Walden University

COLLEGE OF MANAGEMENT AND TECHNOLOGY

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ABSTRACT

Analysis of Contingency Logistic System Reliability for Power Utilities in Florida After a Hurricane

by

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B.A.S., University of Minnesota, Duluth, 1987
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Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy
Applied Management and Decision Science in Engineering Management

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ABSTRACT

The electrical power restoration time in Florida after a hurricane is directly related to the capacity of the investor-owned utilities to provide repair. The problem is the standardized electrical power system reliability calculations do not use repair cost to represent investor-owned utility performance. Some investor-owned utilities increased residential consumer rates 20% in the year after the hurricane season. The purpose of this study is to evaluate the investor-owned utilities contingency logistic system during the Florida 2004 and 2005 hurricane seasons. The theoretical foundation of the study is reliability interference theory of contingency logistics systems using first order of reliability method to calculate the reliability index from archival data provided by the Florida Public Service Commission. The research questions focus on the association between repair cost after hurricane and electrical outage duration and the relationship to power system reliability. This quantitative study uses correlation and regression analysis to investigate the relationship between outage duration and restoration cost. This researcher determines that power system reliability along with electrical outage duration can be used to evaluate the cost of the investor-owned utilities' contingency response after a hurricane. The results indicates that the average time to restore power after a hurricane is 22 hours with a mean cost of 110 million dollars per investor-owned utility. Implication for positive social change is the evaluation of investor-owned utility post hurricane repair cost can insure related consumer rate decisions are justified by the actual impact to the electrical infrastructure.

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DEDICATION

This dissertation is lovingly dedicated to my wife, Mary Jill Van Damme Monaghan. My wife is an extremely intelligent and hard working individual. She has been my soul mate for nearly thirty years and will be forever. I also dedicate this work to my son and daughter. When Riley and Nina told friends and teachers that their Father was working on his doctorate I am sure it was with pride. I hope that I am an example to them that learning is enjoyable, necessary and never ending. I want thank them for their love, support, and patience with this process.

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CHAPTER 1: INTRODUCTION TO THE STUDY

Introduction

In the years 2004 and 2005, the power system in Florida was impacted with multiple long-duration outages caused by hurricanes crossing the state. The hurricanes struck the state of Florida within a short period of time during the summer of 2004 and again in 2005. Several hurricanes created wind paths that crossed or overlapped the same geographic areas (Blake, Jarrell, Rappaport, & Landsea, 2007). The Florida Public Service Commission (2007) stated that “The primary lesson learned from studying the 2004-2005 hurricane impacts is that a high level of storm preparation in Florida is essential”(p. 28).

The contingency logistics system used to provide the material to restore power was stressed to meet the increased demand. The Florida Public Service Commission (2007) reiterated the need for enhancement to natural disaster recovery programs for electrical utilities. The intent of this study was to evaluate the contingency logistic system resulting from the eight hurricanes that impacted Florida using repair cost and duration of the power outage reported by the utilities.

The Florida Public Service Commission was authorized by the Florida legislature to study the electrical power grid including the duration of energy disruptions impacting the citizens of Florida (Florida Public Service Commission, 2007). The power utilities complied with testimony made to the Florida Public Service Commission. Chen, Allen, and Billinton (1995) in their research determined that the amount of time that power is not available is directly related to an increase in cost. As the duration of the outage increases, the cost to restore power as well as customer material loss increases. Wakileh and Pahwa (1996) further stated, as the duration of the power loss increases, and more customers are impacted by the loss of power, the difficulty for the utility to restore power also increases. The duration of the outage, therefore, has a direct bearing on the ability to restore power and the cost to the utility.

The state of Florida is continuing to expand its population. The increase in population drives the electrical power consumption within the control area of the Florida Reliability Coordinating Council. Florida Power & Light (2006) asserted in their storm restoration plan when a hurricane strikes Florida the power system becomes vulnerable to the impact of wind. Wind effects on the power system create damage to the components. For example, the electrical power system is mainly built from overhead suspended electrical conductors with electrical poles made of wood, concrete, or steel which makes the electrical poles susceptible to wind damage (Florida Power & Light, 2006).

The Florida Reliability Coordinating Council and the Florida Public Service Commission require the electrical system operators to report the electrical system outage impacts in a series of reliability equations. The equations and calculations are reported annually and are available to the public. (North American Electric Reliability Corporation, 2007).

In Florida the Public Service Commission requires a report to be provided by the electrical utilities to identify the storm restoration cost after a hurricane has struck. These data are publicly available and given in testimony before the commission. These data impact the rates paid by consumers (Florida Public Service Commission, 2008).

A contingency logistic system develops in response to the immediate need to provide a large amount of material in crisis areas (Thomas, 2002, p. 61). Thomas (2002) reasoned that the reliability of the contingency logistics supply chain is based on the ability to provide the needed parts and materials. His analysis was based on the assumption that failure occurs when a part cannot be delivered or the delivery is delayed. According to Thomas, the environment and the configuration of the supply chain determine the conditions for success.

The electric utility business has changed from a resource-based industry with regional electrical generation to a market-based industry with large-scale generation and transmission. Deregulation of energy, cost, system reliability, and increased demand influence the capability of the electrical power system to perform. The U.S. Department of Energy (2004) asserted that the demands on the transmission grid of the United States have increased without major upgrades in generation or replacement of equipment in use beyond normal service life, while there has been a promotion of development in flood zones and coastal areas susceptible to weather extremes.

The nature of labor and material management has evolved to computer-based maintenance management systems that use enterprise resource planning to identify and track material and labor activities throughout the corporation (Hughes, 1999). The result of the enterprise resource planning is that cost is identifiable to specific issues.

Problem Statement

The restoration of electrical power to customers of an investor-owned utility in Florida after a hurricane is dependent on the capacity of the utility to provide repair. The electrical power restoration time in Florida after a hurricane may be extended due to the capacity of the investor-owned utilities contingency logistic system to provide the repair material. The problem is the standardized electrical power system reliability calculations do not use repair cost to represent investor-owned utility performance. Hurricane repair cost can impact to utility rate structure paid by consumers. Some investor-owned utilities increased residential consumer rates 20% in the year after the hurricane season (Smith, 2006, p. A11).

This research sought to ascertain if the outage duration time and the contingency logistics system repair cost can be used to determine if the restoration was reliable when a hurricane impacted the electrical system in Florida. Power system restoration cost and power system outage duration influence the investor-owned utilities profit in Florida due to the inevitability of hurricane events. Repair cost can be directly impacted by the ability of electrical utilities to receive material. The damage caused by a hurricane increases the normal amount of material required by a power utility. The increase in the amount of material is directly reflected in the cost of the material used as reported to the Florida Public Service Commission.

The specific area of research was the reliability of the supply chain of critical parts to restore power and return the power system to service. The power system supply chain reliability after a hurricane in Florida may be determined with the factors of repair cost and outage duration. Use of the factors of repair cost and outage duration was possible because the association between the two factors indicates correlation. This research examined the individual investor-owned utility association for each hurricanes cost of repair and outage duration to evaluate if these factors can be used to calculate the reliability of the contingency logistics supply chain to provide the material needed for electrical utilities in Florida after a hurricane.

Nature of the Study

This researcher examined the impact of hurricanes on the electrical power system that occurred between 2004 and 2005 that caused major electrical events in Florida to determine trends in repair material needs. In addition electrical power reliability information was reviewed, and the cost of electrical repairs during this period was studied to determine if the association between or within this data provides an estimate of correlation. The evident correlation allows these data to be used to determine the contingency logistics supply reliability.

This study examined the major events of severe weather due to hurricanes and the large-scale blackouts that resulted. The nature of the study was correlational, focused on known variables of electrical restoration cost, equipment reported used, and electrical reliability factors caused by hurricane events in Florida. Numerical data were collected from the Florida Public Service Commission, Florida Reliability Coordinating Council, and the U.S. Department of Energy. Statistical analysis was used to determine if a correlation occurs between post hurricane outage duration, electrical repair cost, electrical system reliability, and contingency logistics supply reliability.

Research Questions

1. Is there an association between hurricane repair cost and electrical outage duration?

2. How is the cost of repair after a hurricane related to electrical power system reliability?

Hypotheses

H_1: There is correlation between repair cost and outage duration; that is, $\rho \neq 0$.

H_2: There is an association between contingency logistic system cost of repair and the electrical power system reliability for a hurricane.

A detailed discussion of the aspects of the contingency logistic system and electrical power system reliability after a hurricane can be found in chapter 3.

Purpose of the Study

Electrical distribution is critical in maintaining national security. In addition, it is essential in maintaining the health care and standard of living for industrial, commercial, and residential customers (Lewis, 2006, p. 19). The U.S. Department of Energy tracks major electrical disturbances to provide data for industry and government agencies to increase reliability. In some areas major electrical disturbances have provided an incentive for an increase of electrical power use rates.

The U.S. Department of Energy Office of Electricity Delivery and Energy Reliability reports major events as official energy statistics from the U.S. Government (Makens, 2006). The goal of this research was to evaluate the contingency logistic system repair cost and the electrical power system reliability when a hurricane impacts Florida. The purpose of this study was using the hurricane data from the 2004 and 2005 hurricane seasons in Florida to determine if the repair cost in a contingency logistics system correlates to the duration of the power loss for power utilities. Then using the cost and duration calculations, the reliability of the contingency logistics system was determined. Finally, the study was used to determine if the power system reliability indices and the contingency logistic system reliability factors could be used to evaluate the performance of an electrical power system during and after a hurricane.

Theoretical Base for the Study

Major events, such as extreme weather, have been the focus of the contingency planning with the main focus being mitigation after the event occurs (Zerriffi, 2004). Zerriffi researched the effects of long-term stress on the reliability of electrical power generation but he ignored extreme weather events.

The theoretical basis for the study is that supply chains are impacted by catastrophic events like a hurricane. The supply chain must meet the requirements of delivery of material in a reliable manner (Thomas, 2002). To quantify the reliability of the supply chain Thomas used reliability interference theory (Thomas). This study applied Thomas's supply chain reliability calculations to factors relating to electrical restoration after a hurricane in Florida.

The underlying question is whether benefit may be found by using power system reliability to evaluate post hurricane supply chain. No research was discovered performing this type of analysis on investor-owned utilities.

Definition of Terms

Alternating current (AC): An electrical current reversing direction at a frequency in North America of 60 hertz (Cassazza & Delea, 2003, p. 2).

Contingency logistic system (CLS): "A set of processes and methods for providing the procurement, distribution, storage and transportation of people, supplies, materials and equipment for supporting contingency operations (Thomas, 2002, p. 61).

Direct current (DC): Voltage and current that operates at a constant level .(Cassazza & Delea, 2003, p. 27).

Distribution: Connects the electrical bulk power (transmission) system to the individual customers (Cassazza & Delea, 2003, p. 85)..

Electrical demand: The average level of use over a short period of time. The demand constantly fluctuates depending on customer use. (Cassazza & Delea, 2003, p. 44).

Electrical utility: Is the term for an electrical service company that provides electrical power (for a fee) to consumers (Cassazza & Delea, 2003, p. 1)..

Generation: Is the process that converts fuel or physical energy into electrical energy . (Cassazza & Delea, 2003, p. 2).

Grid: The arrangement of transmission lines tied together to provide delivery paths from the generation stations to the distribution systems. Often called the transmission grid or "the interconnection" (Cassazza & Delea, 2003, p. 21).

Independent System Operators (ISO): The electrical transmission system is operated by an independent corporation under the direct monitoring of the Federal

Energy Regulatory Commission that purchases electrical power within a deregulated electrical market, calculates available transmission capability, schedules maintenance, has control over the operation of transmission, and ensures reliable operation (Casazza & Delea, 2003, p. 167).

Investor-owned utilities: Electrical power companies owned by stockholders (Philipson & Willis, 2006, p. 17)

Municipal Utilities: Communities that own and operate the electrical utility within the geographical area of the city (Philipson & Willis, 2006, p. 18)

Outage: The loss of electrical power. (Institute of Electrical & Electronics Engineers, 2004, p. 3)

Regional Transmission Organizations (RTO): The electrical transmission system is operated by a regional non-profit corporation under the direct monitoring of the Federal Energy Regulatory Commission and Regional regulating bodies. They purchases electrical power within a deregulated electrical market, calculates available transmission capability, schedules maintenance, has control over the operation of transmission, and ensures reliable operation. (Casazza & Delea, 2003, p. 170).

Reliability: The electrical power system evaluation of possible consumer consequences (Cassazza & Delea, 2003, p. 120).

Transmission: The portion of the electrical system that transmits power from generation stations to substations that distribute the power (Cassazza & Delea, 2003, p. 73).

Voltage sag: The condition where the voltage of the system drops below a defined minimum value (U.S. Department of Energy, 2006).

Voltage spike: The condition where the voltage of the system exceeds the defined maximum value (U.S. Department of Energy, 2006).

Voltage stability: The maintaining of the system voltage at defined upper and lower points (U.S. Department of Energy, 2006).

Abbreviations

AM/FM. Automated Mapping / Facility Management

BAS. Building Automation System

CAD. Computer Aided Design

CAFM. Computer Aided Facility Management

CAIDI. Customer Average Interruption Duration Index

CLS-p. Contingency Logistics System Failure Probability

CMMS. Computerized Maintenance Management System

CFO. Chief Financial Officer

CFR. U.S. Code of Federal Regulations

corr. correlation

COTS. Commercial-Off-the-Shelf

DBMS. Data Base Management System

Df. Degrees of Freedom

DOE. U.S. Department of Energy

ERP. Enterprise Resource Planning

FERC. Federal Energy Regulatory Commission

FPA. Federal Power Act

FPL. Florida Power and Light

FRCC. Florida Reliability Coordinating Council

GIS. Geographic Information System

GULF. Gulf Power

IEEE. Institute of Electrical and Electronic Engineers

IOU. Investor-owned Utility

ISO. Independent Service Operator

JIT. Just In Time

mph. miles per hour

NERC. National Electrical Reliability Council

NESC. National Electrical Safety Code

OMS. Outage Management System

OPF. Optimal Power Flow

PEF. Progress Energy Florida

PSC. Public Service Commission

PUHCA. Public Utility Holding Company Act

REA. Rural Electrification Act

RTO. Regional Transmission Organization

SCADA. Supervisory Control and Data Acquisition

SAIDI. System Average Interruption Duration Index

SAIFI. System Average Interruption Frequency Index

TECO. Tampa Electric Company

TVA. Tennessee Valley Authority

USD. United States Dollar

Assumptions, Limitations, and Scope

The assumptions made are based on the testimony provided to the Florida PSC and FRCC, as well as reports to the Energy Information Administration of the DOE. The testimony provided by the utilities is assumed to be factual and the verification was performed by a government agency or regulatory body. The data for this research were derived from that testimony. The weakness in the study is that direct contact was not made with the individual investor-owned utilities.

The evaluation was based on the supply of electrical materials to the utilities and the impact of restoration of power distribution to areas impacted by hurricanes in Florida. It is assumed that the supply of electrical materials within the reports is reflective of all electrical power restoration materials. The specific assumptions in the analysis of the material supply chain are stated in chapter 3.

One limitation is that some hurricane expenses may not have been provided by the electrical utilities. A further limitation is that power distribution repair is associated with the transmission to the areas impacted and may not reflect the number of customers without service.

The scope of the study is the impact of hurricanes on the state of Florida during the 2004 and 2005 hurricane seasons. The study is delimited to the 2004 and 2005 hurricane seasons because the reporting mechanism has been standardized within that time frame and the reports are consistent in content.

Significance of the Study

Hughes (1986) summarized the social impact of the electrical power industry in North America.

> Modern systems are of many kinds. There are social systems, institutional systems, technical systems, and systems that combine components from these plus many more…. An example of such a technological system...is an electrical power system consisting not only of power plants, transmission lines, and various loads, but also utility corporations, government agencies, and other institutions…. Problems cannot be neatly categorized as financial, technical, or managerial; instead they constitute a seamless web…. Engineering or technical improvements also require financial assistance to fund these improvement(s) and managerial competence to implement them. (as cited in Casazza & Delea, 2003, p. 5)

The electrical power grid is an interconnection of regulatory bodies, financial institutions, and technological impacts. Fuel impacts caused by a hurricane in the Gulf of Mexico affect the entire energy supply chain throughout North America (Lewis, 2006, p. 298). Development of the large geographical electrical power interconnections means that a generation impact in the Northeast can affect power systems from Florida to Manitoba.

This study, using a quantitative case study method for evaluating the electrical supply chain reliability using contingency logistic supply repair cost and outage duration after a hurricane in Florida, provides implication for social change by development of useful information for logistics planning, emergency recovery plans, and emergency support facilities to determine how long before there is electrical power restoration. Further implication for positive social change is the evaluation of investor-owned utility post hurricane repair cost can insure related consumer rate decisions are justified by the actual impact to the electrical infrastructure.

Summary

The state of Florida has always been impacted by hurricanes. The impact when a hurricane strikes the state is becoming greater due to the increase of people moving to the state (Smith, 2005). By the year 2030, the population is projected to be 25 million people with 26% of the people older than 65 (Smith, 2005, p. 35). Electrical power requirements will increase with the increase in population. The impact of a hurricane will increase with the added and older population. By understanding the electrical power impact of a hurricane, plans can be made to prepare for the storm or provide adequate information to the population on the electrical impact.

Chapter 2 is a review of the current literature on the power system industry and deregulation. Deregulation has a major impact on which agencies have responsibilities in the restoration of the electrical system. The articles will be reviewed, and their relevance to the security of electrical systems will be discussed to provide meaningful information for the study.

Chapter 3 is an examination of the current reliability calculations used in the federal and state regulatory systems. The available data from the federal and state regulatory agencies is discussed. The material reliability calculations are detailed in chapter 3 indicating how the required components of the data were analyzed.

The collection of the data and the calculation of the results are performed in chapter 4. The finding of the correlation existence between repair cost and outage duration is detailed. The data was then used to calculate the probability index and validated using regression analysis.

The summary and conclusion of the findings is detailed in chapter 5 identifying possible investor-owned utilities that need additional research. The recommendations point to the need for the Florida Public Service Commission to use the calculation of the reliability index to determine if the hurricane responses are within parameters. A discussion of the social impact identifies that the information is of use to public emergency response agencies.

CHAPTER 2: LITERATURE REVIEW

Introduction

The current literature relating to the North American electrical grid and electrical power restoration are reviewed in this chapter. This literature review was developed to provide the reader with an understanding of the current structure of the North American electrical grid, how the grid was established, and the concepts used to restore electrical power. The literature review starts at the macro level and narrow down to the function of power restoration with a focus on hurricanes in Florida. A review of the literature on computerized maintenance management is included to research how power corporations track the materials and maintenance of the power systems. The literature review was performed using the resources of the Walden University online library, the IEEE online library, IEEE Power Engineering Society publications, INFORMS online library, and books related to the electrical power system.

Introduction to the North American Electrical Grid

The U.S. Department of Energy (2006) stated that electric power has become integrated into every facet of modern life. North American industry relies on electric energy to produce goods, commerce relies on electric energy to deliver and market goods, and individuals rely on electric energy to provide comfort for their homes. Reliable and inexpensive electric power in the United States and Canada is critical to both economies.

Households from the southern United States to northern Canada rely on inexpensive and reliable electric power. Electric power is expected to provide energy whenever a light switch is turned on, an air conditioner runs, television is watched, clothes are washed, or food is refrigerated (U.S. Department of Energy, 2006). Electric power is trusted to preserve a safe and comfortable physical environment.

The United States and Canada have come to expect electric power to be available during all demand levels levied on it by customers and perform in all types of weather. Loss of electric power during any weather extreme is dangerous to the people affected. The U.S. Department of Energy (2006) stated that capacity to provide inexpensive and reliable electric power in an extreme environment has allowed people in the Untied States and Canada to live in these environments successfully.

Electric power used for distribution to customers and in households is alternating current (AC) because of its ability to carry electric power over a long distance with limited energy losses. AC electrical power cannot be collected and stored for future use (Lovins & Lovins, 1982). Electricity must be used as it is created and a standby capacity of electric power must be available upon demand. To preserve the constant and consistent flow of electricity an interconnection of generation, transmission, and distribution occurs from the electrical grid to the service supplying a home, business, or industry.

The failure of electric power to perform at the transmission and distribution level is often because of a fault (Gross, 1993) or may be because of the inability to provide electrical generation to support the demand. There are two major faults that occur in electric power. There is the short circuit fault, which is an undesirable added flow of current, and the open circuit fault which is a blockage of current flow. Faults, or loss of generation capacity, cause the loss of voltage stability and eventually the loss of power to customers.

Upholding voltage stability in electric power distribution can mean anything from prevention of voltage sag lasting a quarter of a second to prevention of a total loss of electric power. A total loss of electrical power is regarded as a major electrical event and is reportable to the U.S. Department of Energy Emergency Operations Center within 24 hours (2006).

Voltage sag can, over time, damage sensitive electronic equipment and cause a cascading effect leading to severe damage to other equipment (Bendre, Divan, Kranz, & Brumsickle, 2006). Voltage sags happen daily in some areas; these sags are not reported and often are not noticed. Voltage sag can happen when voltage is affected by a current related fault. A short circuit will cause a voltage spike and occurs when the normal waveform becomes distorted. Voltage sag can also occur when the circuit is opened. The open circuit condition in large transmission systems occurs during switching conditions when the electrical substation selects a different power system to support the distribution system. The open circuit can occur when equipment failure, environmental conditions, or a physical act impact the electrical system. The modern electrical generation, transmission, and distribution equipment can adjust to the voltage sags through automation. The social impact of voltage sags may be small, but such sags can trigger a major electrical event.

Warren (2002) stated that power utilities could be failing to report major interruptions due to a vague definition in the 1998 version of the *Full Use Guide for Electrical Power Distribution Indices* (Warren p. 650). The 1998 version of the guide stated that a utility needs to report the event only when it exceeds the electrical design of the system (Warren). The IEEE (2004) released the latest standard and narrowed the power distribution reliability classification to a major event if it exceeds the design capacities of the power system and 10% of the customers are impacted.

Power companies reported major events to the state public service commission, the FERC, and DOE when an electric power fault lasts for more than 5 minutes (Bendre et al., 2006). The authority to report a major event is derived from the Code of Federal Regulations Title 10 Volume 4 (2005) and the Federal Energy Administration Act of 1974.

Faults, which are the inherent causes of major events in the loss of electric power, can be physical events like an automobile collision, aircraft collision with electric power lines, vandalism or sabotage, weather, and electric equipment problems (Gross, 1993). Faults can also occur from heat stress on electric equipment because of increased load. The effect of equipment loading problems is worsened by the aging electrical system and the practice of run-to-failure. The run-to-failure practice is where the utility does not proactively replace old equipment but waits until the failure occurs and then mobilizes resources to make rapid or hasty repairs (Smith, 2006). Extreme weather exacerbates the impact to electric stability by increasing stress on aging equipment.

Some stress on electrical transmission occurs from the congestion caused by the electrical market. Bose (2006) asserted that congestion on transmission is caused by real-time automatic load changes, transmission line capacity not large enough to move generation to load, load increases in an area without transmission or generation increase, and mandatory maintenance on equipment.

To send electrical power from the power plant, large transmission towers are used to safely suspend electrical conductors. The transmission line ends and connects into local substations which allow for switching between transmission lines, transformation to lower voltages, and distribution to local areas. The distribution lines carry electrical power to service drops supplying homes and businesses. Pansini (2004) found that in cities and housing developments the most common form of transmission and distribution is electrical cables.

Development of the Electrical Power Grid

As the power system developed in North America the individual local electrical utilities began a process of transmission line development to share electrical resources. The interconnection and operation of the large-scale grid is difficult to achieve when it is not operated normally and provides a new level of complexity in difficult situations (Lovins & Lovins, 1982). Lovins and Lovins determined that the electrical system was the most vulnerable of the major energy systems. The possibility of the power system being severely crippled by damage to a few substations or transmission lines could mean weeks of power loss and rolling blackouts for a year. Lovins and Lovins argued that the federal government needed to look at electrical power in terms of vulnerability and resilience. In the electrical power industry this means to examine the integrity and reliability of the regional grids. Lovins and Lovins complained that the programs in place by the federal government focused more on energy savings rather than on evaluation of renewable resources that are not vulnerable.

Lovins and Lovins (1982) did conclude that the free-market approach to energy will benefit the electrical industry. Their book was written in the era of the Reagan administration which evaluated programs by the effectiveness in the market. Cost effective nonsubsidy programs would hasten the use of resilient technologies according to Lovins and Lovins (p. 297). They predicted the Reagan administration programs of research into new technology and the decreasing of the industrial barriers will enhance the productivity and efficiency of the electrical system.

Lovins and Lovins (1982) believed a consistent policy by the federal government is needed to move toward the deregulation of the cost of electrical energy. Price deregulation would provide the incentive for resilience in electrical energy. The price of electricity (in 1968 dollars) has decreased since the early development of electrical power (p. 336). The reason for the trend is due to the generation plant becoming larger and moving further away from the customer. The movement of generation further away created a condition where the transmission of power is necessary over long distances. Lovins and Lovins concluded that large transmission lines were susceptible to impacts that would shut down the electrical system. Lovins and Lovins believed that smaller localized generation would provide better reliability or resilience. The deregulation of prices would create a condition that would encourage smaller and more localized generation, according to Lovins and Lovins.

Zeriffi (2004), in research on centralized and local electrical generation, determined that distribution of the generation to smaller micro-grids would increase the reliability of the electrical power. Zeriffi's research was not in single event effects to a large centralized electrical power grid, but dealt with the long-term impact due to lack of maintenance and under-investing in equipment on smaller distributive microgrids. Zeriffi concluded that the decentralized electrical system eliminated the need for a large reserve power margin required in large centralized systems. Zeriffi further determined that the smaller distributed electrical microgrid would have a smaller impact in the event of a failure and therefore have a higher rate of reliability.

By 1982 most transmission and generation was under the control of large power corporations. The power utilities grew out of an industry that less than 100 years earlier did not exist. The electrical power industries had to not only deal with the technological issues of producing electricity but had to create a means to deliver it to its customers and charge for its use (Philipson & Willis, 2006). Around the 1930s with the advent of radio the demand for electrical power increased dramatically and in the 1940s the prevalent public attitude was that electrical power was needed in every home (Philipson & Willis). In the 1960s the application of air conditioning in homes increased and is the majority of the electrical usage in some areas.

The electrical power industry evolved from the localized generation originally thought of by Edison to larger generation systems promoted by Westinghouse. The electrical utility in the early years were smaller and investor-owned. In the 1950s the smaller utilities were merged into larger corporations (Philipson & Willis, 2006). The states and local municipalities began to regulate the power industry in the 1950s in order to control and stabilize prices, according to Philipson and Willis.

Legislative Changes to the Electrical Grid

One of the largest impacts in the creation of the North American electrical system is the legislative impacts, according to Casazza and Delea (2003). The regulations and overlapping governmental agencies have created constraints upon the electrical industry that are inconsistent with the laws of physics, have increased costs, and decreased reliability (Cassazza & Delea). Prior to 1935 the regulation of electrical energy as a commercial industry was limited to the state governments. In reaction to the acquisition of smaller utilities by holding companies in a race to monopolize the industry the Public Utility Holding Company Act (PUHCA) was created. The purpose of this act was to insure that adequate financial securities backed the creation of the utility corporation, limit the geographic area of the company, and limit holding company external business affiliations. PUHCA of 1935 in effect created the large electrical utilities by preventing new electrical companies from being created and involved with the interstate electrical market. In 1938 there were 216 electrical utility holding companies; by 1958 this number was reduced to 18 due to acquisition (p. 139).

Along with PUHCA of 1935 was the Federal Power Act (FPA) that created the Federal Power Commission to govern interstate transmission and transactions concerning electrical power. The Federal Power Commission divided the country into five districts for the purpose of creating a voluntary system of electrical power interconnection and coordination (Cassazza & Delea, 2003). The Federal Power Commission had the authority to order a utility to physically interconnect with the electrical system.

In the 1930s the federal government became involved with the creation of two electrical utilities. The Tennessee Valley Authority (TVA) and the Bonneville Power Administration were created and were allowed to sell and market electrical power funded through the federal government. The Rural Electrification Act (REA) in 1936 placed the federal government as the financier of power utilities in rural areas. According to Cassazza and Delea (2003) these governmental businesses and financial responsibilities are still in effect.

In 1977 the DOE consolidated all the energy agencies and replaced the Federal Power Commission with the FERC (Cassazza & Delea, 2003). A series of acts in 1978 passed as the National Energy Act opened the door for the smaller electrical generating entities to enter the utility market. The Public Utilities Regulatory Act (PURPA) required utilities to purchase power from the smaller qualified generators at the market price while bypassing the restrictions of PUHCA. PURPA was created to encourage the use of an alternative energy source to create electrical power in response to the sharp increase in the price of fuel and corresponding increase in the price of electrical power. Cassazza and Delea (2003) stated that the long-term effect of PURPA was that it encouraged and "introduced competition into the generation market" (p. 143).

All states regulate the price of electrical power in some manner according to Cassazza and Delea (2003). The oversight of the electrical industry within the state is allowed by federal regulation. But the recent move toward deregulation has placed some state public utility commissions in opposition to federal energy policy (Cassazza & Delea). Most states have developed varying degrees of deregulation or are in the process of deregulating the power industry, with the exception of Florida which does not intend to deregulate.

The Energy Policy Act of 1992, FERC order 889, and FERC order 888 completely changed the electrical industry. The regional power utilities were now required to purchase power from all qualified generators and allow all generators to use the transmission and distribution lines under their control (Lewis, 2006, p. 256). The national electrical grid created by these actions allowed the wholesale price to fluctuate. The federal government has jurisdiction due to the interstate commerce of the wholesale electrical market (Lewis). The retail prices are fixed by the state for political reasons (Lewis). A major problem exists because the wholesale market price of electrical generation fluctuates while the retail consumer price is fixed by state regulation. In the middle is the electrical grid or the transmission line that is the connection point for generation, the source for the consumer, and the most vulnerable point in the electrical system (Lewis). Lewis stated that the transmission and distribution by an electrical power grid cannot deliver all the generation available and becomes congested in specific areas when the demand cannot be met.

Deregulation of the Electrical Power Grid

The design of the electrical generation and transmission system throughout the United States and Canada is an interconnected transmission grid which allows for major large generation. A sudden loss of the transmission or generation because of a major event can cause the electrical distribution system to separate from the electrical grid and form individual islands of power (Feltes et al., 2006). The individual electrical power island must be able to handle the demand levied on it by the consumers of the local electrical distribution. The ability to handle the electrical demand within an area of generation was the concept of large monopoly-based utilities.

Philipson and Willis (2006) stated that the generation of electricity developed over years into an electrical utility that would generate, transmit, distribute, and sell electricity to a customer. The electrical utility operated as regional governmental authorized monopolies. The electrical utility controlled the price for electricity within their region of control. Sharing of resources and transmission authorizations were negotiated by the electrical utility in control of their localized region. Prior to the federal laws that began deregulation, 250 major utilities controlled 85% of electrical power in the United States (p. 14).

Casazza and Delea (2003) stated that in the year 2000 the DOE reported that 74.2% of the electricity was generated by electrical utilities. The electrical utility generation was made up of 51.2% investor-owned utilities, 3.9% rural cooperatives, 10.6% nonfederal utilities, and 8.3% federally owned utilities (p. 6).

Deregulation was intended to divide the electrical utilities into separate functions of generation, transmission, and distribution with the intention of establishing competition to lower cost to the consumer. Deregulation of the electric utilities began in 1992 and has created an electrical grid system where transmission lines and large power plants have replaced smaller local generation (Pansini, 2004). The large electrical transmission grid now provides most of the support to the local distribution equipment. According to Pasini, the move from local generation to the transmission grid network was intended, for economic reasons, to allow public utilities and smaller power companies to receive ideal pricing in the market.

The United States and Canada are separated into three separate power grids or interconnections. The eastern interconnection contains the eastern United States and Canada from the Hudson Bay to the Gulf of Mexico, the western interconnection contains the western United States and Canada, and the third interconnection is the state of Texas (U.S. Department of Energy, 2004). The three interconnections are electrically independent. The National Energy Reliability Council (NERC) is divided into 10 regional councils that make up various parts of the interconnections. The regional councils oversee the reliability of the electrical interconnections. Within the regions are control areas that are made up of Independent System Operators (ISO) or Regional Transmission Organizations (RTO) that maintain the power system boundaries. The ISOs and RTOs are overseen by the NERC, the U.S. Department of Energy, the Office of Electricity Delivery & Energy Reliability, Natural Resources Canada, and the state Public Service Commission (PSC). The ISO or RTO controls the transmission lines within their area of control and communicates with adjacent ISO's or RTO's. The ISO or RTO levies tariffs in a deregulated area on the use of transmission. Bose (2006) stated that in a state where deregulation is not in effect the state PSC establishes the boundary of tariffs levied to customers and awarded generators.

The control exercised by the ISO or RTO defines the optimal generating unit commitment requirements for the next day or a week. They must forecast the amount of generating capability that must be available to meet local demand. The forecast model plans are used to identify the rates levied on the retail suppliers. The ISO or RTO operates the electrical grid in a manner to provide Optimal Power Flow (OPF). Gribik (2006) identified that the 24-hour in advance plans are used to identify the desired generation through the electrical transmission grid to guarantee the OPF. The usage rate or cost of electricity is determined in advance. The advance electrical utility rate is determined within a range as defined by individual agreements. Deregulation allows the price of electrical power to be defined based on a market. The daily use rates are defined or approved in states controlled by a PSC (Gribik, 2006). Currently only the state of California is completely deregulated. Texas and New York are on the verge of deregulation in the electrical transmission system. Shirmohammadi (2006) stated that deregulation will eventually migrate to all states as the NERC develops stable markets in transmission and the cost of new generation and transmission is met. The quantified economic benefit of deregulation is it provides lower reserve generation cost, lower generation cost, and an increase in reliability.

In the 1990s deregulation began and failed due to the federal government deregulation initiatives and the states maintaining local price controls. Since then the deregulation of the electrical industry has progressed at the federal level not at the state level. Philipson and Willis (2006) further concluded that deregulation needs large transmission lines in order to maintain the electrical power market. Therefore, deregulation will eventually create a large electrical grid with interconnection between the regional grids. Philipson and Willis stated that "The only way to avoid blackouts is to operate a large power grid so that it always has interconnected security" (p. 470).

The Florida Power System

According to the Florida Public Service Commission (2008) it was derived from the regulation of railroads and evolved into a state legislated agency. The members of the Florida Public Service Commission are political appointees of the governor and are approved by the legislature. The Florida Public Service Commission (2008) stated that 1951, they began regulatory authority over the electrical utilities and remains the prime approval authority for utility operational consumer oversight within Florida. The Florida Public Service Commission approves consumer utility rates, determines the transmission tariff structure, settles consumer disputes, and defines safety guidelines.

The Florida Reliability Coordinating Council (2008) stated it was established in 1996 as reliability region in the eastern interconnects operated by the NERC. The FRCC is responsible for the electrical power system interregional operation east of the Apalachicola River. The FRCC monitors the coordination within the peninsula of Florida which, due to the geography, is tied to the eastern interconnection in the North. The reliability coordinator is responsible for real-time monitoring of the Florida Peninsula and directing the action of various generators to maintain reliability of the electrical grid in Florida. According to the FRCC its first full year of reliability coordination will be in 2008 (p. 3).

In response to the FERC orders Nos. 888, 889, and 2000 each electrical utility owning transmission or distribution capability established plans for participation in a regional transmission organization (RTO) with the expectation that all utilities would be part of a RTO by 2001. The three major investor-owned utilities petitioned the FERC to form GridFlorida to be a separate investor-owned transmission corporation operating in the Florida peninsula (Florida Public Service Commission, 2007, p. 14). The FERC concluded that the GridFlorida proposal be operated as an independent system operator (ISO). The affected operators further researched the plan to create GridFlorida RTO and petitioned the FERC to not establish the consolidation of transmission as an ISO. The current transmission system infrastructure remains as part of investor-owned utilities with transmission tariff monitored by the Florida Public Service Commission.

Concerns With the Electrical Grid

The other problem with modern power systems is that most of the equipment is over 50 years old, has reached its life cycle expectancy, and will fail to operate in the next several years (Philipson & Willis, 2006). The electrical utilities have for years followed a run-to-failure operation practice. This means that the power company will not periodically replace aged equipment, but will wait until the equipment breaks and at that time will replace (Philipson & Willis p. 411). The main reason for the inability to maintain replacement levels, according to Philipson and Willis, is the cost of the equipment and the disruptions caused by the work. In many cases the electrical utility is unable to replace the equipment because of the consumer demand levels.

Lovins and Lovins (1982) described the electrical distribution in the United States as becoming increasingly susceptible to the impact of weather as well as sabotage and negligence. The effects of power loss have been disruptions in people's lives, threats to national security, and diminished production of goods. The vulnerability of the electrical grid is of great concern for the Department of Homeland Security since the demand for power has little margin in event of a disturbance (Alverez, 2004). The cost of a loss of power is difficult to quantify in terms of watt-hour loss. A 1 kilowatt hour loss verses a 10 kilowatt hour loss does not mean the impact to society has been increased 10 times (Lovins & Lovins, p. 64). The power loss in terms of cost to society is directly related to the amount of time, the warning received in order to prepare, and the amount of preparation made. The loss of power in a large city can have a major impact on the crime rate. The city's social impact may be greater depending on the societal interactions. An example was made by Lovins and Lovins by comparing the New York blackouts of 1965 and 1977. In 1965 the crime rate in New York City declined while in 1977 major riots occurred during blackouts.

The electrical transmission system is vulnerable to sudden environmental impacts which can cause major disruptions to entire regions of the United States (Brown, Caryle, Salmeron, & Wood, 2005). The regional impact response would be under the control of the regional NERC and the area ISO or RTO. The NERC and ISO or RTO control points can secure or bypass projected or immediate problem areas by rerouting electrical power to or from affected areas. The electrical generation, transmission, and distribution systems are designed to be robust enough to handle a major event caused by environmental causes (Brown et al.). In power system distribution a reliability analysis defines a design as robust when no single point failure exists and the equipment is designed for the environment it is used in (Brown et al.). Brown et al. further determined that transport systems need to use fault tree analysis to decide probability of failure, and robustness is defined as when the probability of failure is low. Current electric utility design of the national grid has created critical points of impact or boundaries that interconnect transmission systems and can worsen the effect of major disturbances.

Transmission allocations created by the ISO can cause congestion on the line into or out of an area. The ISO then must in real time switch loads to limit congestion and provide relief of the impacted transmission link (Roark, 2006). The ISO dispatches megawatts of electrical energy almost immediately. But, according to Roark, they have limitations due to the electrical grid in the area and agreements between neighboring ISOs. Weather is the main cause of the real-time changes in transmission allocations.

The changes occurring within the United States, Canada, and part of Mexico impacted by the NERC regulations are dynamic. Responsibilities for the electrical system are changing but there is a basic core concept. In all stratification of the electrical power there is an input and an output. The basic concept is that fuel is the input and electrical power is the output (Roark, 2006). Generation facilities pass on fuel cost directly through to the rate structure. Everything being equal, the fuel cost developed at the generation level determines the cost of electrical power.

The system reliability is determined by the actions of the ISO that control the real-time allocations and the amount of reserve that is available. The measurements used to evaluate the effectiveness of the ISO controls are the system average interruption duration index (SAIDI) and the system average interruption frequency index (SAIFI). The main causes of increases in these indices are equipment failure, trees due to weather, overloads due to weather, lightning due to weather, and animals connecting with the power line (Cliteur, 2006). Reliability improvements will mainly deal with the impact of weather on electrical transmission and distribution within areas controlled by the ISO or RTO instead of the previous area electrical monopolies. In areas of deregulation improvements in maintenance, replacement of aging equipment, redesign of electrical grid, and operator training are monitored by the ISO. The main issue is that the ISO operates in a reactionary planning mode. It must insure that the process is run reliably and congestion issues are satisfied in real time. DeShazzo (2006) observed that the congestion issues are increasing with demand while transmission and generation has not kept pace. There is also an issue of who is responsible for long-range planning. In the old planning process the monopoly planned with approval from the state PSC. But, as deregulation approaches everyone has input. According to DeShazzo (2006) the state PSC or regulatory agency, the NERC, the generation suppliers, as well as the major customers all have input in planning for new transmission and contingencies.

The design of the electrical system is also based on safety performance guidelines which are meant to provide safety needs for construction, operation, and maintenance (Clapp, 1992). The rules of the National Electrical Safety Code (NESC) defined grades of construction based on the environmental reasons within an area. The grades of construction are meant as safety performance guidelines to prevent contact with electrical parts because of environmental and physical conditions. In electrical transmission and distribution the NESC guidelines mean that the equipment must meet the safety standard for wind in the South Coast due to hurricanes, and changes in weight in the North due to ice.

The vulnerability of the electrical power system needs to be considered in areas susceptible to hurricanes. The IEEE (2003) established methods to calculate reliability within an area. Changes in electrical reliability, if causal or correlated to electrical disturbances, can identify to emergency managers changes required in planning. Currently there seems to be little previous research comparing repair cost and electrical system reliability.

Deregulation has dramatically affected the electrical industry, according to Philipson and Willis (2006). Supply and demand in the market determines the price of power for the customer. Generation of electrical power is competitive as the retail markets attached to the electrical transmission grid vie for optimal pricing. As the demand changes due to impacts on supply, the price changes at a macro economic scale since the electrical power grid is interconnected throughout a region.

Computer Maintenance Management Systems and Enterprise Resource Planning

Early in the 1990s downsizing of the white collar workers changed the management of the infrastructure. Downsizing, according to Teicholz and Ikeda (1995), reduced headcount and technology became a means to supplement and replace staff in the organizations. The rise of the chief financial officer (CFO) in the organizations has driven cost accounting and asset management. Information technology and automation has driven strategic scheduling techniques. Cotts (1999) stated that payoff on investment, cost reduction, and quality movements continue to drive the need to have efficiency of operations.

Unplanned equipment downtime and equipment failures can decrease production while increasing unexpected maintenance and repair costs for power utilities. The unscheduled outage of equipment, or a system, causes production shutdowns and dramatically increases the cost of electrical production. The unscheduled outage increases the costs by causing the diversion of resources to react to the unscheduled outage event. The allocation of resources required to restore operations are dependant on the needs and criticality of the equipment or system (Wireman, 1994). The efficient use of resources to restore and maintain all the equipment within the area of the outage response is time dependant.

The first goal in the power system restoration is to rebuild a stable electrical system (Ancona, 1995). A properly balanced workload is required. The restoration operations manager or engineer must determine what restoration work is required to safely restore customer service after the electrical transmission and distribution systems have stabilized. Monitoring the performance and operation of these tasks as well as the equipment records need to be maintained by the utility. Planning for contingency operations eventually feeds into the strategic plan (Wireman, 1994). Maintenance enhancements can improve the operational readiness, efficiency, or redundancy of a facility system and can decrease operational impacts.

In the past several years the increases in the use of information technology systems have led to the development of Computerized Maintenance Management Systems (CMMS) to document maintenance activities. The CMMS is the most useful tool available due to the immediate resource management reporting capability that it can provide. Cotts (1999) identifies that with a CMMS the shop clerk or the shop personnel input field conditions directly; the department planner uses the metrics immediately available for analysis from the CMMS to plan departmental activities and materials needed.

To meet the major objectives of the strategic plan the need for allocation of resources is necessary. The proper allocation of manpower and material resources is performed through scheduling (Teicholz & Ikeda, 1995). Scheduling is used to assign personnel, control job interruption, prevent work delays, and respond to real-time requests. To assist in the scheduling and provide better control and monitoring of the strategic assets, a Computer Maintenance Management System (CMMS) is deployed. Teicholz and Ikeda (1995) noted that the information and quality of corporation databases require accountability from the maintenance department. The corporation acceptability of the maintenance information is necessary for all parts of the organization. Computer Aided Facility Management (CAFM) is software technology that integrates Computer Aided Design (CAD), Data Base Management Systems (DBMS), Computer Maintenance Management System (CMMS), Building Automation Systems (BAS), Supervisory Control and Data Acquisition (SCADA), and procurement. The new technology moves “outside of the building” where the CAFM is be linked to Automated Mapping / Facility

Management (AM/FM) systems and the Geographic Information System (GIS) (Teicholz & Ikeda, 1995, p. 75).

Drucker (1997) observed that the speed of change in the information era is rapidly increasing. The ability for management to have real-time access to information means that immediate decisions must be made. “The changes in the information revolution are, above all, intellectual” (p. 21). Projects will be bound together by “strategic intention instead of a set structure and hierarchy” (p. 20). In the future the same infrastructure will not be required.

Hughes (1999) stated that aerospace and defense companies are spending billions of dollars over the next 5 years to reengineer and computerize their business processes. The term utilized is Enterprise Resource Planning (ERP). “The modules cover everything from human resources, contracting and finance, manufacturing planning, inventory and maintenance” (p. 68). ERP projects encompass the entire workforce into the system, which includes the elements of a CMMS. An ERP project can be an assimilation of various Commercial Off-The-Shelf (COTS) software or can be a single source vendor. The main reason for the emergence of ERP is that the older system software was developed in the 1970s and requires many people to maintain the multiple and often separate databases.

Zongbin and Pou U (2004) stated that power utilities need to incorporate automated process based ERP. The installation of an automated metering system through the power utility system is becoming common as deregulation is incorporated. The ERP software integrates all parts of the power utility to a single platform. The common platform allows for accurate financial calculations on a daily basis. Most large companies use ERP software to incorporate the planning activities through an entire organizational system.

Electrical Power Restoration

Electrical utilities have a constant influx of problems with the electrical system resulting in outages or loss of power on a smaller scale. These outages are due to localized storms, animals, or accidents. The outages created by large storms are of a different nature in that large storms require cooperation of several electrical utilities and possibly regions to restore power (Lubkeman & Julian, 2004). The Outage Management System (OMS) employed by most utilities is used on a daily basis to provide customers with the duration time of the outage and evaluate the effect of the outage. It is a reactive type of program that is used as a dispatching tool to determine resources needed during a small-scale outage.

The storm OMS uses weather data and performs damage prediction. The damage prediction evaluates the wind and storm surge information of a hurricane for an evaluation of damage to the power distribution system. The purpose is to forecast the amount of damage, estimate resources for restoration, and predict the time for returning service. According to Lubkeman & Julian (2004) the electrical utility then uses this information to determine service crews required and material needed

When a large-scale power outage occurs or has a potential to occur, a separate set of criteria for planning must be employed, using a common set of restoration guidelines, goals, and objectives (Ancona, 1995). The first step is to rebuild a stable electrical system and then to systematically restore the load (Ancona). The initial response is to assess the impact of the disturbance and to then verify the conditions. When a major large-scale outage occurs instability of the transmission and distribution system due to the large-scale damage will cause a rippling effect of cascading outages.

Protective circuitry of the system opens various circuit breakers and fuses when instability of the system occurs caused by a large-scale outage (Kundur, 1994). There may even be a need to secure more of the system back to a transmission or generation source to stabilize the voltage and isolate potential fault creating equipment failures.

The restoration process after a major disturbance begins with the determination of what transmission and distribution system can be safely energized (Ancona, 1995). Ancona (1995) stated that system restoration should avoid the creation of islands of generation separate from the synchronized grid. Individuals islands of generation may occur due to transmission losses, but these islands should remain separate until the restoration path and the core transmission system are stabilized.

Supply Chain

The planning for an electrical major event caused by a hurricane requires a contingency logistic system (CLS) according to Thomas (2002). A CLS plan includes, as key elements, procurement, distribution, storage, and transportation of the material. The military considers the capability of providing material support a critical link in the ability to support. A missed connection in the supply chain can undermine the logistic plan (Morales & Geary, 2003). The U.S. military in the Iraq war in 1991 found that the military services operated a separate supply system for each branch. The Army, Navy, Air Force, and Marines used separate supply systems which resulted in shortages and wrong material being delivered. “Well-stocked inventory that doesn’t get where it’s needed does not deliver value” (Morales & Geary, 2003, p. 2). Since then the U.S. military has combined the logistics systems into one system that serves all military units. The U.S. military has found that using performance based contracts with suppliers has assisted the establishment of a system to determine the flow of material to the specific units. Morales & Geary (2003) found that U.S. military uses radio frequency identification tags to global track containers as they are delivered to the troops.

Dimitruk (2005) stated that the optimal response to hurricane Katrina in Louisiana did not come from the federal government or the Red Cross, but from Wal-Mart. Wal-Mart was able to provide in their stores a constant supply of goods due to their supply chain management. According to Dimitruk the ability to provide goods involves not just transportation but strategic storage of inventory, delivery of inventory only when needed, and managing the distribution in an even manner. Wal-Mart has agreements in place with suppliers directly and can deliver materials to the distribution centers then to the retail stores efficiently due to collective regional planning.

Russell (2005) posited that relief operations have a life-and-death need to provide a coordinated logistics system to supply the impacted people. According to Russell, in the rush to aid victims many relief operations are poorly planned and unstructured. Relief agencies can learn from the commercial supply chain systems how to provide material to the impacted areas. Russell discussed the different levels of relief provided by organizations from one organization that loads a plane with supplies and flies into the area, to one that performs a needs assessment. Russell indicated that a strategic relief plan is needed for contingency operations that encompass each relief agency's program to prevent waste and chaos.

Reliability Interference Theory

The common assumption with engineering is that when a piece of equipment is placed in service there is an infant mortality rate or a rate of failure due to the burn-in. The infant mortality rate or burn-in of equipment when initially placed in service is the initial source of failure of equipment. As equipment ages then the age of the equipment causes an increase in failure. This concept that probability of equipment failure occurs at the beginning and ending of use is the basis for the bathtub curve theory of failure in a system (The Institute of Electrical and Electronic Engineers, 1991).

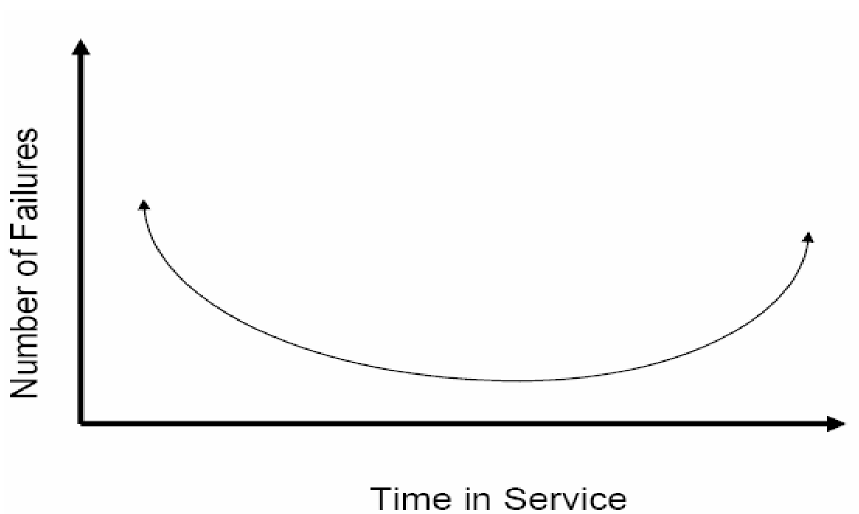


Figure 1. Equipment bathtub curve.

The concept that a piece of equipment has a certain period of time before it fails after it has been placed in service has lost its merit according to Maubray (2007).

Maubray identified the bathtub curve as the common method to define maintenance practices and also, in a philosophical sense, it indicates that everything has a life cycle. According to Maubray the bathtub theory should not be used as a basis of maintenance, but as a reminder that failure can occur at anytime and is a random occurring event.

Smith and Dietrich (1994), in performing analysis on material and component strength, developed an alternate to the bathtub curve theory called the reliability interference theory. The failure of a component or a piece of equipment is relative to the operating environment and the quality. Smith and Dietrich (p. 241) stated that "most failures, regardless of age, can be attributed to wear out."

Thomas (2002) reasoned that the reliability of the supply chain is based on the ability of the supply chain to provide the needed parts and materials. His analysis is based on the concept that if the part or material cannot be delivered or is delayed then a failure occurs. Thomas (2002) concluded that reliability interference theory should be used to analyze a contingency logistics supply chain. The environment and the configuration of the supply chain determine the conditions for success (Thomas, 2002).

Contingency Logistics System

Supply chains providing materials and products from supporting companies inherently become fragile as they become more efficient (Matheson, 2005). Disruptions in the supply chain can create delays in receipt of material. The vulnerability of the supply chain can be either natural or man-made. As the supply chain expands the vulnerability increases with every distribution or delivery point, sometimes referred to as a bottleneck. The distribution centers become areas of vulnerability. Matheson determined that the vulnerability of the supply chain can be mitigated by the creation of additional distribution centers or additional suppliers.

The supply chain can be serial; that would mean each link in the chain would be equally critical to the success of material delivery (Thomas, 2002). In a series Contingency Logistics System (CLS) supply chains would be susceptible to bottlenecks at any point. A series CLS is at one extreme for a logistics system. At the other extreme is the parallel CLS. A parallel logistics system is where all points along the supply chain can support the demand for any other point. Thomas observed that the common situation for a supply chain to exist is where some links on the supply chain are more critical than others and there is some sharing within the system.

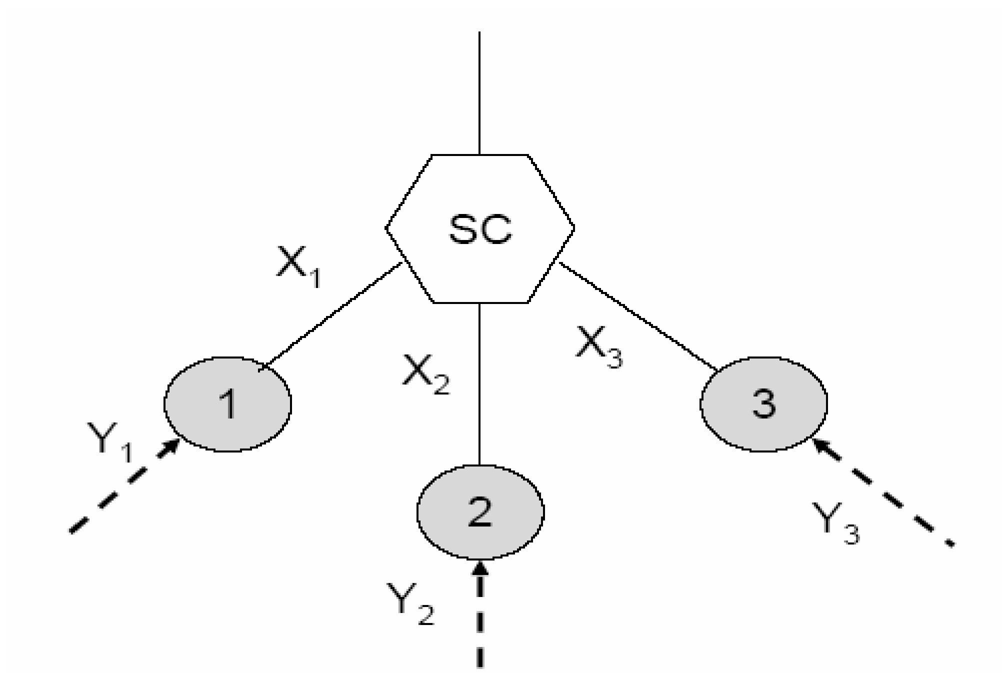


Figure 2. A supply distribution chain for a system with 3 sites. *Supply Chain Reliability for Contingency Operations* by M.U. Thomas, 2002, Proceedings Annual Reliability and Maintainability Symposium, p. 61. Copyright 2006 IEEE. Reprinted with permission.

Figure 2 identifies a supply chain (SC) supporting 3 sites with a random variable (X) representing the demand at each site and random variable (Y) representing the supply. The individual sites pull material from the supply chain (Thomas, 2002).

Summary

Lovins and Lovins (1982) advocated smaller generation systems being created to enhance reliability. The trend is to create a larger and larger grid system of interconnections controlled by the individual power utilities. The larger grid system would be more susceptible to large-scale outages and smaller localized electrical grids would provide better reliability and resilience concluded Lovins and Lovins. Zeriffi (2004) further concluded that the large-scale grid system would cause long-term impact in the event of a single major event. Zeriffi concluded that smaller microgrids would have a higher rate of reliability. Philipson and Willis (2006) discussed the creation of the large power grid and how the grid has evolved from smaller scale localized utilities to large corporations. Philipson and Willis concluded that the large-scale utilities would perform with deregulation of pricing to the consumer. Casazza and Delea concluded that the grid was created from an accumulation of governmental regulations. The federal government pursuit of deregulation was not implemented at the state level. Specifically, Florida has no plan to deregulate the power industry. Lewis (2006) stated that the regional power utilities are now required to purchase power from all qualified generators and allow all generators to use the transmission lines maintained by the ISO or the RTO. On the national level the wholesale price of power is allowed to fluctuate while the state regulatory bodies control the retail price to the consumer. The national grid has evolved to a large complex interconnection of electrical power generation, transmission, and distribution systems managed by utilities that are attempting to make a profit while being regulated at many levels. There is disagreement with power engineers whether the national grid is best or smaller localized generation systems would be better. Philipson and Willis (2006) stated that the overriding issue is that the maintenance of the equipment has become a complex issue of determining at which level will the capital investment be made for a more reliable and resilient system (p. 99).

As an everyday occurrence electrical utility power outages occur. The local utilities use a storm OMS to determine damage predication (Lubkeman & Julian, 2004). In management of power outages the utilities should have in place necessary materials to constitute resources for restoration. Anconna (1995) stated that the restoration process involves assessment, repair, and restoration. Kundar's (1994) concern was that the power system needs to be stabilized before restoring power to the system. The delays in the process can come from a lack of material to create a stabilized system to energize.

Supply chains in support of contingency logistic operations can use new technology as indicated by the U.S. military (Morales & Geary, 2003). Commercial supply methods were found to be highly efficient during hurricane Katrina in their ability to redirect supplies to the areas (Dimitruk, 2005). Russell (2005) indicated that relief supplies need a coordination of effort to prevent waste and chaos.

The use of reliability interface theory to define a system is based on the concept that a system is determined by the quality of the components in service and the environment that it operates within. Thomas (2002) used this concept to define the contingency logistic system.

CHAPTER 3: METHODOLOGY

Introduction

The purpose of this study is to determine if the repair cost in a contingency logistics system correlates to the duration of the power loss for investor-owned utilities in Florida due to hurricanes and can the repair cost provide an indication of power system reliability. The first chapter introduced the problem that standardized electrical power reports do not use cost of repair after a hurricane in determination of the system reliability. The second chapter identified research into the nature of the electrical power system in North America, the impact of deregulation, the current nature of maintenance using computer maintenance management systems, the use of the supply chain, and reliability interface theory.

The third chapter describes the research design and methodology for this quantitative study. The setting of the data collection and the treatment used in evaluation of the data is described. The instrument used to determine the supply chain reliability is presented. An explanation of the data analysis is made identifying the relationship of the hypothesis to the research questions. The chapter concludes with a summary of the major points and issues.

Research Design and Approach

The research began with an inquiry of the Florida Public Service Commission testimony for data on the individual investor-owned utilities. The basic information needed to perform this research was available through archival investigation and a survey of the investor-owned utilities was not necessary. The data mining process included online and direct contact with the Florida Public Service Commission. Contact was made with the Florida Public Service Commission to insure the information was from valid testimony. Power system reliability information was researched online with the Florida Reliability Coordination Council on the reliability indices reported by the investor-owned utilities. After the data was collected a scatter plot (figure 8) was developed to graphically display the data and to provide a visual understanding of the nature of the data. The repair cost reported by the investor-owned utilities and the electrical outage duration was examined using regression analysis to determine the association of the data. The correlation of the utility repair cost and outage duration was found to be positive and Thomas's (2002) calculation of contingency supply chain reliability was made. Final examination was made to determine the association of the supply chain reliability is correlated with the electrical power reliability indices.

Thomas's (2002) approach to evaluation of contingency supply chain reliability was used because other supply chain reliability evaluations utilize multi-echelon trade-off between the stock at the operating locations and supporting depots as a determination of stock levels (Sherbrooke, 2004). Normal inventory management systems deal with providing a consistent supply of material. Thomas (2002) indicated how to deal with a crisis due to catastrophic event in the inventory system.

Setting and Sample

The years of 2004 and 2005 had a great impact on the power system in Florida due to multiple hurricanes crossing the state. Table 1 identifies the hurricanes and the magnitude of the hurricanes crossing the state of Florida during the 2004 and 2005 hurricane season. Several of the hurricanes overlapped the same geographical areas which may have intensified the hurricane impact.

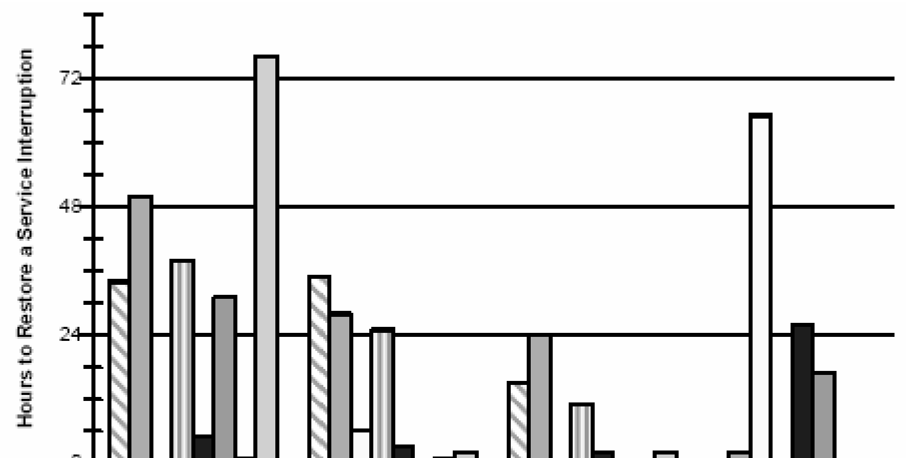
Table 1
2004 and 2005 Florida Hurricanes

Year	Month	Name	Category of Hurricane Florida	Max. Wind (mph)
2004	Aug	Charley	4	145
2004	Sep	Francis	2	105
2004	Sep	Ivan	3	130
2004	Sep	Jeanne	3	120
2005	Jul	Dennis	3	120
2005	Aug	Katrina	2	80
2005	Sep	Rita	2	62
2005	Oct	Wilma	3	125

Note. The data are from *Report to the Legislature on Enhancing the Reliability of Florida's Distribution and Transmission Grids During Extreme Weather* by Florida Public Service Commission, Copyright 2007. Florida PSC. Reprint with permission.

After the hurricanes the Florida PSC and the FRCC held hearings on the impact. The total cost of a repair to an electrical power system is relative to price fluctuations and demands made upon the manufacturers. The cost of materials is the manufacturer's delivered cost to the utility. The costs are added together to determine the total cost (Ayyab & McCuen, 2003). Reliability was determined using Thomas (2002) calculations with the factors total cost and the electrical outage duration after a specific hurricane as reported by the utility to the Florida Public Services Commission. Not all utilities in the state of Florida may be impacted by a specific hurricane because of the jurisdiction of the responsible areas of the utilities.

Chen, Allen, and Billinton (1995, p. 643) researched optimal design of distribution power systems using software to perform value based distribution reliability assessment. Value based reliability assessment performs an analysis of the history of utility outage records to determine the types of equipment failures observed and determine the optimal methods to maintain service reliability. As the duration of the loss of utility power is longer the cost to restore power and customer material loss increases (Chen, Allen, & Billington, 1995). By observation of what types of equipment failures are occurring an optimal distribution system analysis can be made to determine the most reliable methods to lower operational costs (Chen, Allen & Billington, 1995).



	FPL	PEF	TECO	GULF
'04 Charley	34	35	15	
'04 Frances	50	28	24	2
'04 Ivan		6		65
'04 Jeanne	38	25	11	
'05 Dennis	5	3	2	26
'05 Katrina	31			17
'05 Rita	1	1		
'05 Wilma	76	2	2	

Figure 3. Average time to restore power. *Report to the Legislature on Enhancing the Reliability of Florida's Distribution and Transmission Grids During Extreme Weather* by Florida Public Service Commission, 2007, p. 15. Copyright 2007 Florida PSC. Reprint with permission.

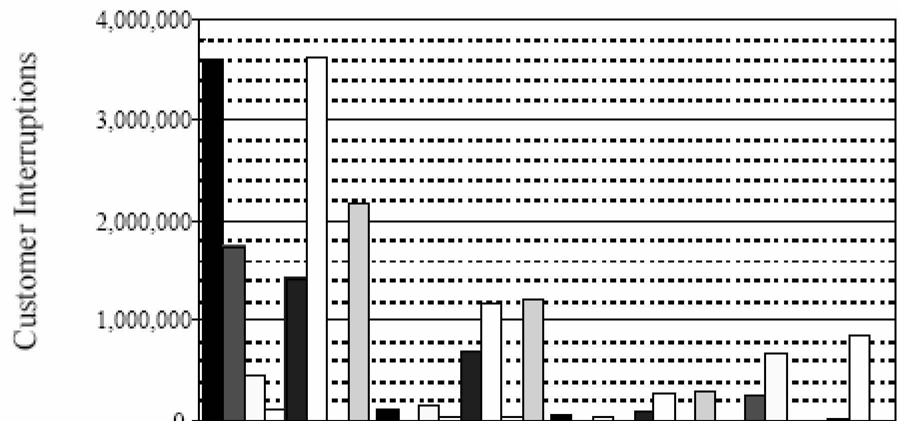
Figure 3 identifies the hours of interruption by the major power utilities during the hurricanes of the 2004 and 2005 season. As indicated by the table several utilities were impacted several times due to multiple storms. The duration of the individual storms can be observed by the table and will aid in determination of the outage duration impact of this analysis.

Wakileh and Pahwa (1996, p. 643) further stated "the cost of energy interruption to customers depends on outage duration." As the duration of the power loss and the numbers of customers impacted by the loss of power increases, the difficulty for the utility to restore power increases. As the difficulty increases the longer time there is needed to restore power and cost of restoration increases. To evaluate the cost Wakileh and Pahwa (1996) used an actual kilowatt-hour rate structure, interest rate, and inflation index for calculation of real cost during a loss of power.

Figure 4 indicates the number of individual customers impacted by the various utility outages caused by hurricanes during the 2004 and 2005 season. The table also provides indication as to the wide scale impact of the individual storms.

This study analyses if cost and duration of the outage after a hurricane is directly correlated. This study differs from previous studies in that it used actual material repair cost after a hurricane in place of equipment failures or rate structure in determination if a duration of energy interruption is directly correlated.

Data were provided and validated by the Florida Public Service Commission as a public record. All hurricanes that impacted investor-owned utilities electrical systems in Florida between 2004 and 2005 were selected due to validity and reliability of the data. Prior to 2004 the data available for public record were incomplete since long periods of time would occur between hurricane events. There was insufficient data available after 2005 of hurricanes in Florida.



	FPL	PEF	TECO	GULF
■ Hurricane Wilma	3,606,882	114,634	48,079	
■ Hurricane Katrina	1,742,082			255,727
□ Hurricane Dennis	448,614	153,694	35,565	675,289
■ Hurricane Rita	112,282	29,545		
■ Hurricane Charley	1,417,033	707,600	97,790	
■ Hurricane Frances	3,617,790	1,180,965	268,000	8,190
■ Hurricane Ivan		25,072		847,795
□ Hurricane Jeanne	2,162,857	1,217,270	285,000	

Figure 4. Number of Customer Interruptions - 2004 and 2005 Hurricane Seasons. *Report on transmission system reliability and response to emergency contingency conditions in the state of Florida*. By Florida Public Service Commission, 2007, p. 28. Copyright 2007 Florida PSC. Reprinted with permission.

Reliability and Validity

The number of customers impacted by the electrical outages and the outage durations were used to calculate the electrical reliability indices and do support the calculation and testing of the contingency logistics supply chain reliability. Prior to June of 2006 in reporting of the electrical reliability indices the investor-owned utility (IOU) were exempted from reporting outage impacts as a result of hurricanes. The data submitted to the Florida PSC was considered adjusted data. The Florida PSC acted upon the reliability of the data by stating that, "unadjusted data provides an indication of the robustness of the distribution system" (Florida Public Service Commission, 2006, p. 5). The unadjusted IOU reliability data for the years 2004 and 2005 was requested by the Florida PSC and published in December 2006 as the "Review of Florida's Investor-Owned Electrical Utilities' Service Reliability in 2005."

The study is based on archival data and no survey or interviews were used. The reliability and validity of the study is based on calculations using standard engineering and statistical methods.

IEEE Standard for Power Reliability

The IEEE (2004) provides a standardized means for electrical power utilities to report the electrical performance. The Florida PSC uses the data provided by the reports to monitor the Florida IOU. The data provided to the Florida PSC is used to calculate several parameters of the utilities.

The customer average interruption duration index (CAIDI) indicates the amount of time the customers were without power. The CAIDI provides information on the magnitude of the power outage and indicates the time to correct the anomalies.

$$\text{CAIDI} = \frac{\text{Customer Interruption Durations}}{\text{Total Number of Customers Interrupted}} \quad (1)$$

The system average interruption frequency index (SAIFI) is calculated to determine the average customer sustained outage frequency. The SAIFI indicates the number of times the electrical service was interrupted and indicates if there are repeated service outages occurring.

$$\text{SAIFI} = \frac{\text{Total number of Customers Interrupted}}{\text{Total Number of Customers Served}} \qquad (2)$$

The system average interruption duration index (SAIDI) is an indication of the overall reliability performance of the electrical system for the IOU. The SAIDI is composed of the outage frequency and the outage duration. The SAIDI is the product of the CAIDI and the SAIFI. The SAIDI provides the overall average reliability of the outage impacts to the customers of the utility. The unadjusted Florida PSC reliability for the 2004 and 2005 information is provided as the SAIDI indicator for the electrical utilities.

$$\text{SAIDI} = \frac{\text{Customer Interruption Durations}}{\text{Total Number of Customers Served}} \qquad (3)$$

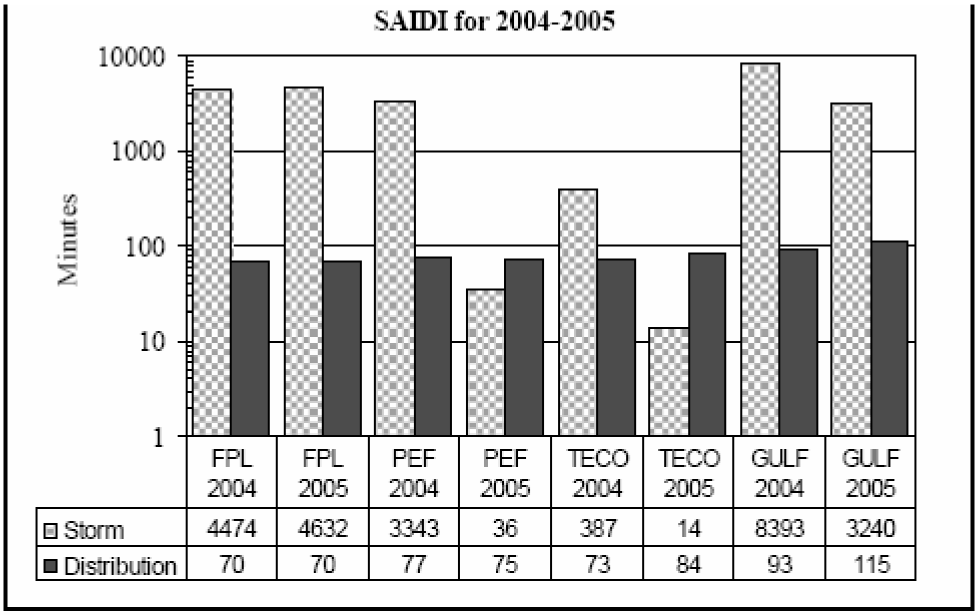


Figure 5. Storm Effects and Non-storm Distribution Reliability. *Review of Florida's investor-owned electrical utilities in 2005.* By Florida Public Service Commission, 2006, p. 8. Copyright 2006 Florida PSC. Reprinted with permission.

The Florida PSC receives information on the reliability of the four major IOU using the IEEE reliability indices. The Figure 5 compares the unadjusted distribution reliability (storm) with the adjusted reliability (non-storm) factor for both 2004 and 2005 hurricane seasons. The differences between SAIDI impacts as reported by the utilities indicate the varying track and magnitude of the hurricanes within the year. Not all hurricanes impacted each utility in the same and equal manner. The variation occurs due to the area the hurricane strikes and whether the individual electrical utility has jurisdiction in that area.

Instrumentation and Materials

During the 2004-2005 hurricane seasons for Florida the investor-owned utilities used all the stock material and needed to order a substantial amount of material after the storm damage assessment. The stock material quantities were based on typical logistics ordering calculations. The common approach would be to use the item approach to indicate the amount of stock needed (Sherbrooke, 2004). The item approach for the amount of item stock would be to insure material is always available to make repairs. The material lead time with a level of safety stock in case of demand variability would be the normal stock order quantity. Sherbrooke (2004, p. 13) identified the common item order quantity calculation to compensate for demand variability in the following equation.

$$s = \mu + k\sigma \qquad (3)$$

Where: s = units of spare stock
μ = average demand over lead time
σ = standard deviation of lead time demand
k = positive constant for the amount of protection (safety stock)

The normal stock order quantity is based on the life expectance of the materials used in electrical distribution. For example a wooden power pole average life span is 20 years (Department of the Army, the Navy and the Air Force, 1996, p. 4-4). The U.S. Air Force normally uses a k = 1.73 for the safety stock constant (Sherbrooke, 2004, p. 13). The average demand over lead time (μ) and (σ) standard deviation of lead time demand is quite small for a wood pole and the unit of spare stock would be around two wooden poles (with the safety stock factor rounded to the nearest integer) depending on the number of wooden poles in service.

After a hurricane the investor-owned utilities can deplete their entire stock supply very rapidly, depending on the impact of the storm, as indicated by the item order calculation. In emergencies and emergency preparedness item order calculations should not be used since the material needs far exceed the normal stock supply. The order quantities should be directly correlated to the cost to deliver the material. Sherbrooke (2004) stated that for emergency repair it does not mater how much the items cost only how soon they can be delivered.

Thomas (2002) called a supply chain that operates in an emergency condition a contingency logistics system. When an unexpected crisis occurs, like a hurricane, the logistics support for the relief agencies is required to immediately respond. The logistical response requires that a contingency supply chain must be developed immediately to provide support to the power companies. This unexpected crisis is a random event. The resulting supply chain is a stochastic process where a number of units must be available to be used immediately after the hurricane. Thomas identified the contingency logistics system as a set of processes that supports the contingency operations with supplies and in this case the equipment necessary to repair the electrical distribution system in Florida after a hurricane.

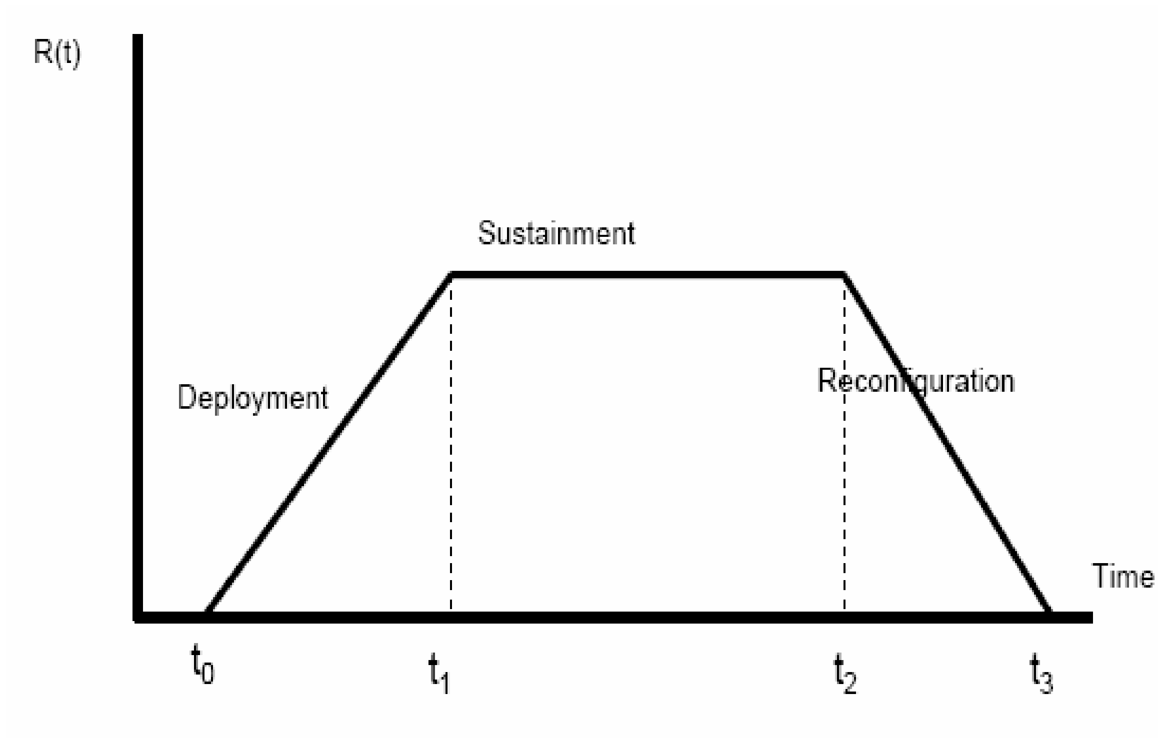


Figure 6. Contingency life-cycle resources loading profile. "Supply Chain Reliability for Contingency Operations" by M. U. Thomas, 2002, Proceedings Annual Reliability and Maintainability Symposium, p. 61. Copyright 2006 IEEE. Reprinted with permission.

The contingency life-cycle resource as indicated by Thomas (2002) and shown in Figure 6 indicates that the deployment of materials begins shortly after the random event occurs. The initial orders for material begin after an assessment of the damage and start at time t_0 and carry through the deployment stage as materials begin to arrive. The ramping up of material continues until a stage 2 occurs when the contingency operation is in sustainment at time t_1. As time progresses the contingency operations drop off in the reconfiguration phase of the operation at time t_2 until normal operations occurs at t_3.

According to Thomas (2002) the process for determining the reliability of the contingency logistics system is based on the criticality of each site receiving material, determination of supply chain failures, and estimates of the probability of failure of the supply chain.

For this analysis the following assumptions will be made:

1. The time for the contingency support is fixed for each utility.
2. Supplies are received at a distribution center and equally allocated to utilities.
3. The demand by each utility is independent of the on-hand supply.
4. The supply and demand have a normal distribution.

Data Analysis for Hypothesis One

The data analysis began with the determination of whether investor -owned utility outage duration after a hurricane is correlated with their hurricane repair cost. First a scatter plot was created with the horizontal axis representing outage duration as a factor of time and the vertical axis represents the repair cost. For each investor-owned utility a dot was placed on the graph, horizontally positioned as far right as the investor-owned utility outage duration and vertically up as far as the repair cost.

The correlation of the investor-owned utility cost for hurricane materials and the after hurricane outage duration was computed using statistical analysis software. The correlation was performed by first computing the mean of the hurricane repair cost and the standard deviation of the data and performing a similar calculation for the hurricane outage duration. "The data is said to be perfectly correlated if the distance from the mean (measured in standard deviations) of one variable corresponds exactly to the distance (again measured in standard deviations) from the mean of the other variable" (Starbird, 2006, p. 98).

$$r = \frac{\sum_{i=1}^{n}\left(\frac{x_i - \bar{x}}{s_x}\right)\left(\frac{y_i - \bar{y}}{s_y}\right)}{n-1} \tag{4}$$

The formula for correlation (4) will take the mean of the products of the hurricane repair cost and the after hurricane outage duration over the number of utilities impacted by each hurricane to find the correlation. Pardoe (2006) identified that the correlation number was used to measure the strength of the linear association between the repair cost (*x*) and the outage duration (*y*). If the relationship is positive the repair cost increases will outage duration, while a negative relationship is when the repair cost increase the outage duration would decrease. Pardoe (2006) further stated that the correlation number (*r*) will yield a number closer to +1 if there is a positive correlation or a number closer to -1 if there is a negative correlation. A correlation number closer to zero indicates no specific correlation would exist. The calculation answered the first research question. What is the investor-owned utility association after a hurricane between repair cost used in the contingency logistics system and electrical outage duration? The calculation of the correlation between hurricane repair cost for the investor-owned electrical utilities and outage duration was used to resolve the first hypothesis, H_1: The association between the repair cost and electrical outage duration after a hurricane is a positive correlation.

Data Analysis for Probability of Failure

With a normal distribution between supply and demand assumption the probability of failure is calculated as a first order of reliability method (Ayyub & McCuen, 2003). The investor-owned utility reliability was calculated as described by Thomas (2002) in the discussion on determining the effectiveness of a supply chain to provide goods and services during and directly after a crisis. The impact on the electrical power system of generation, transmission, and distribution by a hurricane establishes a unique and random crisis to the investor-owned utilities electrical equipment. Thomas (2002, p. 65) used the cumulative distribution function (ϕ) to evaluate a normally distributed supply and demand failure probability for the data when determining the supply contingency reliability (7). The cumulative distribution function (ϕ) is the probability that in a normal distribution with the population mean (μ) equals 0 and the population standard deviation (σ) equals 1 and the event will be less than or equal to cot to restore power.

The relation between the average time to restore power (demand) and the restoration cost (supply) was found to be a linear relationship and a correlation does exist, the data set was then used to determine the failure probability (P) using Thomas's (2002) equation on determination of the effectiveness of the contingency logistics system.

$$P = \Phi\left(-\frac{\mu_x - \mu_y}{\sqrt{\sigma_x^2 + \sigma_y^2}}\right) \qquad (5)$$

$$P = 1 - \phi(\beta) \tag{6}$$

$$\beta = \left(\frac{\mu_x - \mu_y}{\sqrt{\sigma_x^2 + \sigma_y^2}} \right) \tag{7}$$

Where: σ= standard deviation
μ= mean
x = restoration cost
y = average time to restore power
ϕ = cumulative probability distribution function
β = reliability index

The reliability index of the average time to restore power for each investor-owned utility was computed using a standard score or normal relationship for the sample data (Triola, 1998). The resulting equation (8) was used to calculate the individual reliability index for each investor-owned utility based on the random variable of restoration cost to restore power. The contingency logistics system probability of failure (9) for each investor-owned utility based on a normal probability distribution and provides the number of standard deviations that the individual cost values for each hurricane is away from the cumulative mean value for cost (Render & Stair, 1997).

$$\beta_j = \frac{\overline{x}_{xj} - \overline{x}_z}{s_z} \tag{8}$$

$$CLS - p_j = 1 - \phi(\beta_j) \tag{9}$$

Where: β_j = reliability index for cost of each investor owned utility
s_z = cumulative sample standard deviation for cost
$\overline{x}_z$ = cumulative normal distribution sample mean for cost

$\overline{x_{xj}}$ = individual investor owned utility cost to restore power

P_j = Probability of Failure for each investor owned utility

ϕ = cumulative probability distribution function

The cumulative distribution function in this analysis for each investor-owned utility was derived by evaluation of each investor-owned utility reliability index (β_j) using Ayyub and McCuen (2003, Appendix A) Table A-1.

The association of the contingency logistics system probability of failure and the IEEE reliability indices for the hurricane seasons 2004-2005 was then compared to determine if a correlation exists within or between these data using regression analysis. Regression analysis is used when more than one predictor is possible to determine the dependant variable (Breyfogle, 2003). Using the regression analysis software the determination was made of the relationship of the output variable for the contingency logistics system probability of failure as measure of material reliability for hurricanes in Florida to the independent variable of storm effect distribution IEEE reliability indices. The results of the analysis will aid in determination of comparisons between cost, outage duration and with electrical system reliability. The correlation analysis was used to answer the second research question: How is the contingency logistic system reliability compared to electrical power system reliability?

Summary

The research used data from the Florida Public Service Commission provided in testimony from public and privately owned electrical utilities. These data of outage duration and repair cost are analyzed to determine if they are correlated. If a positive correlation does exist then theses data are used to find the failure probability of the investor-owned utilities supply. The failure probability is then compared to the IEEE reliability indices of the investor owned utility.

The questions to be answered by this research focus on the ability to supply contingency materials to the utilities and the ability to supply such material when multiple hurricanes impact the area. The research data is presented in chapter 4 in graphical and tabular format identifying affected geographical areas within Florida, hurricane index level, materials restoration cost, number of customers, and restoration time. The material data used is from the Florida Public Service Commission testimony by the Florida investor-owned electrical utilities.

CHAPTER 4: RESEARCH FINDINGS

Introduction

In Florida, the 2004 and 2005 hurricane seasons were among the most destructive seasons on record. Several hurricane events passed over the same area within a short period of time. The storms savaged the electrical power system overhead distribution systems. The repair requirements were shared throughout the electrical power utilities. Several times as the storms passed over Florida, multiple investor-owned utilities were impacted.

The Florida Public Service Commission (PSC) is mandated by the state legislature with regulatory authority over investor-owned utilities. The Florida PSC monitors regulations, receives information from the various utilities, and reports findings. The Florida PSC uses this information in establishment of the utility rate structure. There have been several reports released by the Florida PSC on the 2004 and 2005 hurricanes identifying the impact to the electrical power distribution and transmission systems. The data used within this report (Table 2) were compiled through historical research of the Florida PSC released reports, hearing transcripts, and docket filings to the PSC by the investor-owned utilities.

The 2004 hurricane year in Florida was a dramatic series of events with hurricanes Charley, Frances, Ivan, and Jeanne crossing the state. Almost all of the state of Florida was impacted by some type of hurricane event. Power loss caused by the hurricanes was evident throughout northwest, central, and southern Florida. Overlapping hurricane impacts caused power outages to be repeated soon after the power distribution system was repaired. Severe destruction of residential areas occurred, sometimes miles from the coast. The hurricane wind envelope, Figure 7, graphically indicates repeated hurricane events.

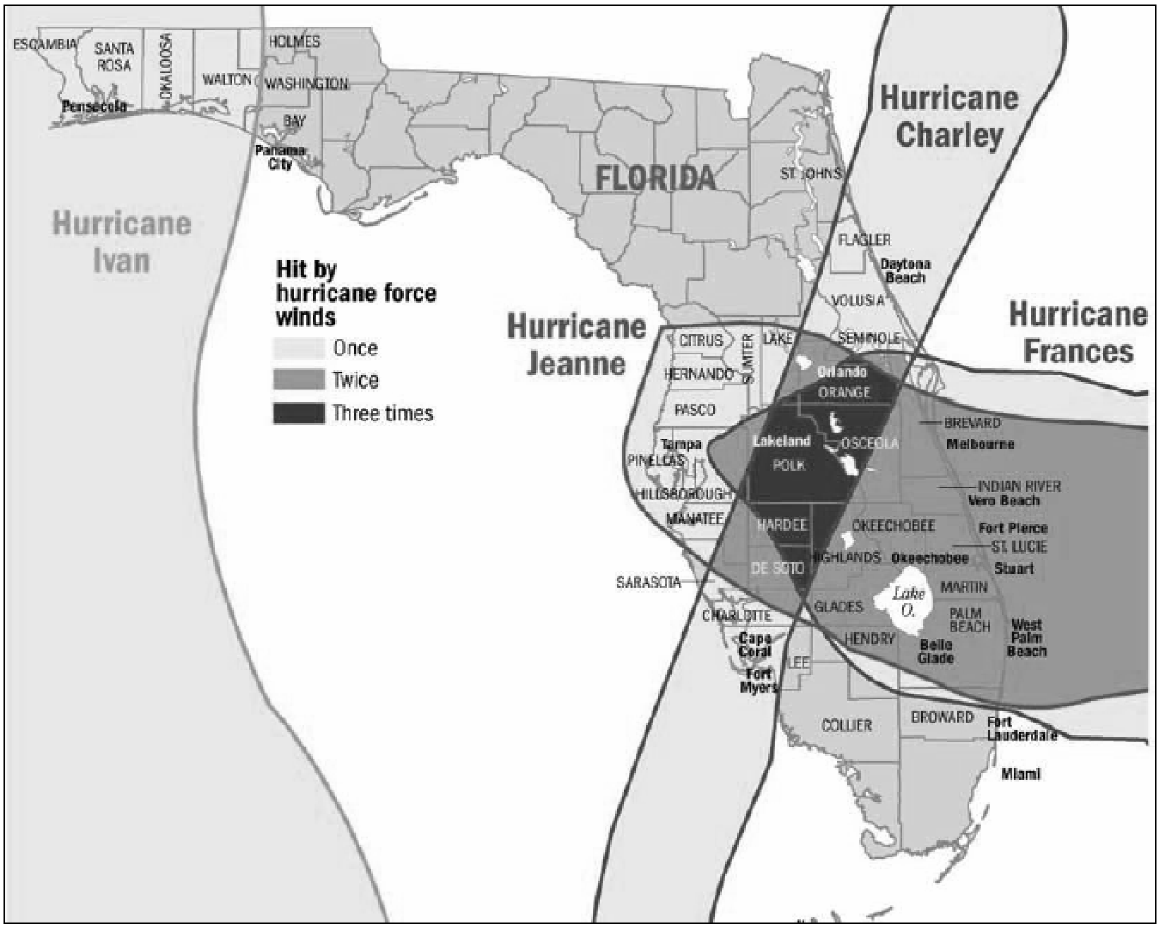


Figure 7. Florida wind envelope during the 2004 hurricane season. *Report to the legislature on enhancing the reliability of Florida's distribution and transmission grids during extreme weather* by Florida public service commission, 2007, p. 7. Copyright 2007 Florida PSC. Reprinted with permission.

The following year the hurricane events continued with hurricanes Dennis, Katrina, Rita, and Wilma impacting the state of Florida. The southern part of the state experienced overlapping hurricane force wind events. The hurricane force winds were evident in central and south Florida several times with the most damaging being hurricane Wilma. The 2005 hurricane season was the year that the most destructive hurricane in recent years hit the Gulf coast. Hurricane Katrina was only a category 2 hurricane when it crossed Florida but became a category 5 hurricane in the Gulf of Mexico before it struck Louisiana and Mississippi.

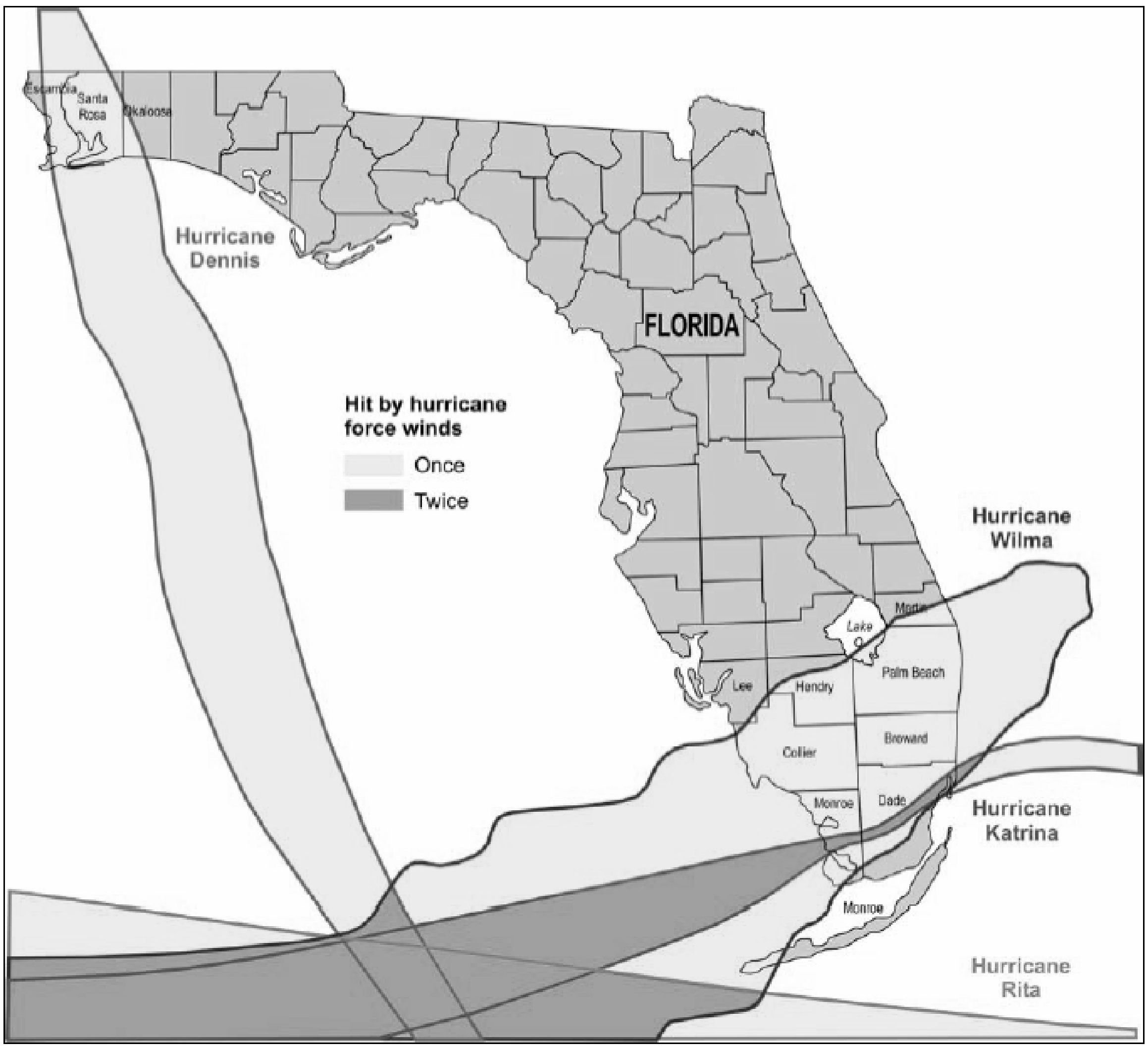


Figure 8. Florida wind envelope during the 2005 hurricane season. *Report to the legislature on enhancing the reliability of Florida's distribution and transmission grids during extreme weather* by Florida public service commission, 2007, p. 11. Copyright 2007 Florida PSC. Reprinted with permission.

The data analysis for this study focused on the impact of the hurricane events on the electrical power distribution and transmission system to the investor-owned utilities in the state of Florida. The analysis provides an indication of impact and response of the investor-owned utilities after a hurricane. The social impact of the power restoration time and cost after a hurricane event in Florida is the potential to increase utility or consumer product cost due to requested rate increases by the investor-owned utility to pay for repairs or replenish hurricane contingency funds.

Hypothesis One

The first discussion focuses on the correlation between the outage duration and the repair cost for the investor-owned utility after a hurricane has impacted an area. The hypothesis set to be tested was as stated below.

H_0: There is no correlation between repair cost and outage duration; that is, $\rho = 0$, where ρ is the correlation coefficient.

H_1: There is correlation between repair cost and outage duration; that is, $\rho \neq 0$.

Table 2 identifies the hurricane event, investor-owned utility, the outage duration, and the repair cost reported by the utility. Table 2 is the base data table used throughout the study. The table is arranged in a time series with the earliest event first, then with each hurricane, and the impacted investor-owned utility. The restoration cost number is given in millions of U.S. dollars (USD). The average time to restore power is the average time the investor-owned utility took to restore power after a hurricane. The restoration cost amount was reported to the Florida Public Service Commission by the individual investor-owned utilities.

Table 2

Table of Restoration Cost and Average Time to Restore Power.

Date	Hurricane Name	Sustained Winds over Florida (mph)	Category of Hurricane	Investor Owned Electric Utility	Restoration cost (USD) (Millions)	Average time to restore Power (hours)
8/13/2004	Charley	145	4	FPL	252	34
8/13/2004	Charley	145	4	PEF	152	35
8/13/2004	Charley	145	4	TECO	13.9	15
9/4/2004	Frances	105	2	FPL	316	35
9/4/2004	Frances	105	2	PEF	130	28
9/4/2004	Frances	105	2	TECO	25.3	24
9/16/2004	Ivan	130	3	PEF	8	6
9/16/2004	Ivan	130	3	GPC	134	65
9/25/2004	Jeanne	120	3	FPL	322	38
9/25/2004	Jeanne	120	3	PEF	84	25
9/25/2004	Jeanne	120	3	TECO	34.2	11
7/10/2005	Dennis	120	3	FPL	10	5
7/10/2005	Dennis	120	3	PEF	3.6	3
7/10/2005	Dennis	120	3	TECO	0.3	2
7/10/2005	Dennis	120	3	GPC	59	26
8/25/2005	Katrina	80	2	FPL	162	31
8/25/2005	Katrina	80	2	GPC	4	17
9/20/2005	Rita	62	2	FPL	12	1
9/20/2005	Rita	62	2	PEF	0.3	1
10/24/2005	Wilma	125	3	FPL	696	76
10/24/2005	Wilma	125	3	PEF	3.8	2
10/24/2005	Wilma	125	3	TECO	0.3	2

Note. The data are from *Report to the Legislature on Enhancing the Reliability of Florida's Distribution and Transmission Grids During Extreme Weather* by Florida Public Service Commission, 2007, p. 15. Copyright 2007 Florida PSC. *Florida Power & Light Co.: Response to information requests 1/23/2006 commission staff workshop.* by Florida Public Service Commission, (2006), p. 3. Copyright 2006 Florida PSC. *PEF: Responses to E.I.W. data request.* by Florida Public Service Commission, 2006, p. 3. Copyright 2006 Florida PSC. *Tampa Electric: Responses commission staff workshop questions electric utility infrastructure.* by Florida Public Service Commission, 2006, p. 1. Copyright 2006 Florida PSC. Reprinted with permission.

Figure 7 shows an ascending pattern of restoration cost and average time to restore power. Each point indicates a separate utility and hurricane event. The dots indicate the point where the investor-owned utility for the specific hurricane restoration cost intersects with the left scale of U.S. dollars (USD) in millions and with the average time for the power utility to restore power after the hurricane on the right hand scale in hours.

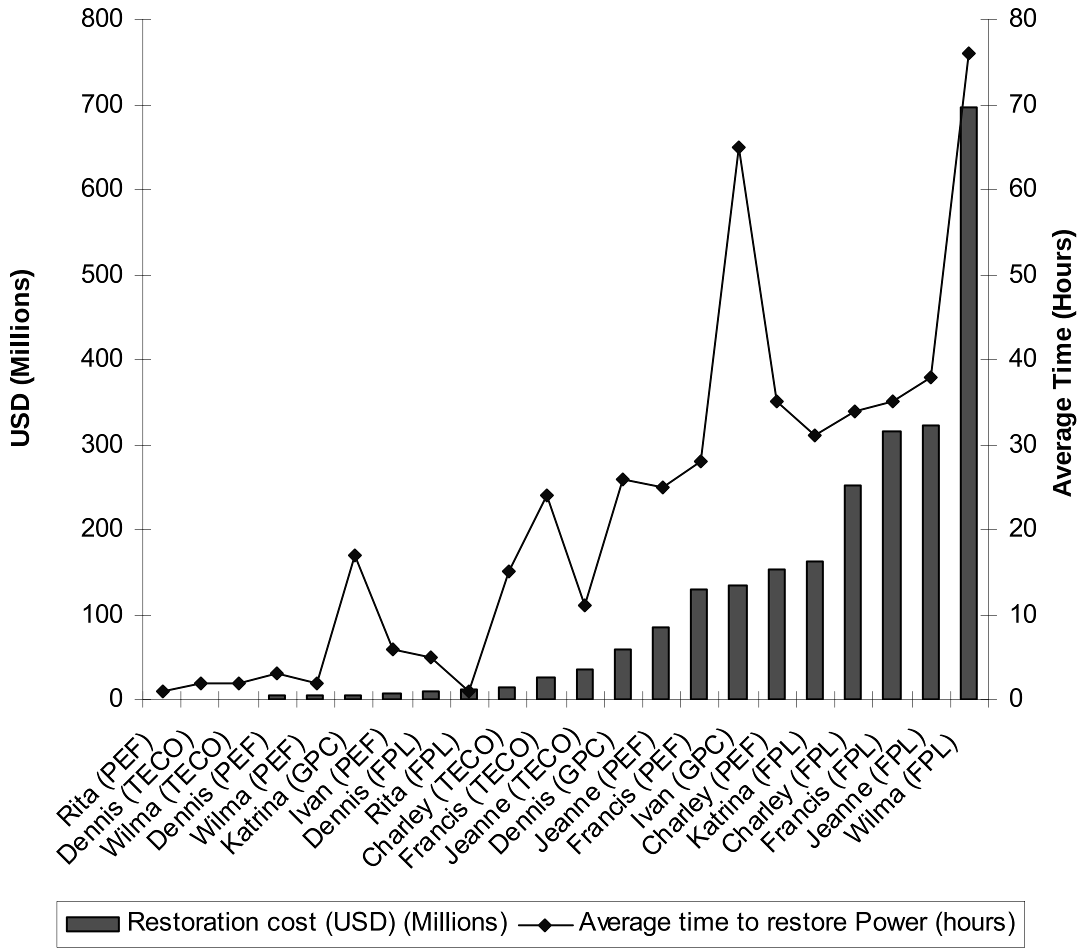


Figure 7. Ascending figure of restoration cost and average time to restore power

The Pearson product moment correlation (10) to measure the strength of the linear relation in the sample paired values was used to test the null hypothesis stated earlier. The

Pearson product moment correlation can be referred to as the Pearson *r* or the linear correlation coefficient (Wasson, 2007, p. 2). The Pearson *r* is used to measure the strength of the relationship between restoration cost (x) and the average time to restore power (y). The calculation of the linear correlation (*r*) was made by use of the following equation (Wasson, 2007, p. 3).

$$r = \frac{n \Sigma xy - (\Sigma x)(\Sigma y)}{\sqrt{n \Sigma x^2 - (\Sigma x)^2} \sqrt{n \Sigma y^2 - (\Sigma y)^2}} \qquad (10)$$

Where: n = the number of pairs of data
x = the restoration cost
y = the average time to restore power
r = the computed value of the Pearson *r*

Table 3

Calculation of Pearson r.

Year	Hurricane Name & IOU	Category of Hurricane in Florida	Restoration cost (USD) (Millions) (*x*)	Average time to restore Power (hours) (*y*)	*xy*	*x* (squared)	*y* (squared)
2005	Rita (PEF)	2	0.3	1	0.3	0.09	1
2005	Dennis (TECO)	3	0.3	2	0.6	0.09	4
2005	Wilma (TECO)	3	0.3	2	0.6	0.09	4
2005	Dennis (PEF)	3	3.6	3	10.8	12.96	9
2005	Wilma (PEF)	3	3.8	2	7.6	14.44	4
2005	Katrina (GPC)	2	4	17	68	16	289
2004	Ivan (PEF)	3	8	6	48	64	36
2005	Dennis (FPL)	3	10	5	50	100	25
2005	Rita (FPL)	2	12	1	12	144	1
2004	Charley (TECO)	4	13.9	15	208.5	193.21	225
2004	Francis (TECO)	2	25.3	24	607.2	640.09	576
2004	Jeanne (TECO)	3	34.2	11	376.2	1169.64	121
2005	Dennis (GPC)	3	59	26	1534	3481	676
2004	Jeanne (PEF)	3	84	25	2100	7056	625
2004	Francis (PEF)	2	130	28	3640	16900	784
2004	Ivan (GPC)	3	134	65	8710	17956	4225
2004	Charley (PEF)	4	152	35	5320	23104	1225
2005	Katrina (FPL)	2	162	31	5022	26244	961
2004	Charley (FPL)	4	252	34	8568	63504	1156
2004	Francis (FPL)	2	316	35	11060	99856	1225
2004	Jeanne (FPL)	3	322	38	12236	103684	1444
2005	Wilma (FPL)	3	696	76	52896	484416	5776
Sum			2422.7	482	112475.8	848555.61	19392
		***r* =**	**0.82863725**				
		***t* =**	**6.619991887**				

A significance level of α = .05 was chosen for the *t* test to minimize the possibility of a Type I error. The significance level of α = .05 defines the region where there is probability of 0.05 that the H_0 is rejected if the null hypothesis is true . When the number of pairs of data n = 22 and α = .05 equates to a critical value of the Pearson *r* correlation coefficient test statistic is tabulated a value of .404 (Mercer 2007, p. 2). The calculated value of the sample correlation equaled 0.828. The result was larger than 0.404 and the null hypothesis that there is no correlation between restoration cost and the average time to restore power was rejected.

To determine a positive relationship between restoration cost and the average time to restore power the hypothesis was changed to test for a right tailed test of the population.

H_0: The relationship between repair cost and outage duration is not a positive relationship; that is, $\rho \leq 0$, where ρ is the correlation coefficient.

H_1: The relationship between repair cost and outage duration is a positive relationship; that is, $\rho > 0$.

The test statistic was calculated of the sample using the equation for *t*. The table of critical values of the *t* distribution (Aczel & Sounderpandian, 2002, p. 839) at a significant level of α= .05 the critical value with degrees of freedom of 20 (degrees of freedom = (n-2) where: n=22) is 1.725. The calculated *t* where r = +0.828 and n = 22 is t = 6.619. Since *t* is greater than 0 and t : 6.619 > 1.725 the null hypothesis can be rejected. Aczel and Sounderpandian (2002) stated, "When *r* is large and positive (closer to +1), we say that the two variables are highly correlated in a positive way" (p. 461).

There exists a significant positive correlation between the average time to restore power and restoration cost with α = .05. The following scatter plot (figure 8) identifies the average time to restore power as compared to restoration cost for the Florida hurricanes between 2004 and 2005. The dots indicate the point where the average time to restore power intersects with the restoration cost for each power utility reporting a failure after a hurricane. Each point indicates a separate utility and hurricane event.

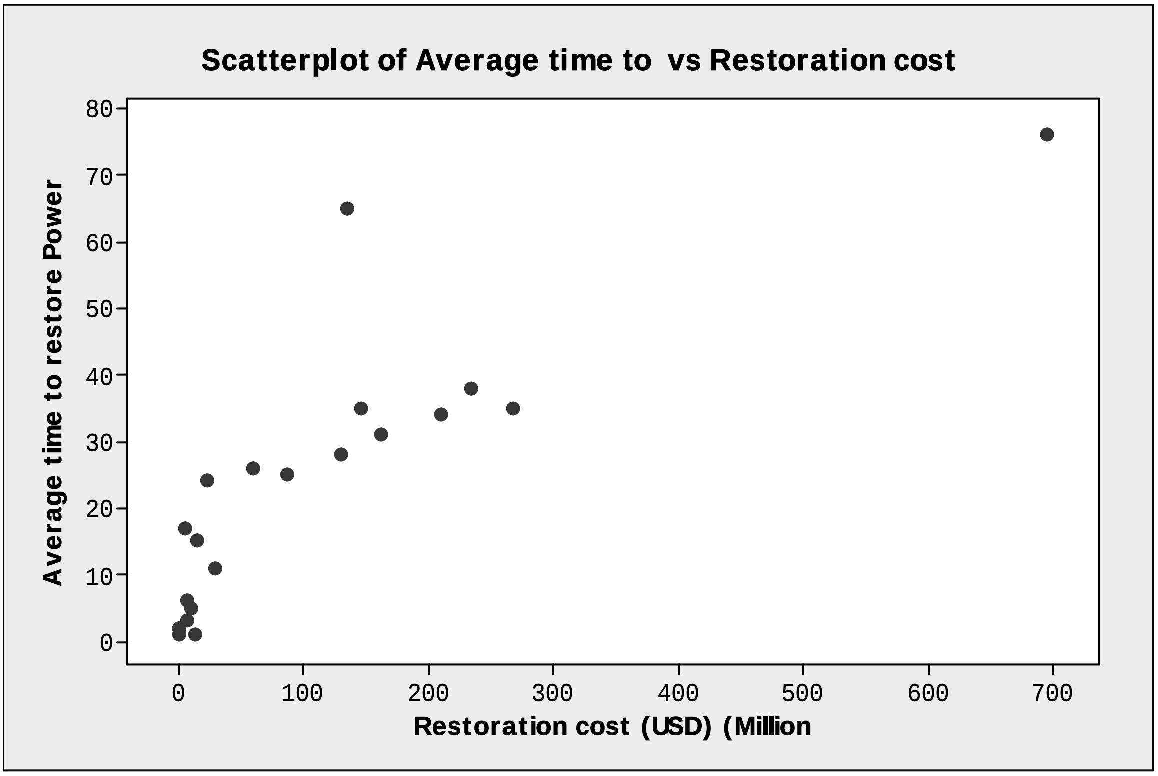


Figure 8. Scatter plot of restoration cost compared to average time to restore power.

The analysis is consistent with Chen, Allen, and Billington (1995) in that as the duration of the loss of utility power is longer the cost to restore power and customer material loss increases.

Calculation of Probability of Failure

Hypothesis 1 shows a correlation does exist between the average time to restore power and the restoration cost. With a normal distribution the probability of failure using a first order of reliability method is calculated (Ayyub & McCuen, 2003). The failure region is the point where the power is lost. The assumption was made that the supply and demand of material supplies is a normal distribution with the random variable being the cost to restore power.

The investor-owned utility reliability was calculated as described by Thomas (2002) in the discussion on determining the effectiveness of a supply chain to provide goods and services during and directly after a crisis. The impact on the electrical power system of generation, transmission, and distribution by a hurricane establishes a unique and random crisis to the investor-owned utilities' electrical equipment.

The investor-owned utility probability of failures begins with the calculation of the mean and standard deviation for restoration cost and outage duration. The values are calculated using each investor-owned utility and hurricane event (Table 2). In computation of the cumulative restoration cost the mean of the investor-owned utilities is found to be 110.2 USD with a standard deviation of 166.44 USD. The cumulative average time to restore power is found to be 21.91 hours with a standard deviation of 20.51 hours. Using the calculation for the cumulative supply contingency reliability index (β) is calculated using equation (7) as $\beta = .52$ from the table for cumulative distribution function of a normal curve (Ayyub & McCuen, 2003, p. 494) $\phi(\beta) = .698468$. Using equation 6 the probability of failure is .301532. There is a 30.1 percentage of failure that the factors of restoration cost or outage duration or the combination of restoration cost and outage duration would exceed the mean value (Low & Phoon, 2002). The investor-owned utilities contingency logistic system probability of failure for cost of hurricane repair is calculated and shown in Table 4. The calculation is made by using equation (9) for each investor-owned utility. The reliability index is calculated using equation (8) with the cumulative sample standard deviation for cost $s_z = 166.44$ USD and the cumulative normal distribution sample mean for cost $\overline{x_z} = 110.2$ USD. The contingency logistic system probability of failure (CLS-p) provides indication of how far the cost was the distance from the mean value.

Table 4

Reliability Index for Investor-owned Utilities.

Year	Hurricane Name	Investor Owned Electric Utility	Restoration cost (USD)	Average time to restore Power	Reliability index for each IOU	cumulative distribution function	Probability of Failure (CLS-p)
2004	Charley	FPL	252	34	0.8521635	0.802337	0.197663
2004	Charley	PEF	152	35	0.2512019	0.598706	0.401294
2004	Charley	TECO	13.9	15	-0.578726	0.715661	0.284339
2004	Frances	FPL	316	35	1.2367788	0.890651	0.109349
2004	Frances	PEF	130	28	0.1189904	0.543796	0.456204
2004	Frances	TECO	25.3	24	-0.5102163	0.694975	0.305025
2004	Ivan	GPC	134	65	0.1430288	0.555671	0.444329
2004	Ivan	PEF	8	6	-0.6141827	0.729069	0.270931
2004	Jeanne	FPL	322	38	1.2728365	0.897958	0.102042
2004	Jeanne	PEF	84	25	-0.1574519	0.559618	0.440382
2004	Jeanne	TECO	34.2	11	-0.4567308	0.673645	0.326355
2005	Dennis	FPL	10	5	-0.6021635	0.725747	0.274253
2005	Dennis	GPC	59	26	-0.3076923	0.617912	0.382088
2005	Dennis	PEF	3.6	3	-0.640625	0.738914	0.261086
2005	Dennis	TECO	0.3	2	-0.6604567	0.745374	0.254626
2005	Katrina	FPL	162	31	0.3112981	0.61272	0.38728
2005	Katrina	GPC	4	17	-0.6382212	0.735653	0.264347
2005	Rita	FPL	12	1	-0.5901442	0.722405	0.277595
2005	Rita	PEF	0.3	1	-0.6604567	0.74374	0.25626
2005	Wilma	FPL	696	76	3.5204327	0.999784	0.000216
2005	Wilma	PEF	3.8	2	-0.6394231	0.735653	0.264347
2005	Wilma	TECO	0.3	2	-0.6604567	0.74374	0.25626

Note. The cumulative distribution function is from Ayyub and McCuen (2003, Appendix A) Table A-1.

Calculation of IEEE Reliability Indices

For this analysis electrical power system reliability was calculated using a set of the Institute of Electrical and Electronic Engineers (IEEE) reliability indices. The IEEE developed the reliability indices to provide consistent factors in which electrical power utilities report service reliability. The IEEE distribution reliability indices were also developed to provide a constant set of factors for reporting utility reliability that can be used in external analysis of electrical utilities for comparison (IEEE, 2004, p. 1). The factors used in this analysis are the factors that deal with power interruption in order to evaluate the performance of the investor-owned utility during the period of time needed to deal with a specific hurricane.

The first factor is system average interruption frequency index (SAIFI) equation (2) and it is calculated by dividing the sum of the total number of customers interrupted by the total number of customers served. SAIFI provides an indication of how often the customer experiences a loss of power after a specific hurricane.

The system average interruption duration index (SAIDI) equation (3) provides a method to measure the amount of time the average customer was out of power during or after the individual hurricane event. SAIDI is calculated by dividing the sum of customer interruption durations by the total number of customers served.

The customer average interruption duration index (CAIDI) equation (1) is calculated by dividing the sum of customer interruption duration by total number of customers interrupted. Mathematically the CAIDI is the a weighted average and the product of the SAIDI divided by the SAIFI. CAIDI provides an indication of the average time required for the investor-owned utility to restore electrical power during or after a specific hurricane event in Florida.

The Florida PSC (2006) released a report on the enhancement of the power systems providing the raw data necessary to determine the reliability factors. The Florida PSC and the Florida Regional Coordinating Council (FRCC) periodically requires the investor-owned utility to report the power system reliability based on the IEEE reliability indices. These periodic reports provide special considerations for the investor-owned utility to report their reliability. In some cases the system reliability reported by the investor-owned utility would not be reported due to special considerations or were factored into the annual report (Florida PSC, 2006, p. 5). Therefore for this analysis it was necessary to individually calculate the IEEE reliability indices for each investor-owned utility and each hurricane. The individual calculation by investor-owned utility and hurricane provides a consistent factor in a specific period of time. The specific time used was the investor-owned utility reported average time to restore power after each hurricane event.

Table 5

IEEE Indices for Investor-owned Utilities.

Year	Hurricane	IOU	Total Number of Customers served	Number of Customers Interupted	SAIFI	SAIDI	CAIDI
2004	Charley	FPL	4189689	1424494	0.34	11.56	34
2004	Charley	PEF	1541402	739873	0.48	16.8	35
2004	Charley	TECO	627620	100419	0.16	2.4	15
2004	Frances	FPL	4189689	3603133	0.86	30.1	35
2004	Frances	PEF	1541402	1186880	0.77	21.56	28
2004	Frances	TECO	627620	94143	0.15	3.6	24
2004	Ivan	GPC	395774	846956	2.14	139.1	65
2004	Ivan	PEF	1541402	30828	0.02	0.12	6
2004	Jeanne	FPL	4189689	2178638	0.52	19.76	38
2004	Jeanne	PEF	1541402	1217708	0.79	19.75	25
2004	Jeanne	TECO	627620	25105	0.04	0.44	11
2005	Dennis	FPL	4360199	436020	0.1	0.5	5
2005	Dennis	GPC	408641	674258	1.65	42.9	26
2005	Dennis	PEF	1579806	157981	0.1	0.3	3
2005	Dennis	TECO	646735	32337	0.05	0.1	2
2005	Katrina	FPL	4360199	1744080	0.4	12.4	31
2005	Katrina	GPC	408641	257444	0.63	10.71	17
2005	Rita	FPL	4360199	130806	0.03	0.03	1
2005	Rita	PEF	1579806	31596	0.02	0.02	1
2005	Wilma	FPL	4360199	3662567	0.84	63.84	76
2005	Wilma	PEF	1579806	189577	0.12	0.24	2
2005	Wilma	TECO	646735	45271	0.07	0.14	2

Note. These data are from *Report to the Legislature on Enhancing the Reliability of Florida's Distribution and Transmission Grids During Extreme Weather* by Florida Public Service Commission, 2007, p. 15. Copyright 2007 Florida PSC. *Florida Power & Light Co.: Response to information requests 1/23/2006 commission staff workshop.* by Florida Public Service Commission, (2006), p. 3. Copyright 2006 Florida PSC. *PEF: Responses to E.I.W. data request.* by Florida Public Service Commission, 2006, p. 3. Copyright 2006 Florida PSC. *Tampa Electric: Responses commission staff workshop questions electric utility infrastructure.* by Florida Public Service Commission, 2006, p. 1. Copyright 2006 Florida PSC. Reprinted with permission.

Hypothesis Two

The second hypothesis is concerned with the impact of a hurricane by using Thomas's (2002) theory that contingency logistics supply is based on the probability of failure for the supply site to provide the necessary support. The second hypothesis identifies that there is an association between contingency logistic system cost of repair and the electrical power system reliability for a hurricane. This analysis is to test the ability for the investor-owned utility to provide electrical power using the cost of power restoration after a hurricane in Florida and the average time to restore power against the hurricane category in Florida and the event related investor-owned utility IEEE reliability indices. A correlation was determined between the contingency logistics system probability of failure (CLS-p), the hurricane category in Florida, system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI), and customer average interruption duration index (CAIDI).

The dependant variable (y) was the probability of failure of the contingency logistics supply with the predictors being the individual hurricane average sustaining wind over Florida and the calculated IEEE reliability indices. A statistical hypothesis test of the linear relationship between the dependent variable (y) the independent variables was used to determine if the coefficients of the independent variables are equal to zero was performed.

(H_0): The hurricane average sustaining wind over Florida and the calculated IEEE reliability indices could not be used as predictors in determination of contingency logistics system cost of repair (CLS-p) for each investor-owned utility, $b_j = 0$.

(H_1) The hurricane average sustaining wind over Florida and the calculated IEEE reliability indices have a direct determination of contingency logistics system cost of repair (CLS-p) for each investor-owned utility, $b_j \neq 0$.

In order to evaluate the CLS probability of failure multiple regression must be used with the estimated regression relationship equation (Aczel & Sounderpandian, 2002, p. 505).

$$y_j = b_0 + b_1x_1 + b_2x_2 + \ldots + b_jx_j + e_j \text{ where: } j = 1, \ldots, n \qquad (11)$$

Where: y_i = probability of failure of the (CLS-p)

b_j = sample estimates of the coefficient

x_1 = hurricane average sustained wind speed

x_2 = system average interruption frequency index (SAIFI)

x_3 = system average interruption duration index (SAIDI)

x_4 = customer average interruption duration index (CAIDI)

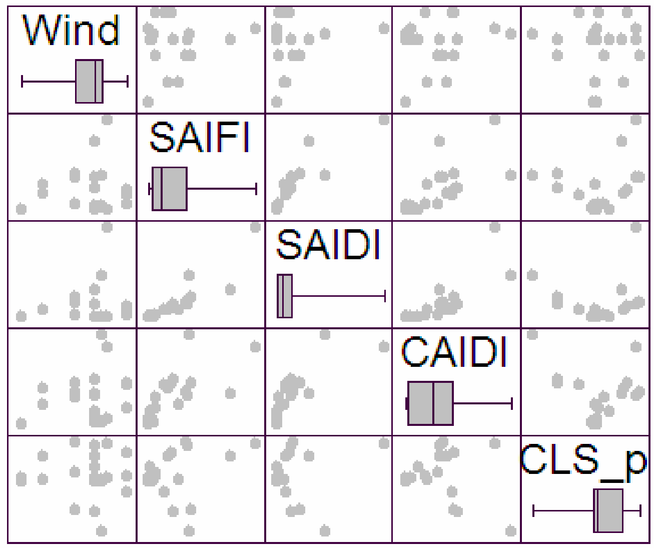


Figure 9. Scatterplot matrix of Florida hurricane CLS probability of failure and IEEE indices.

In order to visually analyze the data a matrix plot of the hurricane average sustained winds over Florida (Wind), SAIFI, SAIDI, CAIDI, and probability of failure of the contingency logistic system (CLS-p) was produced in Figure 9 using Statgraphics™. Figure 9 indicates that there is an indication of linear relationship between the individual coefficients of SAIDI, SAIFI, CAIDI, and each other. The coefficients of Wind and CLS-p do not indicate an individual linear relationship.

Table 6

Significance of Independent Variables

		Standard	*T*	
Parameter	*Estimate*	*Error*	*Statistic*	*P-Value*
CONSTANT	0.265	0.114	2.31	0.0334
Wind	0.000264	0.000997	0.265	0.7941
SAIFI	0.163	0.0945	1.73	0.1025
SAIDI	-0.000121	0.00192	-0.063	0.9505
CAIDI	-0.00395	0.0019	-2.08	0.0530

The result identified in Table 6 indicates the significance of the independent variables wind, SAIFI, SAIDI, and CAIDI using Statgraphics software. The dependant variable (y) in this analysis is CLS-p. The regression coefficients, standard error, *t* statistic and p-value were calculated from the data set identified in table 5.

Breyfogle (2003) identified that in performance of a multiple regression analysis if the predictor value (p-value) is less than or equal to 0.05 the independent variable, the null hypothesis, is rejected and the variable is considered statistically significant (p. 535). Values greater than 0.10 indicate that there is no linear relationship and removed from the model. The result indicated in Table 6 for the p-values calculated for independent variables of wind and SAIDI indicate there may not be linear relationship between these variables and CLS-p. The multiple regression analysis was performed again using Statgraphics software with SAIFI and CAIDI as independent variables with the dependant variable being CLS-p.

Table 7

Significance of Variables for SAIFI and CAIDI

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	0.295	0.0315	9.35	0.0000
SAIFI	0.158	0.0564	2.79	0.0116
CAIDI	-0.00391	0.00152	-2.57	0.0187

Table 8

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	0.0837	2	0.0418	4.23	0.0302
Residual	0.188	19	0.00989		
Total (Corr.)	0.272	21			

The p-value in Table 7 and the analysis of variance (ANOVA) in Table 8 is less than 0.05 and indicates that there is a significant relationship between CLS-p, SAIFI, and CAIDI at a 95% confidence level. The resultant fitted line equation from the multiple regression analysis is as follows:

$$\text{CLS-p} = 0.295 + 0.158\text{SAIFI} - 0.00391\text{CAIDI} \qquad (12)$$

The R-squared statistic indicates that the model data explains 30.8% of CLS-p. An excellent fit of the R-squared statistic would be 100% while a poor fit of the data would be 0. The adjusted R-squared statistic accommodates for the degrees of freedom determined by sample size and number of variables. The adjusted R-squared statistic as calculated in Statgraphics software is 23.5%. The adjusted R-squared static is used to explain data other than the model data.

R-squared = 30.8 percent

R-squared (adjusted for degrees of freedom) = 23.5 percent

Standard Error of Estimate = 0.0995

Mean absolute error = 0.0751

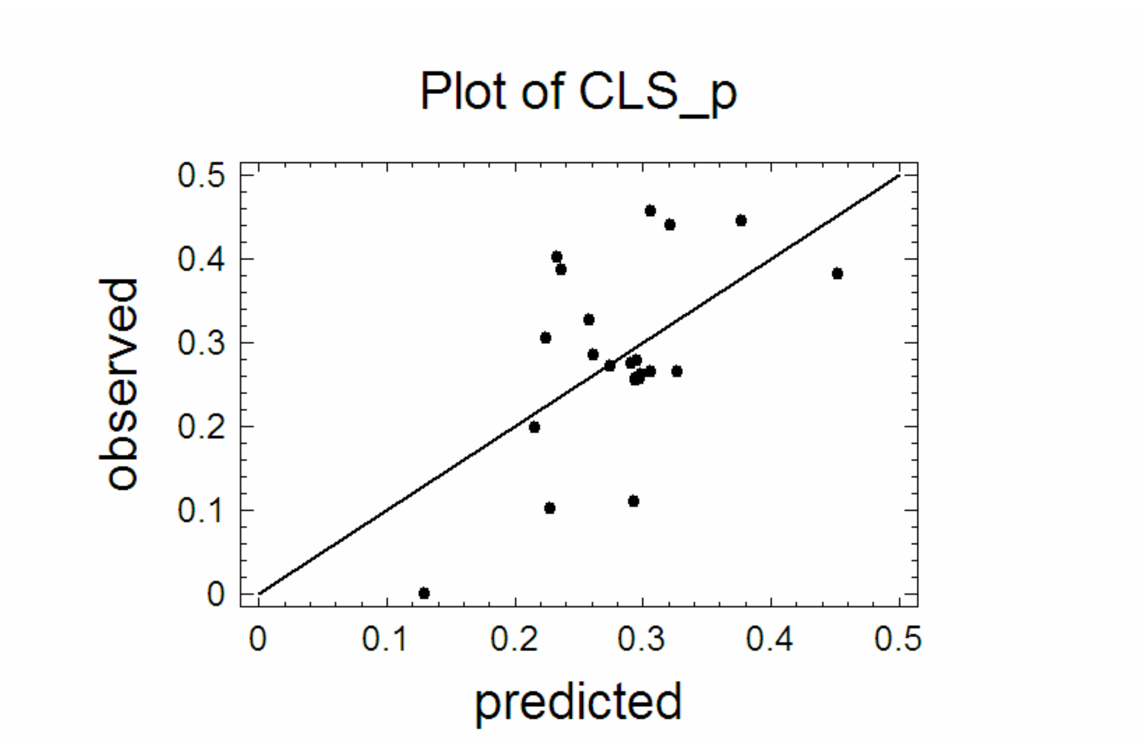


Figure 10. Graph of residuals.

Figure 10 indicates the graph of the normal probability plot of the independent variables comparison to the Florida CLS probability of failure using the resulting multiple regression equation. The residual number is the difference of the fitted value subtracted by the actual value (Aczel & Sounderpandian, 2002). The graph indicates a near linear relationship and a near normal distribution.

The hypothesis test used is a two tailed *t* test to determine whether to accept the null hypothesis using the SAIFI test statistic of 2.79 and the CAIDI test statistic of -2.57

from Table 10. The significance level is 5%, but since this is a two tailed *t* test the 97.5th percentile of the *t* distribution is used (half of the significance level on each tail). The degrees of freedom was calculated to be 19 (Pardoe, 2006).

$$n\text{-}k\text{-}1 = \text{degree of freedom} \tag{13}$$

Where: n = number of samples

k = number of significant variables

From Appendix C Table 3 of Aczel and Sounderpandian (2003, p. 839) the *t* distribution critical value is 2.093. The null hypothesis rejection region is any t-statistic greater than 2.093 or less than -2.093. Since the *t* statistic for SAIFI is 2.79 and is greater than 2.093 the null hypothesis is rejected in favor of the alternate hypothesis. CAIDI *t* statistic of -2.57 was found less than the critical value of -2.093 and therefore the null hypothesis for CAIDI is rejected in favor of the alternate hypothesis.

There were two points that affected these data because of their difference from the other points. Two outliers identified in the bar graph (Figure 7) and scatter plot (Figure 8) of cost and average time have different characteristics than common hurricane events. One point identified the longer than average outage duration at a lower than average cost of repair for Gulf Power in their response to hurricane Ivan. The second point identified in the analysis was Florida Power and Light's response to hurricane Wilma that reported the largest cost impact and longest outage duration. Added analysis performed determined the Cook's distance of the two points (Pardoe, 2006, p. 171). Minitab software was used to calculate the Cook's distance. The regression analysis found that with or without the two points, there was no significant difference in the results. The conclusion was that while the points have a high-level of influence they have a low-level of leverage. These two data points are valid therefore removal would not be a reasonable decision without added information.

Summary

The data analysis of the cost to restore power and the duration of the outage showed that there is a positive correlation between the variables. The first supposition rejected the null hypothesis that stated the relationship between repair cost and outage duration is not a positive relationship. This analysis indicated that the outage duration caused by hurricane to the electrical power system can aid in determination of cost to repair at a 95% confidence level.

After calculation of the contingency logistic system cost of repair probability of failure and the individual investor-owned utility IEEE reliability indices a research hypothesis was postulated. The research null hypothesis identifies that the hurricane average sustaining wind over Florida and the calculated IEEE reliability indices could not be used as predictors in determination of contingency logistics system cost failure probability for each investor-owned utility. The research, using multiple regression analysis, failed to reject the research hypothesis for the use of system average interruption duration index (SAIDI) and the hurricane average sustaining wind (Wind) for predictors of contingency logistics system cost failure probability. The research was able to reject the null hypothesis at a 95% confidence level the second alternative hypothesis for the use of the IEEE indexes of customer average interruption index (CAIDI) and the system average interruption frequency (SAIFI). This supposition identifies that the IEEE indexes of SAIFI and CAIDI can be used as a predictor of the contingency logistics system cost failure probability for each investor-owned utility.

CHAPTER 5: SUMMARY, CONCLUSION, AND RECOMMENDATIONS

Summary

Power restoration cost and outage duration are continuing concerns in Florida because of the inevitability of hurricanes. A hurricane event ravages the electrical power system and extensive power outages occur. The problem of restoring consumer electrical power in Florida after a hurricane is dependent on the capacity of the investor-owned utility to provide repair. The problem is the standardized electrical power system reliability calculations do not use repair cost to represent investor-owned utility performance. Hurricane repair cost can impact utility rate structure paid by consumers. The research offers several findings concerning the relationship among electrical restoration cost, consumer outage duration, hurricane wind field, and electrical reliability because of the severe weather that occurred in Florida during 2004 and 2005 hurricane seasons.

The results of the research showed there is an association between the cost of investor-owned utility post hurricane repair and consumer electrical outage duration. An added finding of the research is a correlation between the contingency logistics system cost failure probability and the Institute of Electrical and Electronic Engineers (IEEE) standard utility reliability indices. The research method used is a quantitative case study to determine the correlation between the investor-owned utility post hurricane cost and consumer outage duration. The theoretical foundation stems from reliability inference theory and first order reliability method of a contingency logistics system. The questions answered by this research focused on the capacity to supply materials to the utilities and the ability to supply such material when hurricanes affect Florida. Archival data for both investor-owned utility post hurricane cost and consumer electrical power restoration time determined supply chain reliability. The Florida Public Service Commission and the U.S. Department of Energy provided these data.

Interpretation of Findings

Several conclusions stemmed from this research. First, the research supported a research statement by Chen, Allen, and Billington (1995): The longer the electrical power outage occurs the greater the cost of repair. The answer to the research question associating repair cost and electrical power outages experienced by the investor-owned utilities in Florida indicated there is a positive correlation between repair cost and outage duration. A review of the Florida Public Service Commission (PSC) records and statements made by spokespersons of the investor-owned utilities identified the restoration cost and average time to restore power. The research determined that a correlation did exist between restoration cost and the average time to restore power and hypothesis testing confirmed that a positive relationship did exist. The result is consistent with the first requirement in Thomas's (2002) process for estimating the reliability of a contingency logistic system. Thomas's (2002) second need is to set up failure condition of the supply chain for each site. An assumption was made that each utility has a serial supply chain with a normal probability of failure.

Third, continuing with Thomas's (2002) process for estimating the reliability of contingency operations, the reliability index estimates the probability of failure of repair cost for each investor-owned utility. The success of the contingency support determined the failure probability. The contingency logistic system probability of failure for each investor-owned utility hurricane is the dependent variable CLS-p.

The fourth research area was to determine the relationship between the dependent variable of contingency logistic system probability of failure (CLS-p) and independent variables for hurricanes. The independent variables described the condition of the electrical power system through the IEEE reliability indices and the strength of the hurricane wind. The research question of how is the contingency logistics system compared to electrical power system reliability was analyzed. The factor used for the contingency logistics system is the cost of repair failure probability. The researcher found in a multiple regression analysis of the independent variables that two of the coefficients in the regression are significantly different from zero. System average interruption duration index (SAIDI) and the hurricane average sustaining wind (Wind) were rejected as predictors of contingency logistics system cost failure probability. The research found that the IEEE indexes of customer average interruption index (CAIDI) and the system average interruption frequency (SAIFI) could be used as a predictor of the contingency logistics system cost failure probability for each investor-owned utility.

Study Limitations

The study is limited by the information provided to the Florida Public Service Commission by the investor-owned utilities. The dollar values provided did not indicate the exact material or labor used in the repairs in some cases. Specific material costs and labor expenses would enhance the study criteria. The supply providers for the investor-owned utilities and the time to delivery would further enhance a study of the post hurricane contingency logistic system.

Social Impact

The investor-owned utilities reported their annual reliability to the various oversight state and national regulators. These reports provided information to the Florida Public Service Commission to approve utility rates changes. After the hurricanes in Florida in 2004 and 2005 there was an increase in the awareness of the impact of the loss of power. Florida Public Service Commission (2006) quoted Progress Energy of Florida (2006) in discussion of hardening the power system that, "Any change from current practices that accomplishes both a reduction in the number of service interruptions and a reduction in the cost of storm restoration" (p. 11), will provide a benefit to the state of Florida.

The study provides an estimated power outage time that can be used by planning agencies to control assets to have available for contingency. In Florida, the mean value for power outage time is roughly 22 hours with a standard deviation of 20 hours. The maximum average time was 76 hours and the minimum was 1 hour. Managers can use this information to plan for standby energy sources and fuel for the standby systems. When a utility exceeds the mean and a standard deviation boundary the Florida Public Service Commission could look into why the power outages lasted longer than normal.

The research of the Florida Public Service Commission data found cost to perform the repairs ripples into the power utility rates. The power rate changes are reflective of the cost to perform the necessary post hurricane repairs. Wakileh and Pahwa

(1996) in their research on the ideal design of a power system cited the Chen, Allen, and Billington (1995) conclusion that consumer electrical outage duration is reflected in the cost of electrical power.

Smith (2006) reported that insurance does not cover damage by hurricanes to the electrical distribution or transmission infrastructure and the rate structure must burden the cost. Florida Power & Light relies upon a storm fund to cushion the cost of repair. The Florida Public Service Commission regulates the amount of money collected by the investor-owned utilities for the individual storm funds. Smith (2006) further identified that an increase post hurricane repair and fuel cost resulted in a 20% increase in consumer rates (p. A11).

This research identified that when the electrical outage is caused by a hurricane the electrical repair costs increase are associated with the length of the outage. This researcher used costs identified as the direct cost of repair by the independently owned utilities. This research shows that there is a mean value for post hurricane repair that can be used by the Florida Pubic Service Commission to evaluate the utility rate surcharges requested by the utility.

The consumer costs during an electrical outage are difficult to quantify, according to Makansi (2007, p. 17), but the psychological impact, as well as the financial impact, is large. The darkness witnessed directly after a hurricane concerns public officials. A threat exists to public safety when the power system is damaged. Makansi stated that the commercial cost because of just 1 hour of a power outage can be high. One example is the average loss to just one cell phone tower would be more than $41,000 (p. 17). The commercial cost ripples down to the consumer. Thus, reducing the duration of outage impacts not only the direct cost of repair, but auxiliary costs to the consumer as well.

Recommendations for Action

Changes by engineers in the design of power utilities reduce the impact of hurricane force winds to citizens of Florida. As an example, the city of Winter Park, Florida, a public utility, is redesigning their power distribution system to bury the power distribution lines throughout the city (Shaffer, 2006). Another engineering consideration is the debris from vegetation around the distribution and power lines causes damage during a hurricane (Florida Public Service Commission, 2006).

This study showed an indication of outage performance of the investor-owned utilities in post hurricane response. Finding out an investor-owned utility post hurricane cost points out that some utilities costs were the exception to the norm. The Florida Public Service Commission and the Florida Reliability Coordination Council could use the study results for evaluation of investor-owned utility response to discover what caused the exceptions. Consumers of the electrical power system can use the information to help in determination of how long the posthurricane power outage can last. The information on the posthurricane outage duration in Florida can aid households, public officials, and medical communities on how long they should plan to be without power.

Recommendations for Further Study

Further research of the repair cost of municipal, public, and investor-owned utilities could provide more information on what cost of repair entails. Repair material research would develop into the recommended safety stock to be available for posthurricane response. Cost could also reflect delay in receiving material from a supplier or workforce to perform work. Analysis of cost can look into delay of material or difficulties in personnel reporting for work. The assumption used in this analysis is made that each utility has a serial supply chain with a normal probability of failure (Thomas, 2002). Further research could discover a serial or parallel supply chain and as a result, whether the probability of failure was a normal, exponential, or other distribution.

Since the entire United States is interconnected through the electrical power grid how do the major power outages in the Southeast during hurricane season impact the national grid? Soon after Hurricane Katrina struck the Gulf coast on August 25, 2005, the cost of on-peak electrical power at the California-Oregon and Nevada-Oregon border reached $94.16 per megawatt hour (*The Wall Street Journal*, October 1, 2005, p. B13). The following year the cost of on peak power at the same point dropped to a cost of $39.04 per megawatt hour (*The Wall Street Journal*, September 30, 2006, p. B5). This dramatic change in the cost of a megawatt hour of electrical power could be directly related to the impact of hurricanes. Further research is needed to evaluate the cost swings at a macro economic scale.

Gulf Power experienced a longer than average outage duration at a less than average cost of repair for hurricane Ivan while Florida Power and Light experienced the longest outage and largest cost impact in hurricane Wilma. Further research to find out the reasons that caused these significant changes from the normal response characteristics can lead to an understanding of the impact of hurricanes on power utilities. The supply chain may or may not have been the problem. Gulf Power does supply a more rural area of Florida while Florida Power and Light's impact caused by hurricane Wilma was in the metropolitan area of Miami, Florida. The research question could center on how population density affects the posthurricane response.

Closing Statement

The hurricane seasons of 2004 and 2005 were the most devastating hurricane seasons in recent record in Florida. Individual hurricanes do occur in Florida every season, but the 2004-2005 seasons were one of the only times hurricanes occurred in repeated succession. Hayden (2006) quoted Bell (2005), a NOAA meteorologist, when he said "We're 11 years into the cycle. I can't tell you if it will last another ten years, or thirty" (p. 76). To support citizens the Florida Public Service Commission needs investor-owned utilities to report the impact of hurricanes to understand, learn, and plan for contingency response. This research implies an additional gauge of cost is needed evaluate how the investor-owned utilities are performing.

Since the 2004 and 2005 hurricane seasons many citizens in Florida have taken actions to provide independent electrical support through generators. The individuals, businesses, and governmental agencies prepare for an electrical utility outage by estimating the supplies available for the contingency support. Information on the reliability of the contingency to restore electrical power helps in estimation of supplies necessary. Second, analysis of the public utilities and agencies insure the costs are reflective of the response.

A change is on the horizon in the electrical industry because of increased demand, increasing cost to produce energy, federal laws, security concerns, and materials used in the electrical industry. Future regulatory agencies will need detailed evaluation of severe impacts to the electrical system. Understanding the electrical power industry response after a hurricane is one part in the larger understanding of what actions to take to prepare for unplanned electrical events in Florida.

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APPENDIX A

Approval to Perform Research

==

From: research@waldenu.edu
Date: 2007/07/17 Tue PM 02:39:56 CDT
To: mmona001@win.waldenu.edu
CC: rmaurer@win.waldenu.edu, amdsadvise@waldenu.edu
Subject: Mark Monaghan - Notification of Approval to Conduct Research

Mr. Monaghan:

This email is to serve as your notification that Walden University has approved your dissertation proposal and your application to the Institutional Review Board. As such, you are approved by Walden University to conduct research.

Please contact the Research Office at research@waldenu.edu if you have any questions.

Congratulations!

Jeff Ford
Research Coordinator
Walden University

==

Mark W. Monaghan
AMDS-Engineering Management
e-mail: mmona001@waldenu.edu

==

From: research@waldenu.edu
Date: 2007/07/17 Tue PM 02:39:24 CDT
To: mmona001@win.waldenu.edu
CC: rmaurer@win.waldenu.edu, amdsadvise@waldenu.edu
Subject: Mark Monaghan - IRB materials approved

Dear Mr. Monaghan:

This email is to notify you that the Institutional Review Board (IRB) has approved your application for the study entitled, "Analysis of Contingency Logistics Supply Chain Reliability for Power Utilities in Florida After a Hurricane."

Your approval # is 07-17-07-0058297. You will need to reference this number in the appendix of your dissertation and in any future funding or publication submissions.

Your IRB approval expires on July 17, 2008. One month before this expiration date, you will be sent a Continuing Review Form, which must be submitted if you wish to collect data beyond the approval expiration date.

Your IRB approval is contingent upon your adherence to the exact procedures described in your original application. If you need to make any changes to your research staff or procedures, you must obtain IRB approval by submitting the IRB Request for Change in Procedures Form. You will receive an IRB approval status update within 1 week of submitting the change request form and are not permitted to implement changes prior to receiving approval. Please note that Walden University does not accept responsibility or liability for research activities conducted without the IRB's approval, and the University will not accept or grant credit for student work that fails to comply with the policies and procedures related to ethical standards in research.

When you submitted your IRB application, you a made commitment to communicate both discrete adverse events and general problems to the IRB within 1 week of their occurrence/realization. Failure to do so may result in invalidation of data, loss of academic credit, and/or loss of legal protections otherwise available to the researcher.

Both the Adverse Event Reporting form and Request for Change in Procedures form can be obtained at the IRB section of the Walden web site or by emailing irb@waldenu.edu:

http://inside.waldenu.edu/c/Student_Faculty/StudentFaculty_4274.htm

Researchers are expected to keep detailed records of their research activities (i.e., participant log sheets, completed consent forms, etc.) for the same period of time they retain the original data. If, in the future, you require copies of the originally submitted IRB materials, you may request them from Walden Research Center.

Please note that this letter indicates that the IRB has approved your research. You may not begin the research phase of your dissertation, however, until you have received the Notification of Approval to Conduct Research (which indicates that your committee and Program Chair have also approved your research proposal). Once you have received this notification by email, you may begin your data collection.

Please let me know if you have any questions.

Thank you,
Jeff Ford
Research Coordinator
Walden University
==

Mark W. Monaghan
AMDS-Engineering Management
e-mail: mmona001@waldenu.edu

APPENDIX B

Permission to Reprint

Comments/Response to Case ID:

ReplyTo:

From: Jacqueline Hansson   Date: 02/09/2007

Subject: Re: Use of figure in dissertation   Send To: "Mark W. Monaghan" <ce1monag@cfl.rr.com>

cc:

Dear Mark W. Monaghan:

This is in response to your letter below, in which you have requested permission to reprint, in your upcoming thesis/dissertation, one IEEE copyrighted figure. We are happy to grant this permission.

Our only requirements are that you credit the original source (author, paper, and publication), and that the IEEE copyright line (© [Year] IEEE) appears prominently with the reprinted figure.

Sincerely yours,

Jacqueline Hansson

From: John Slemkewicz [JSlemkew@PSC.STATE.FL.US]
Sent: Friday, January 12, 2007 2:25 PM
To: ce1monag@cfl.rr.com
Cc: Tim Devlin; Marshall Willis; Cheryl Bulecza-Banks; Bill McNulty; Rhonda Hicks
Subject: Storm Damage Orders

The following is a list of the latest orders that address the recovery of storm damage costs for the four major investor-owned electric utilities in Florida.

	Document No.	Docket No.
Gulf Power Company	06060-06	060154-EI
Florida Power & Light Company	04676-06	060038-EI
Progress Energy Florida, Inc.	06678-05	041272-EI
Tampa Electric Company	05852-05	050225-EI

These documents can be accessed at our website as follows:
www.psc.state.fl.us
click on "Documents" under the "Dockets & Filings" tab
enter the document number in the "By Document Number:" box

From: Samantha Cibula [SCibula@PSC.STATE.FL.US]
Sent: Friday, September 28, 2007 4:40 PM
To: ce1monag@cfl.rr.com
Subject: Use of Commission Created Charts and Graphs

Mr. Monaghan,

The Florida Public Service Commission is in receipt of your request to include in your dissertation certain charts and graphs created by Commission staff, included in the Commission's report to the Governor and Florida Legislature. We hereby give our permission to use such materials.

Samantha Cibula, Office of the General Counsel