vulnerability to disasters in developed and developing countries;<br><br>Proposing mechanisms to addressing the emergency needs of aging populations around the world based on agreed-upon plans and procedures made through discussions between the public and the private sectors; | Presentation and documentation of a rapid need assessment tool for screening disaster vulnerable elders with urgent needs: the SWIFT, Seniors Without Family Triage screening tool designed to reduce harmful and fatal impacts of hurricane disasters on old adults and make relief efforts more efficient; | Evaluating the success of individual and community recovery efforts in the aftermath of Hurricane Katrina | To understand the mechanism of interaction of older adults with general hazard information and warnings in an attempt to identify their disaster-related special needs; | To estimate the number of community dwelling older adults with disability or required to use health-related special equipment toward reducing rates of harms and casualties in case of disasters; | To study how the elderly perceive and respond to natural disasters from<br><br>sociological, psychological, and medical perspectives;<br><br>To identify individual variables of risk that contribute to the differential and disproportionate vulnerability of the elderly populations in situation of disasters; |
| Methodology | Focus group, Data collection/ Multidimensional scaling and Cluster analysis | Literature review | Questionnaire | Community-based planning process to identify the New Orleans groups that would coordinate mobilization to evacuate the elderly residents during a future hurricane threat | Description of the normative age-related characteristics as contrasted with some idiosyncratic changes of the older adults; | Analysis of data from the 2003 and 2004 Behavioral Risk Factor Surveillance System (BRFSS), a state-based, random digit dialed telephone survey of the non-institutionalized US population, aged 18 years or older employed to monitor behavior associated with the leading causes of morbidity and mortality; | Literature review on disaster impacts on the elderly using primarily peer-reviewed research articles compiled from medicine, psychology and sociology databases |
| Spatial Coverage | The USA | World | New Orleans, LA | New Orleans, LA | The USA | New Orleans-Metairie-Kenner Louisiana, LA Metropolitan or Metropolitan Statistical Area, MMSA | Global |
| Temporal Coverage | 1969 - 1999 | 2007 - 2050 | 2007 | 2007 | 2005 | 2007 | 2001 |
| Data Analysis | Yes | No | Yes | No | No | Yes | Yes |
| Type of source / media | Academic journals, books, reports | Academic journals, books, reports | Academic journals, books, reports | Academic journals, books, reports | Academic journals, books, reports | Academic journals, books, reports | Academic journals, books, reports |
| Contribution | Provision of a formal definition and a typology of the concept evacuation;<br><br>The decision to evacuate was found to be bounded within the three continua of the (internal and external) | Proposal to integrate both needs and contributions of older adults in emergency preparedness using different the U.S. Administration on Aging's (1995), and the International | Proposal and design of a new tool to swiftly identify older adults in situation of urgent disaster needs. | Suggestion of a community-based and participatory planning process to identify the groups that would coordinate a comprehensive mobilization to evacuate the elderly residents during a | Revival of the Protective Action Decision Model, PADM (Lindell and Perry, 2004);<br><br>Recommendations to tailor risk communication messages for | Derivation of a method to measure prevalence of older adults with a disability and/or who require special equipment as a function of demographic characteristics; | Proposition of five main relationships Actual Loss versus Relative need; Perception of loss; Service stigma; Psychological vulnerability; and Morbidity and mortality) as the basis |

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| | environment, operational determinants, and extent of foci; | Longevity Center approaches: in the developed countries; and the Help Age International's (2003) guidelines for the developing countries. | | future hurricane threat. | older adults in a way which compensates for the age-related negative changes (e.g. sensory impairments and decreased mobility) inherent in that demographic group. | Assistance in understanding the needs of community dwelling older adults with disability and special equipment requirements for better delivery of necessary services during the next disaster. | of a conceptual model on elderly's response to disasters;<br><br>Suggestions to associate initiatives aiming at responding to elderly disaster needs with (1) targeting; (2) connection; and (3) modification |

| **Criteria** | Pekovic, V., Seff, L., &Rothman, M. B. (2007). | Phifer, J. F., Kaniasty, K. Z., & Norris, F. H.(1988) | Bayleyegn, T., Wolkin, A., Oberst, K., Young, S., Sanchez, C., Phelps, A., Schulte, J., Rubin, C., and Batts, D. (2005). | Baker, E. J. (2011) | Gibson, M. J. (2006) | World Health Organization [WHO],2007 | Martinson, M. & Berridge,C. (2014) |
|---|---|---|---|---|---|---|---|
| Scope | Needs of elders in natural disasters: planning and response | Impact of natural disaster on the health of older adults | Rapid assessment of post-hurricane needs and health status | Household preparedness for hurricanes | Disaster protection of older persons in both the community<br><br>and nursing homes | City [old] age friendliness | Successful aging and discontents |
| Objective | Identifying and sizing up the special needs of elders in relation to natural disaster management | To examine the impacts of flood exposure on the physical health of older adults;<br><br>To clarify the [exact] nature of the relationship between disaster and physical health in older adults | To assess the post-event needs and health status of affected community in Santa Rosa and Escambia Counties, Florida;<br><br>To providing timely and reliable information that could be used in response efforts and aid planning for future disasters; | To assess household-level disaster preparedness in a situation of high scale loss of electricity and other utilities | To provide suggestions and links to practical<br><br>tools and resources helpful to policy makers; non-governmental organizations; and older persons, family caregivers, and persons with disabilities | To provide a guide describing the core age-friendly city features which promotes active aging;<br><br>To ultimately engage cities to become more age-friendly so as to tap the potential that older people represent for humanity | To analyze the critiques of successful aging models and the suggestions for improvement as expressed in the social gerontology literature |
| Methodology | Reviewing of vulnerability and risk facing older persons particularly in disaster situations in terms of: 1) the assistance required to carry out activities of daily living; 2) the inability to quickly react to alerts requiring immediate actions; and<br><br>3) various physical and mental health problems; | Interview (six waves) ona sample of 222 elders who experienced losses in the Kentucky 1981 and 1984 flood events;<br><br>Maximum-likelihood factor analysis, regression analysis, linear, quadratic and cubic trend analysis techniques | Rapid needs assessment (RNA) survey using a questionnaire adapted from templates developed by the Centers for Disease Control and Prevention (CDC);<br><br>Modified cluster sampling method;<br><br>Probability proportional to size sampling methodology modified from the World Health Organization; | Telephone interviews;<br><br>Performance score computation; | Literature review and short survey | Focus group with old adults and old adult caregivers using a bottom-up participatory approach | Literature review and qualitative method analysis |
| Spatial Coverage | Global | State of Kentucky | Santa Rosa County and Escambia County, Florida | The state of Florida | The USA | World | N/A |
| Temporal Coverage | 2007 | 1981 - 1985 | 2004 | 2004 - 2006 | 2006 | 2006 - 2007 | 1987 - 2013 |
| Data Analysis | No | Yes | Yes | Yes | No | Yes | Yes |
| Type of source / media | Academic journals | Academic journals | Academic journals | Academic journals | Institution technical report | Institutional report / field study | Academic journals |

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| Contribution | Preconization of a flexible disaster planning (integrating coordination among aging services network providers and non-aging service providers and practice) as a way to effectively address the disaster needs identified for older persons in disaster situations;<br><br>Suggestion of an all-hazard perspective concerning older people's disaster needs; | Provision of a formal definition of the "older adults" concept (that is: adults of 55 or more);<br><br>Devising a relationship between flood exposure and health status of older people as follows such that<br><br>pre-flood health was the strongest predictor of post flood health for each health measure with small contributions of the socio- demographic factors; | Recommendations to planners to give special consideration to the needs of sensitive and vulnerable groups (such as the elderly), and the chronically ill people in a post-hurricane situation;<br><br>Suggestions to identify how best to restore public utilities in the first days after a hurricane through evaluating the community resources essential to a great number of residents; | Identification of predictors of hurricane preparedness;<br><br>Levels of hurricane preparedness is presented as a function of wealth, education, ethnicity (lower in blacks and Hispanics), and extreme low and high ages. | 71% of the 1,330 deaths brought about by Hurricane Katrina in the New Orleans, LA metropolitan area were older than age 60, and 47 % of those were over age 75;<br><br>About 13 million persons age 50 or older in the U.S. say they will need help to evacuate, and about half of these individuals will require help from someone outside of their household; | Explores eight topics relative to city's age-friendliness covering the city's structures, services environment, and policies that reflect the determinants of active ageing such as: outdoors paces and buildings; transportation; housing; social participation; respect and social inclusion; civic participation and employment; communication and information; and community support and health services. | Distinguish four categories of critiques of the Rowe and Kahn's original successful aging model which individually are associated with improvements ranging from definition criteria to the proposition of alternative models;<br><br>Suggest greater reflexivity about gerontology's use of<br><br>"successful aging" and necessity for other normative models; |

| **Criteria** | Sanders, S., Bowie, S. L., & Bowie, Y. D. (2004). | Wiles et al. (2012) | Dickerson et al. 2007 | United States Government Accountability Office [GAO] (2006) | United States Government Accountability Office (2004). | Phelan et al. (2004) | Martin et al. (2014) |
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| Scope | Health impacts of forced relocation on older adults | Reflection on the ideal place to age / grow old | Transportation and aging | Disaster evacuation of vulnerable population | Review of the mobility needs of transportation-disadvantage seniors | Older adults view of successful aging | Successful aging |
| Objective | To study the impacts of forcible relocation on older adults | To investigate how older people understand the meaning of "aging in place" | To review the state of knowledge about older driver safety and mobility, and highlight research needs for achieving the safety and mobility goals for the aging baby boomers and future generations of older drivers | To discuss GAO's preliminary observations on ongoing work on the evacuation of vulnerable populations due to hurricanes and other disasters | To identify (1) federal programs that address elderly's mobility issues, (2) the extent to which these programs meet their mobility needs, (3) program practices that enhance their mobility and the cost-effectiveness of service delivery, and (4) obstacles to addressing their mobility needs and strategies for overcoming those obstacles; | To determine whether older adults have thought about aging and aging successfully and to compare their perceptions of successful aging with attributes of successful aging identified in the published literature. | To highlights work of scholars who made significant theoretical contributions to the topic |
| Methodology | Survey | Focus group and interview based case study | Description of key areas to meet the goals of crash prevention and mobility maintenance for older adults | Interview with hospital and nursing home officials, local and state officials on emergency evacuation | Interview with transport planners, federal officials and seniors mobility experts;<br><br>Review of prior GAO reports on the coordination of transportation services for disadvantaged populations | Cross-sectional, mailed survey | Literature review |
| Spatial Coverage | Miami-Dade County | Aotearoa New Zealand | The USA | Florida, Mississippi, California, New York | The USA | King County, Washington | Global |
| Temporal Coverage | 1992 | 2012 | 2007 | 2006 | 2000 - 2004 | 1992 - 2004 | 1990 - 2004 |
| Data Analysis | Yes | Yes | Yes | No | Yes | Yes | No |
| Type of source / media | Academic journals | Academic journal | Academic journal | Institutional /governmental report | Institutional / governmental report | Academic journal | Academic journal |
| Contribution | Discuss implications regarding the need for pre-emptive "elder-sensitive" strategic planning, the role of Public Housing Authorities in properly caring for older adults before and after a hurricane or other natural disaster, the need | Present thematic and narrative analyses on the meaning of aging in place;<br><br>Find that older people prefer having control on | Propose the adoption of an interdisciplinary research approach to address the issues surrounding the maintenance of safe transportation for older adults; | Highlights the challenges hospital and nursing home administrators, local government and state officials face in time of hurricane evacuation including: transport means, adequate receiving | Shows that:<br><br>Most transportation-<br><br>disadvantage seniors needs are not being met; Inconsistent methods to assess seniors' mobility needs through HHS's Administration on | Find that older adults do think of aging and aging successfully whose<br><br>Attainment they associate with at least 13 important attributes and following a | Suggest the necessity of further theoretical work to better understand successful aging, including the way it can encompass disability and death and dying as well as the extent at which rapid social and technological change |

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| | for appropriate training of public housing property managers, and the key role of social workers during post-disaster interventions with older adults and their families. | their aging places: preferably communities they are attached to and from which they derive a feeling of security, familiarity, and identity;<br><br>Propose that aging place and the way it operates should be taken into account in both policy and research; | Point out four cross-cutting themes emerging importance of safe transportation for older<br><br>Variety and diversity older adults needs, abilities, and resources; synergic benefits to persons with disabilities from research on transportation needs for older; and multifacetedness of transportation issues concerning older adults; | facilities and/or evacuation shelters | Aging not holding to its mission to provide guidance to states on how to assess seniors' need for services;<br><br>Recommends actions to improve guidance and information on transportation-disadvantaged seniors' mobility, including guidance on assessing mobility needs and publicizing information on alternative transportation services; | perception which changes over time;<br><br>Show that none already published work describing g successful aging include the four (physical, functional, psychological, and social) health dimensions assigned to successful aging by the surveyed older adults; | influences views on successful aging; |

| **Criteria** | Fernandez, S. L., Byard, D., Lin, C-C., Benson, S. & Barbera, J. A. (2002) | Adler and Rottunda (2006) | Institute of Food and Agricultural Sciences<br><br>University of Florida (1998) | Brossoie, N., Roberto, K.A., Willis-Walton, S., & Reynolds, S. (2010) | Department of Elder Affairs, State of Florida | Denson, C. R. (2000) | Rosenbloom, S. (2009) |
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| Scope | Emergency management strategies for elderly | Driving cessation in older adults | Disaster Planning for Elderly and disabled populations | Rapid aging and associated challenges in the US | Elder's need assessment | Public transportation satisfaction of people with disabilities | Transportation needs and aging |
| Objective | To identify the vulnerabilities of elderly to disasters, and to develop strategies to address these vulnerabilities; | Data collection / focus groups | To help extension personnel assist<br><br>their communities in times of disaster | To examine the level of preparedness of communities across America; to tap the vast potential of the oncoming wave of adults and evaluate the initiatives underway to address the "aging/maturing America" | To determine the needs of elders residing in the community in order to assist service planners, agency directors and policy makers with their planning endeavors | To examine consumer satisfaction of para-transit service | To explore options for making transportation in our communities<br><br>more aging-friendly |
| Methodology | Literature review | Data collection / focus groups | Literature review and others | Telephone survey | Survey (of people age 60 or older) | Interview / Survey | Opinion / Reflection |
| Spatial Coverage | Global | The US Midwest | Florida | USA nationwide | Florida (statewide) | Delaware (statewide) | The USA |
| Temporal Coverage | 2002 | 2006 | 1998 | 2010 | 2013 | 2000 | 2010 |
| Data Analysis | No | Yes | No | Yes | Yes | Yes | No |
| Type of source / media | Academic journal | Academic Journals | Institutional report | Institutional report | Institutional report | Journal article | Journal article |
| Contribution | Find disaster vulnerability in old adults to be related to impaired cognitive sensory and mobility conditions and socio-economic limitations that prevent their adequate preparation for disasters, and hinder their adaptability during disasters;<br><br>Recommend emergency managers recognize the frail elderly as a<br><br>special needs population, and develop | Recommend the self-evaluation, and periodic evaluation of old drivers with medical conditions and the recourse to a "retirement from driving" worksheet as ways of helping old drivers realizing when to stop driving and what to do for alternative transportation;<br><br>Also recommend the inclusion of the topic driving cessation incorporate | Propose a specific approach to identify and properly handle the needs of elderly and disabled population based on their adequate identification provision of disaster information whose transmission accounts for hearing, visual and mental impairments they may have;<br><br>Further recommends evacuation actions which take into account their frailty and various health | Reveal challenges and important advances being made including increase in specialized training for emergency and public safety staff in dealing withholder adults; growth of in-home supportive services; greater support for advanced education for the workforce; and expanded volunteer opportunities<br><br>Cautioned against the insufficiency of the progress made to ensure that | Findings:<br><br>Global needs of Floridian elders have increased over the 2004 - 2006 period with more elders living alone with more nutrition, home and job related (lower salary rates) problems;<br><br>4% of elders were not able to go where they needed and when they needed to; | Findings:<br><br>Satisfaction varies with the type of disabilities with hearing impaired being the least satisfied; and walking impaired less satisfied (of transit fares, bus comfort) as compared to people with no mobility restrictions;<br><br>People with disability voice for increased para-transit services; | Finds the auto-based system and walking to be the most realistic<br><br>travel options currently available for many older adults;<br><br>Recommends: more funding for transit operators to develop meaningful transit services and<br><br>increase ADA-type para-transit services for older people without serious disabilities; promotion of community |

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| | targeted strategies that meet their needs; | retirement seminars to make driving cessation a part of typical retirement planning process.<br><br>Rather than a response to an adverse event; | issues and impairments, their sheltering in particular shelters medically equipped and able to accommodate eservice animals; and their optimal re-entry in their community or nursing homes after the disaster; | communities are livable for people of all ages including the elderly; | 33% of elders reported mobility impediments due to health problems<br><br>Males and females in Florida have about identical rates of transportation use despite having differences inactivity and mobility; | Recommendations:<br><br>Transit providers wanting to satisfy para-transit service consumers should understand their needs and socio-demographic and political composition. | transport provision; enhancement and maintenance of pedestrian network; enforcement of traffic regulation; |

| **Criteria** | Whelan, M., Langford, J., Oxley, J., Koppel, S. & Charlton, J. (2006) | Koffman, D., Weiner, R., Pfeiffer, A. &Chapman, S. (2010) | Ortman, J. M., Velkoff, V.A. and Hogan, H. (2014) | Berkoune, D., Renaud, J., Rekik M., & Ruiz, A. (2012) | Saunders, J. M. (2007). | Caunhye et al. (2012 | Kar & Hodgson (2008) |
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| Scope | Elderly mobility | Public transportation funding needs and aging population | US Population and aging | Transportation in disaster response operation | Vulnerable population and disaster sheltering | Optimization models in emergency management | Evacuation shelter location site analysis |
| Objective | To assess the current state of knowledge on driving and travel pattern changes, ageing, health status and mobility; | To identify the range of actions needed to expand mobility options for older people; quantify the demand for these public transportation services; and estimate the associated funding needed; | To examine expected change mechanisms in US age structure with a focus on older population | To define and formulate the Transportation Problem in Disaster Response Operations (TP-DRO), a practical problem often encountered by crisis managers in emergency situations | To examine problems facing hurricane Katrina stricken and displaced people as well as the experience of health care workers who attended patients those disaster victims; | To provide a focused allowing to identify the research gaps and suggest future research directions in emergency logistics | To rank the existing and candidate shelters available in the study area based on their site suitability |
| Methodology | Literature review | Data collection and time projection | Time projection of demographic data | Literature review; modeling and algorithm development; | Model of Vulnerable Populations (a conceptual framework) | Literature review | Implementation of a GIS-based model integrating the Weighted Linear Combination principle to screen existing and candidate shelters for environmental and socio-economic suitability; |
| Spatial Coverage | Global | The USA | The USA | N/A | Jacksonville, FL | N/A | South Florida 17 counties |
| Temporal Coverage | 2000 - 2006 | 2010 to 2030 | 2013 to 2050 | 2011 | 2007 | 2012 | 2008 |
| Data Analysis | No | Yes | Yes | No | No | No | Yes |
| Type of source / media | Institutional report | Institutional report | Institutional report | Journal article | Journal article | Journal article | Journal article |
| Contribution | Show that:<br>Driving cessation in older adults results in reduced mobility and associated quality of life with women and financially disadvantaged groups being more affected by such reductions;<br>Old drivers have declining driving skills which they adjust | Estimate the dollar amount needed through time (2010 - 2030) to operate a desirable level of public transportation services for older people in the United States;<br>Suggest enhancement actions needed in transportation operation and planning; vehicles; supplementary | Find that:<br>The US population will grow older over the next decade due to the baby boomers projected moving to the old adult group;<br>The US older population is projected to be larger than that of the other developed countries except for China; | Modeled a practical transportation problem faced by crisis managers;<br>Developed heuristic algorithm which can solve large instances of the TP-DRO problem at hand in relatively short computation times putting an efficient crisis management tool in the hand of emergency managers; | Demonstrated the potential of the Model of Vulnerable Populations as a tool to improve mental health assessment and services by counseling, advocacy, triage, and teaching disease prevention strategies such as hand washing; | Situated the post 2005period as that of an exponential growth in emergency logistics research publication; Made recommendations relative to better data availability, more efficient information sharing, and the reduction of solving of optimization models; | Found 48% of the existing shelters and 57% of the candidate shelters respectively to be located in physically unsuitable areas;<br>Showed a spatial mismatch between the demand and supply of shelters with the more populated Southern portion of the study area revealed with a shelter deficit |

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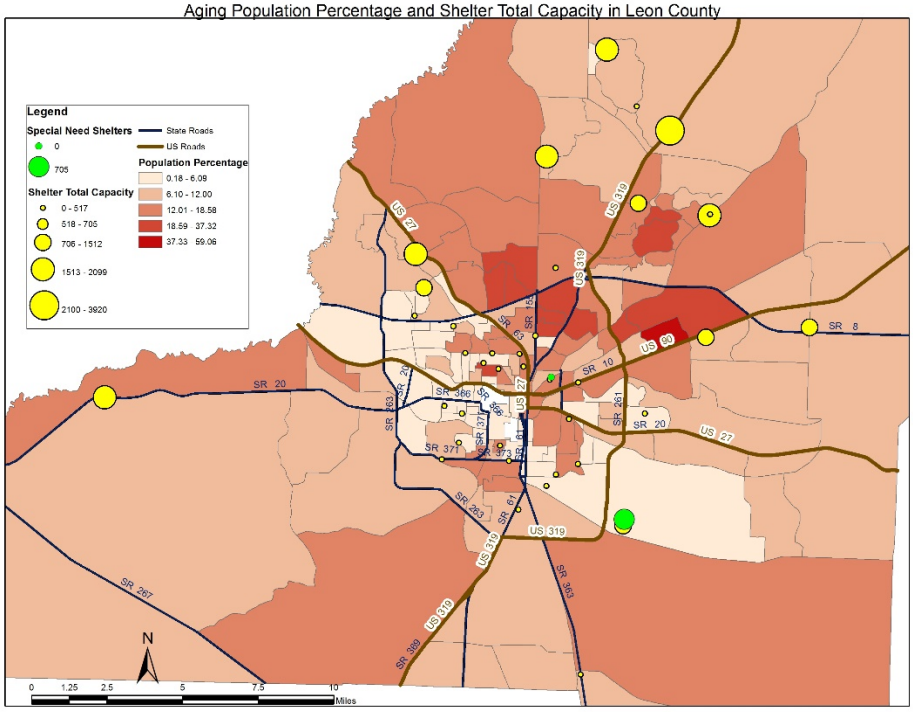
| | behaviorally through self-regulation;<br><br>Safer vehicles, roads, and provision and promotion of alternative transport options may increase mobility and associated quality of life of elderly population. | services and design strategies; | The expected changes in old population may provoke a shift in the country's needs (in education and health care in particular); | | | | contrasting with the Northern part being, the site of a shelter surplus; |

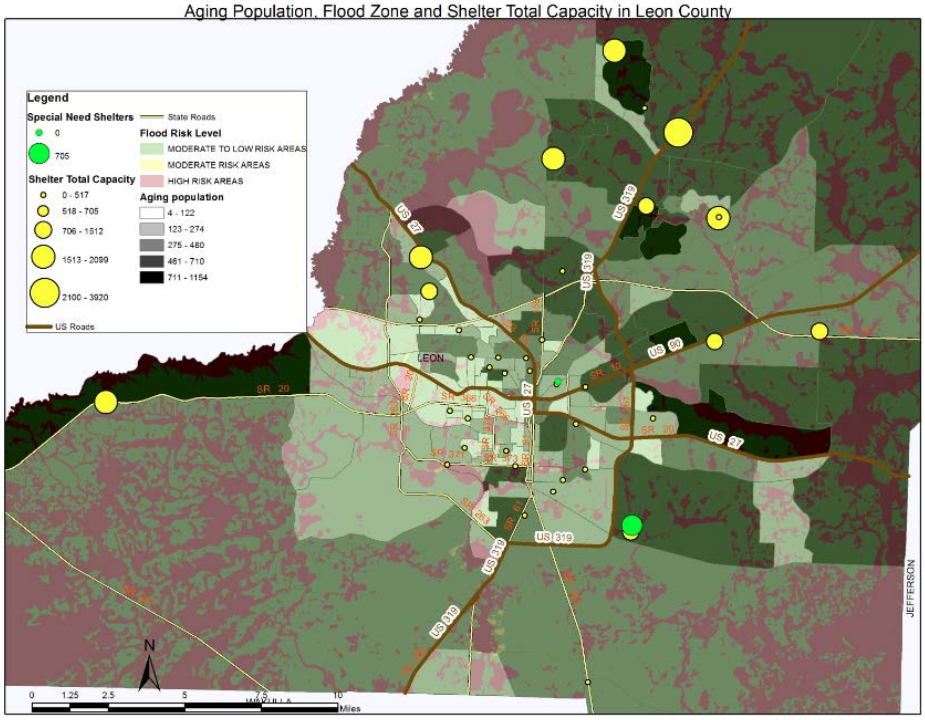
# Appendix B GIS Maps for Leon County

Aging Population Percentage and Shelter Total Capacity in Leon County

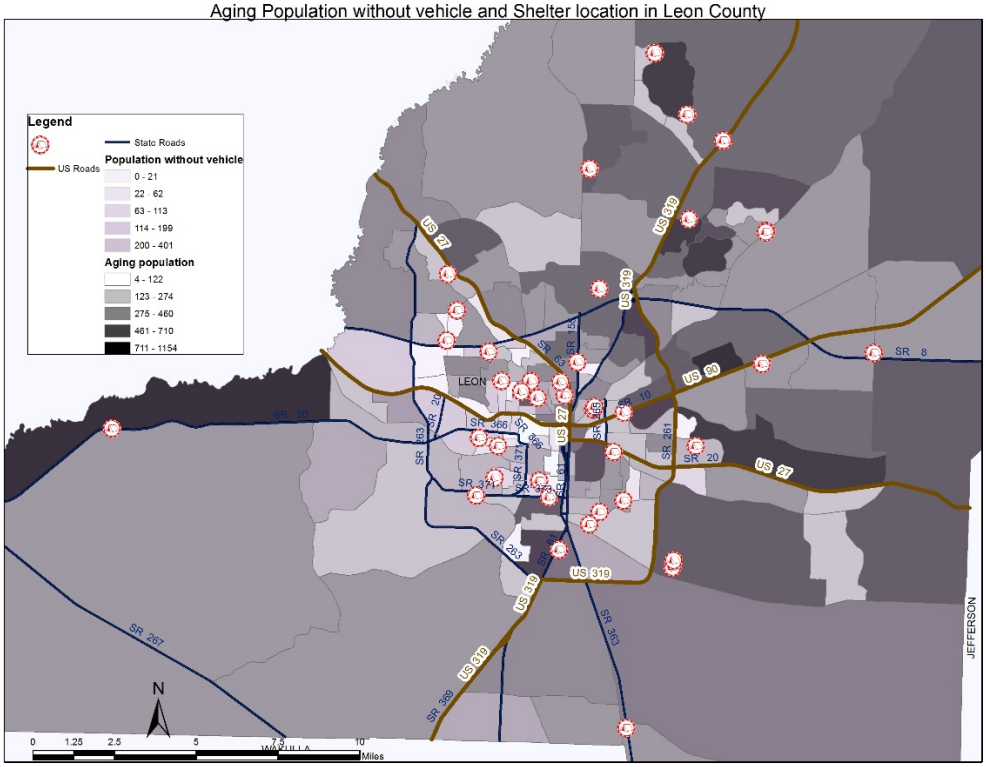



*FLORIDA STATE UNIVERSITY CIVIL ENGINEERING DEPARTMENT 2014*

Aging Population, Flood Zone and Shelter Total Capacity in Leon County

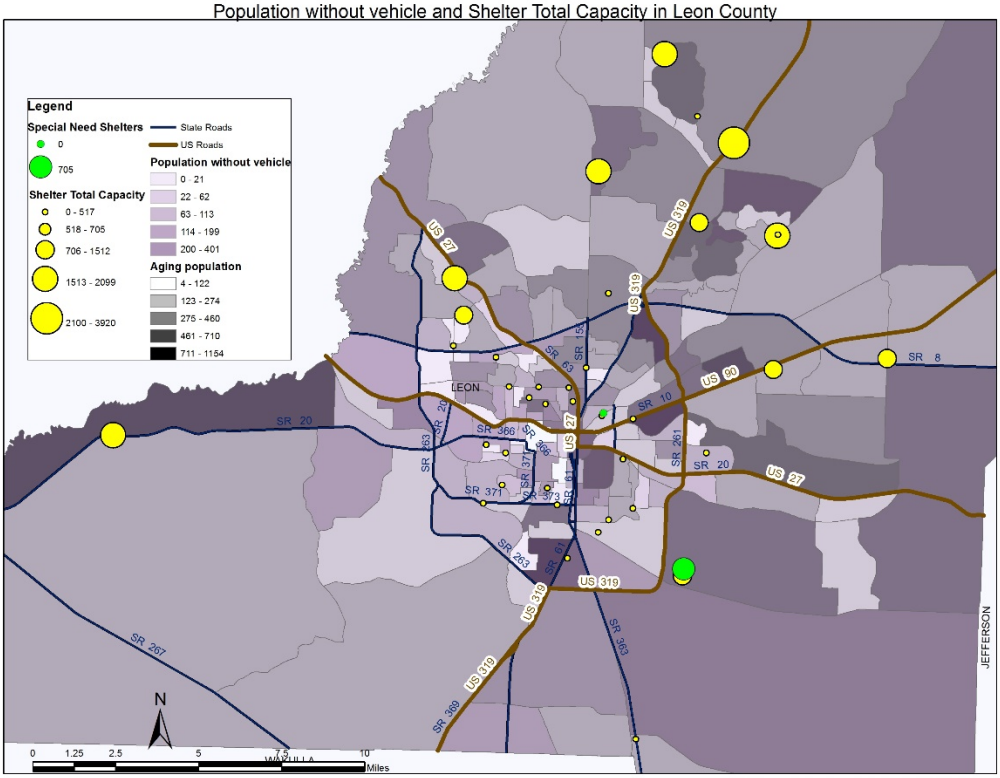


Aging Population without vehicle and Shelter location in Leon County



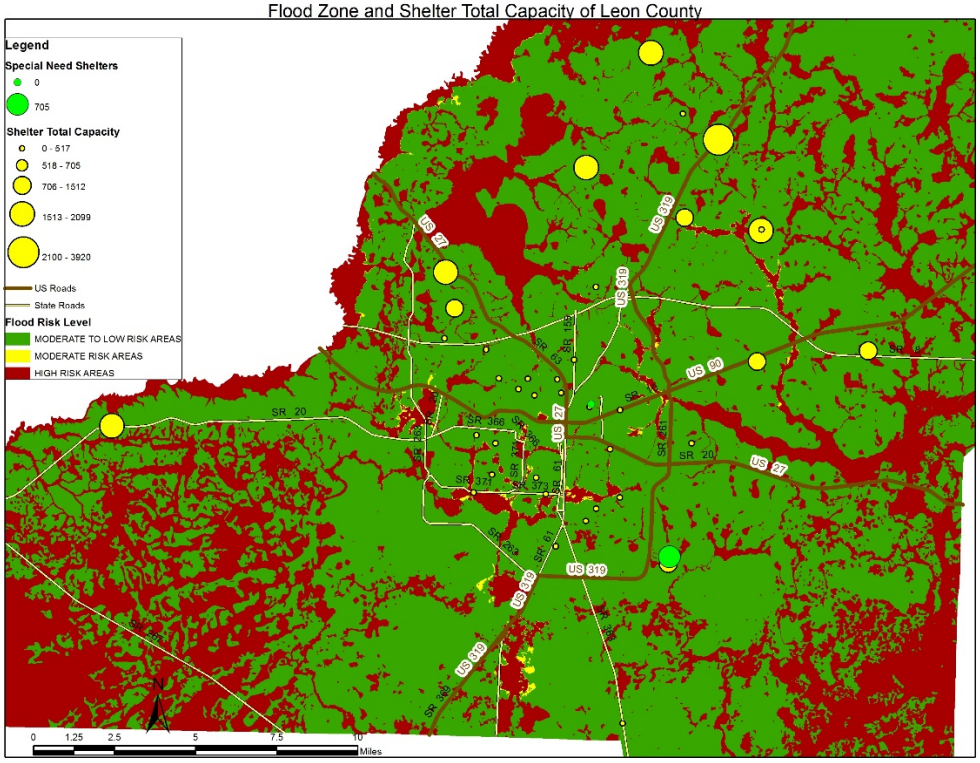

*FLORIDA STATE UNIVERSITY CIVIL ENGINEERING DEPARTMENT 2014*

Population without vehicle and Shelter Total Capacity in Leon County



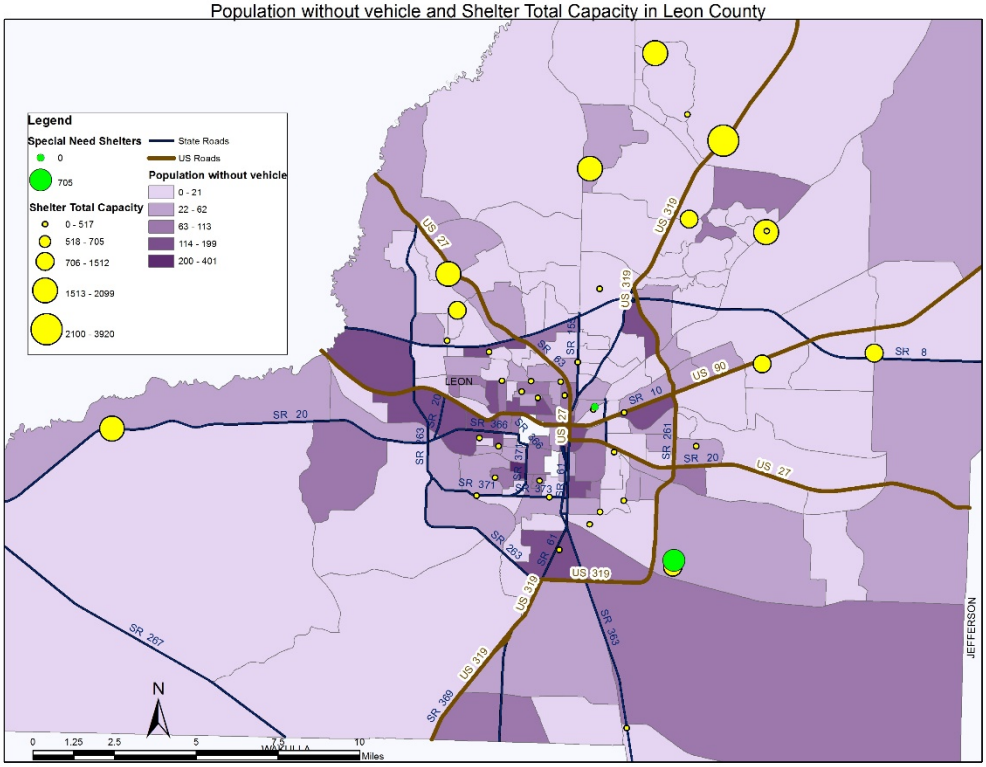

*FLORIDA STATE UNIVERSITY CIVIL ENGINEERING DEPARTMENT 2014*

Flood Zone and Shelter Total Capacity of Leon County

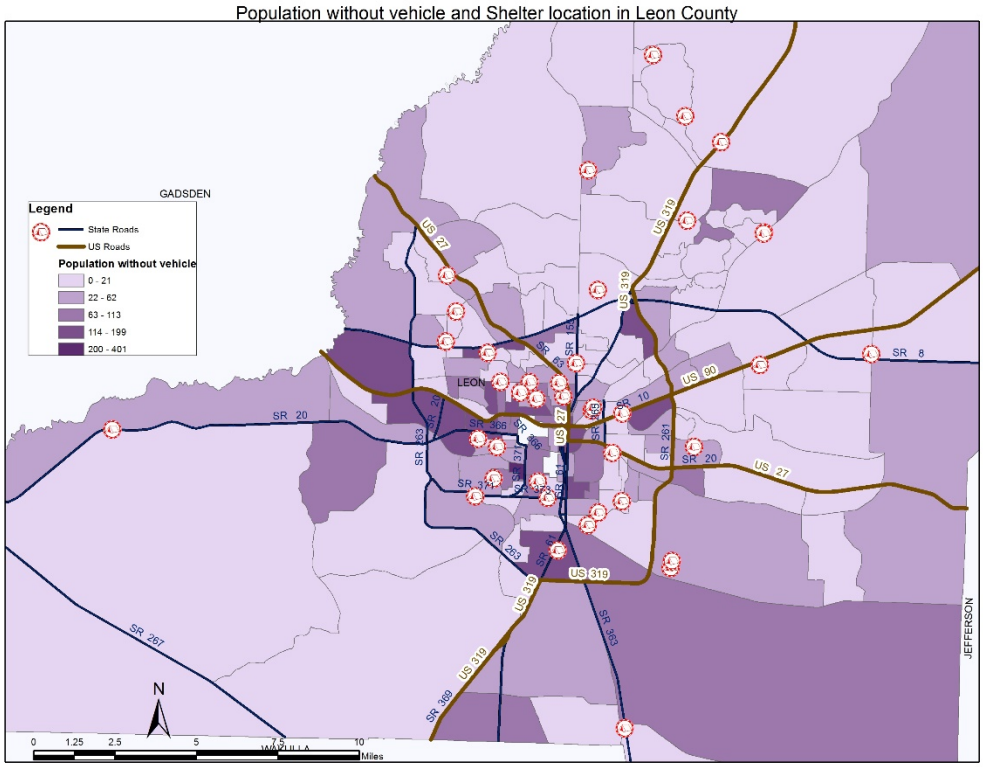



*FLORIDA STATE UNIVERSITY CIVIL ENGINEERING DEPARTMENT 2014*

Population without vehicle and Shelter Total Capacity in Leon County




*FLORIDA STATE UNIVERSITY CIVIL ENGINEERING DEPARTMENT 2014*

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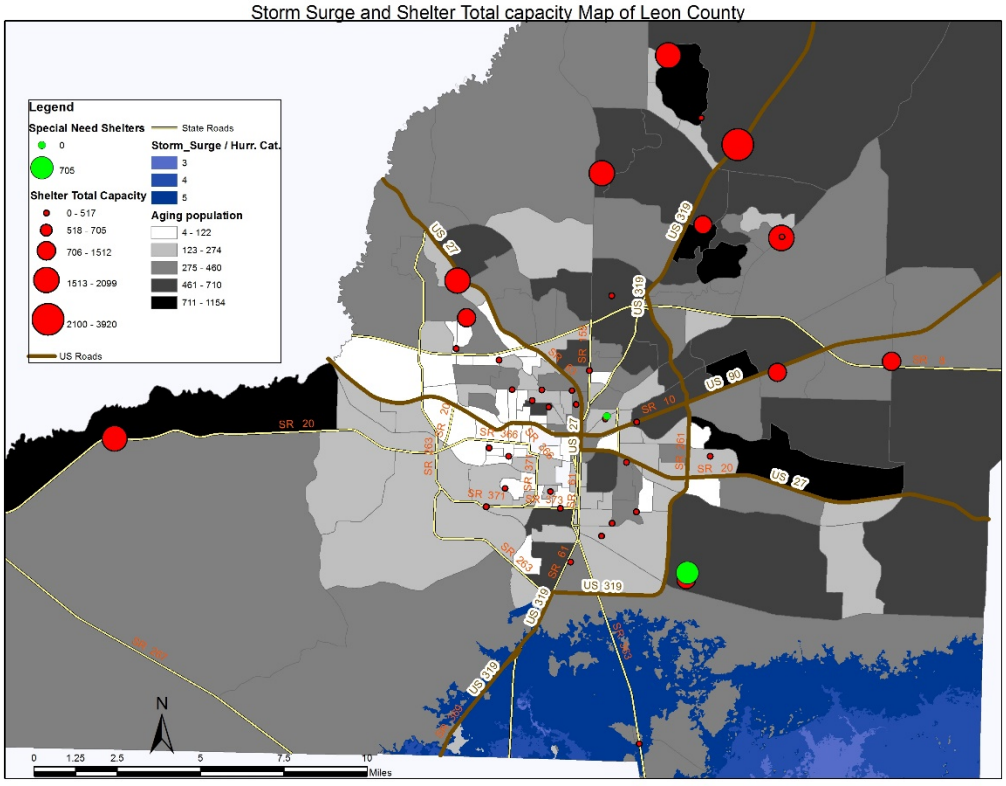


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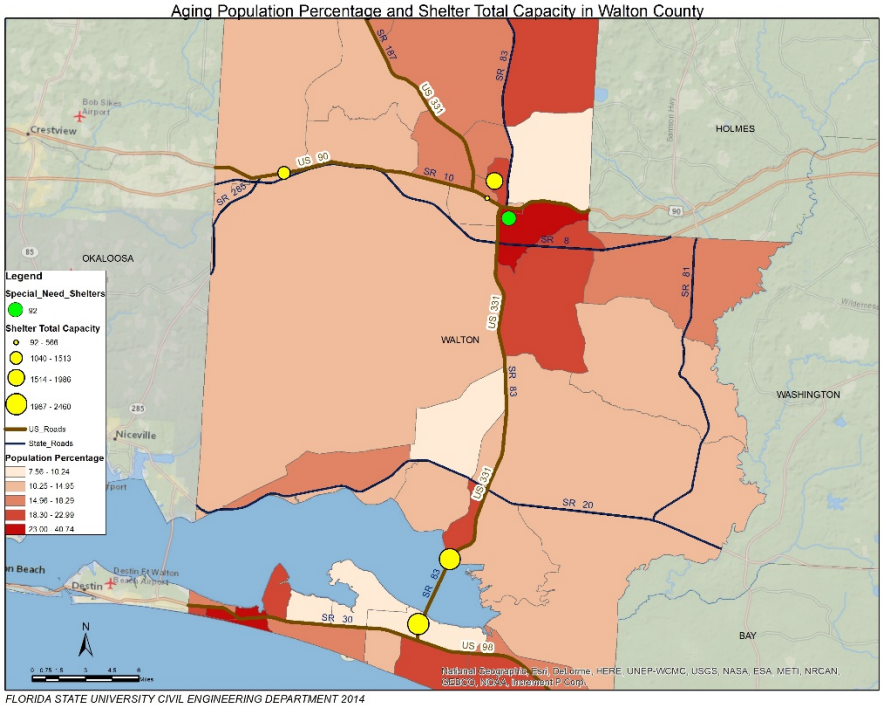
**Figure B.1.** Leon County Maps

# Appendix C GIS Maps for Walton County

Aging Population Percentage and Shelter Total Capacity in Walton County

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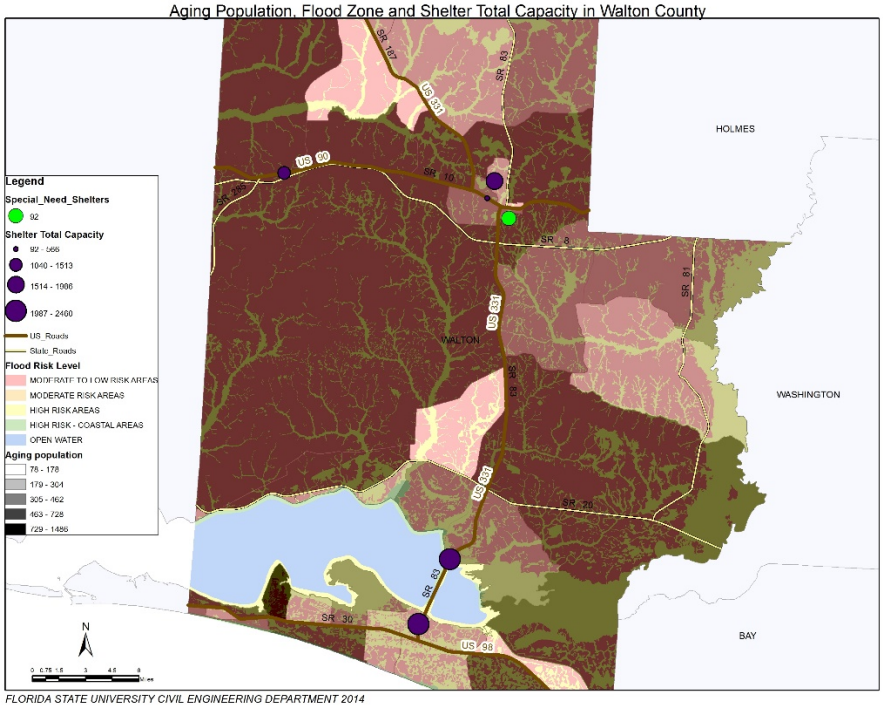
Aging Population, Flood Zone and Shelter Total Capacity in Walton County

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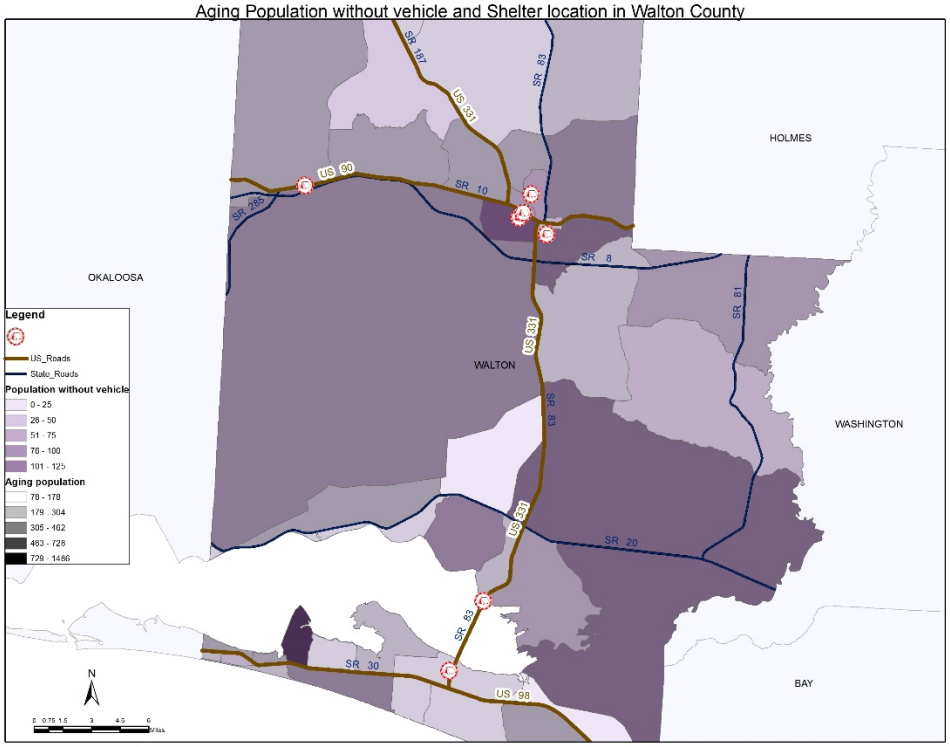
Aging Population without vehicle and Shelter location in Walton County

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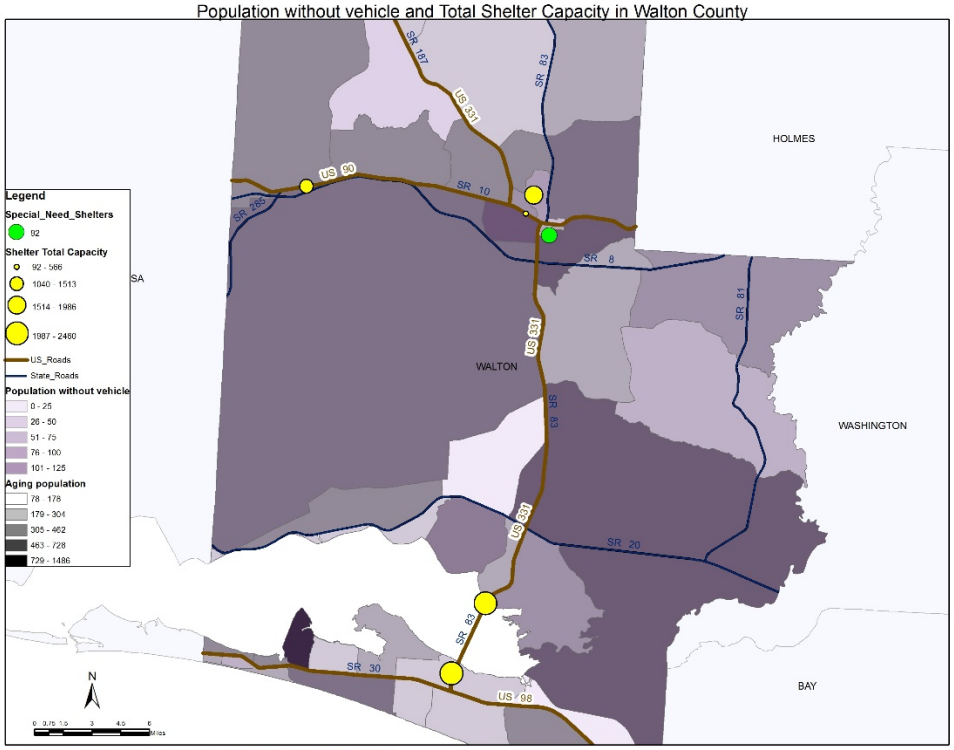
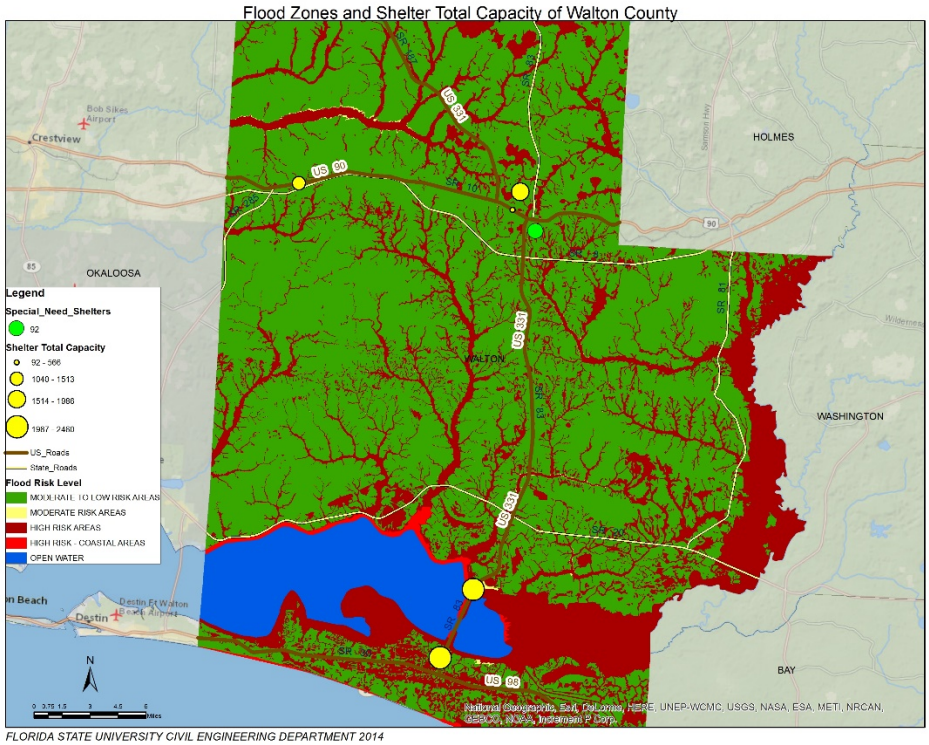
Population without vehicle and Total Shelter Capacity in Walton County




*FLORIDA STATE UNIVERSITY CIVIL ENGINEERING DEPARTMENT 2014*




*FLORIDA STATE UNIVERSITY CIVIL ENGINEERING DEPARTMENT 2014*

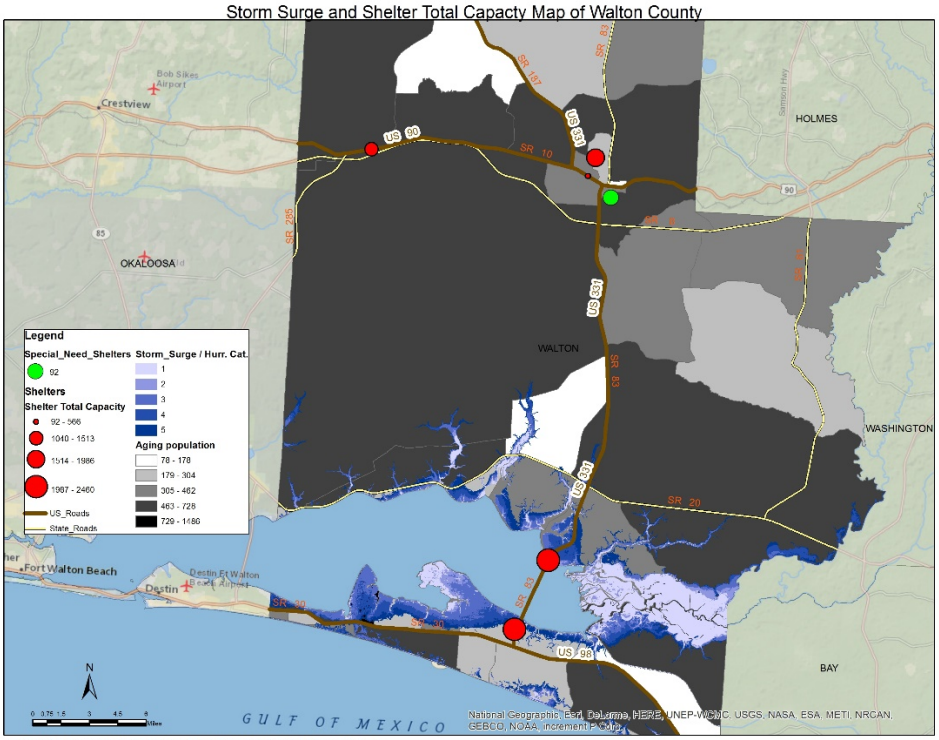



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**Figure C.2.** Walton County Maps