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AN ANALYSIS OF A HURRICANE LOSS MODEL, VALIDATION FROM TYNDALL AFB, AND APPLICATIONS FOR THE AIR FORCE

THESIS

Nestor Hernandez, Second Lieutenant, USAF

AFIT-ENV-MS-20-M-211

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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THESIS

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In Partial Fulfillment of the Requirements for the

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Nestor Hernandez, BS

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AN ANALYSIS OF A HURRICANE LOSS MODEL, VALIDATION FROM

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Abstract

The recent reconstruction of infrastructure and its associated cost due to hurricanes justify research into hurricane loss models that can provide a more robust cost estimate. Academic research indicates that hurricane disasters are becoming more frequent and are becoming costlier. This research intends to explore hurricane loss models used by the Federal Emergency Management Agency (FEMA), Risk Management Solution (RMS) and Florida State University (FSU). Within the literature review, key components of hurricane loss models were identified. These models and the key components were explored in order to help bring an understanding of loss estimation. The research found that the implementation of the HAZUS model may aid in calculating the replacement cost of buildings using the specific building loss functions. The building loss functions are dependent on terrain type and building characteristics, however. HAZUS user define facilities capability reports the probability of specific building damage, however not the replacement cost. The generic building stock results prove to be off by approximately 70% when comparing building averages. The building loss functions results prove to be off by approximately 195% and the user define facilities proved to be off by approximately 438% when comparing building to building results. The limitations included unavailable awarded contracts, the analysis was only applied to 41 buildings and that default generic building stock data within the software. Within the DoD, HAZUS conveys that rougher terrain and masonry buildings can be advantageous when building near the shore. Using the building loss functions method is a simpler, quicker and

standardized approach to get replacement cost results. Overall, this research determined that HAZUS may give valuable insight when looking at hurricane strikes in a study region.

Acknowledgments

I would like to express my sincere appreciation to my faculty advisor, Lt Col Hoisington, for his guidance and support throughout the course of this thesis effort. The insight and experience was certainly appreciated. I would also like to thank my family and friends for both the support and latitude provided to me in this endeavor.

Nestor Hernandez

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AN ANALYSIS OF HURRICANE LOSS MODELS AND THEIR USE WITHIN THE AIR FORCE

I. Introduction

General Issue

"Plans are worthless, but planning is everything."

- President Dwight D. Eisenhower, National Defense Executive Reserve Conference, 1957.

The words from President Eisenhower gave, while discussing emergency situations are still relevant in 2020, after the fourth highest year of weather and climate disasters behind the years 2017, 2011 and 2016 respectively [1]. In addition, the United States also experienced the fourth highest total costs of natural disasters at $91 billion, only surpassed by the years 2017, 2005 and 2012 [1]. Though the $91 billion included all weather and climate disasters, eight of those events were hurricanes. Out of those eight, two were a category 3 or higher totaling a cost of $49B (53.8% of the total cost) [2]. Hurricane Michael was one of the two and was reclassified from a Category 4 to a Category 5, making just the fourth Category 5 hurricane to land in the continental U.S. in recorded history [3]. As most of these greater than or equal to three category hurricanes have occurred within the last decade, a growing concern has been determining the building repair costs and time it takes organizations to recover [4], [5].

The purpose of this research stems from recent government reports regarding the accuracy of the building replacement cost assessments [6]. The accuracy of these building replacement cost assessments can prove to be beneficial as underbudgeting, restructuring of money, goal derailment, incomplete projects, lower profit margin and ultimately debt could be the aftermath of such mistakes. The objective of this research is to determine the optimal hurricane loss model to use following a landfall in order to plan more appropriately. Catastrophes like Katrina sparked great interest in capturing a more detailed method of capturing losses [7]. Before the early 2000s and late 1990s most models where based off an actuarial methodology which relied heavily on historical data. Moving forward, a push towards hurricane simulation modeling, coupled with building behavior and even economic tendencies has been part of hurricane loss models attempt to improve prediction.

Problem Statement

The research stems from the struggles following Hurricane Michael in 2018. The hurricane has taken its toll in Panama City, Florida and has affected business, to include the Air Force. Tyndall AFB loss has proven to be a multidimensional problem as the recovery processes, and all other stages of reconstruction (A/E design, procurement, construction, etc.) has seen its fair share of issues. Implementing a hurricane loss model in scenarios like Tyndall AFB may help more accurately depict the cost associated with the damage. This research hopes to show the implications of hurricane loss models and how, if employed, can ease the recovery process and get a military installation back to normal operations.

Today, the Air Force does not accurately estimate hurricane damage costs. Being able to estimate the cost of hurricane damage is a difficult problem to solve and having a systematic approach, that is reliable, is needed. Finding the best way to approach hurricane losses within DoD installations may save time, money and ultimately impact the greater mission of the DoD. The end goal of this thesis is to convey if HAZUS can reflect reliable cost estimates and be used as a planning tool to generate a proactive response rather than reactive responses from organizations vulnerable to hurricane catastrophes.

Research Objectives

This research aims to answer the following questions:

1. Of the three methods analyzed, which one is the most effective?
2. Is HAZUS a reliable tool for replacement cost estimates?
3. How can the Air Force and DoD apply the best hurricane loss model?

Thesis Organization

The thesis presented follows a traditional style format. It begins with a literature review on hurricanes, economic losses and an overview of what is found in hurricane loss models. It also gives an explanation of each model's respective build up. This section gives details and schematics as to how each model works and where they were derived. Furthermore, an explanation as to why the models were chosen for comparison is included. HAZUS was the model implemented for further analysis. The methodology section conveys the data used and how it was cleaned up. It also conveys the three methods used within HAZUS to compare results to the Tyndall AFB assessment. Next is the results and discussion section. Within this section, the HAZUS results is conveyed. Following the results, the discussion gets into suggested conclusions and what the results indicate. Lastly, there is a conclusion of the research, the significance of it and recommendations for future research.

II. Literature Review

Chapter Overview

The purpose of this chapter is to capture relevant research for hurricane loss models. It explains hurricanes and how they are categorized. The literature review also conveys the impact hurricanes have had in terms of economic losses and describes the major components of a hurricane loss model. Furthermore, an explanation of each hurricane loss model is given and a reasoning why HAZUS was the one that was chosen for analysis.

Relevant Research

Hurricanes

Hurricanes are categorized into five levels in the Saffir-Simpson Hurricane Wind Scale. The rating is based on the hurricane’s wind speed and was then used to estimate the potential destruction power of those winds. Hurricanes that have winds within a category 1 or 2 are considered minor, however, still hazardous and require preemptive actions. If a hurricane is a Category 3 or higher, than it is considered a major hurricane as it has the possibility for considerable damage and loss of life [8]. Table 1 details the categories and the damages that are associated at each level. As shown on the Saffir-Simpson Wind Scale, the higher the category the greater the damage sustained and a corresponding higher recovery cost. Indeed, cost analysts in Florida have predicted a minimum of a $1B dollar infrastructure cost every five years for their state due to hurricanes [9].

Table 1 The Saffir-Simpson Wind Scale [8].

Category	Sustained Winds	Types of Damage Due to Hurricane Winds
1	74-95 mph	Some damage will be produced: Some homes may have damage to roof, shingles, siding and gutters. Power outages could last a few to several days.
2	96-110 mph	Extensive damage will be caused: Homes could sustain major roof and siding damage. Nearly no power with outages from several days to weeks.
3 (major)	111-129 mph	Devastating damage will occur: Major damage may be incurred or removal of roof decking and gable ends. Water and electricity will be unavailable for several days to weeks after the storm.
4 (major)	130-156 mph	Catastrophic damage will occur: Severe damage with loss of most of the roof structure and/or exterior walls. Power outages will take weeks to even months. The area will be uninhabitable for weeks or months.
5 (major)	157 mph or higher	Catastrophic damage will occur: A vast majority of the homes will be destroyed. There will complete roof and wall failure. The area will be uninhabitable for weeks or months.

Economic Losses

Hurricanes cause a considerable amount of economic losses. If the Great Miami Hurricane of 1926 would have occurred in the 21st century, it would have resulted in $129B of damages [9]. Hurricane Sandy impacted over a dozen states totaling $71B in 2012 [10]. In Louisiana, the damage was approximately $125B in economic losses from hurricane Katrina. The Louisiana Katrina Reconstruction Act (S. 1765) approved up to $250 billion in spending on a wide range of activities involving federal agencies, such as the Department of Transportation (DOT), the Environmental Protection Agency (EPA), and the Army Corps of Engineers [11]. In Houston, hurricane Harvey cost $125B, the second costliest hurricane in United States History [12]. Most recently, hurricane Michael is projecting a $15B loss to Florida. [13]. The United States Air Force had a negative economic impact as Tyndall Air Force Base saw the eye of the hurricane, and it is projected to cost $3.4 billion to reconstruct [14]. Hurricanes have affected coastal economies time and time again. Over recent years, economic losses due to hurricanes have been stacking on top of each other, making the recovery efforts difficult to budget especially when building replacement costs estimates are imprecise.

Hurricane Loss Models

Hurricane loss models have been developed to estimate damages. Though many exist, they generally consist of five major components to include input information, wind model, surface friction and topography, damage/ vulnerability, and frequency of occurrence [15]. Furthermore, as acknowledged in studies, hurricane loss models are unique, complex, and difficult to comprehend as developing low probability and high severity events are often based on proprietary data that is difficult to understand from the perspective of data availability and intricacy of the models [15].

There has been an array of research on differences between hurricane models. Studies from a meteorological, engineering and insurance point of view have found differences due to assumptions related to wind fields, topography, landfall frequencies, etc. [15]–[19]. Other studies have observed differences in how the models construe a buildings structural attributes [20]. Additionally, important factors include climate conditions, global climate change, and demand surge have also been identified [20]. As a result of the differences between models, variation in loss estimates occur. Some literature finds these loss estimates to vary greatly, up to of three times as much and that the difference is noticeably higher in inland areas [15].

Input databases are used with all hurricane loss models. It is important to note the databases used influence the outputs of the results [15]. Some models use resources such as a cloud-based construction cost database and others use experience from similar projects or historical data that has been gathered [21]. RS Means is a popular database used to determine the cost of construction materials [22]. FEMA's National Flood Insurance Program (NFIP) provides most of the residential and commercial flood insurance data for anyone within the FEMA Special Flood Hazard Areas (SFHAs) [23]. Industry's methods involve lots of participation from state emergency management agencies, U.S. government agencies, insurance information sources, state and regional climate centers and even news media sources [24], [25]. Model also contain datasets related to typical a mix construction in a given area such as percentage of wood frame, steel frame and concrete block buildings [15], [26]. Additionally, a library of historical hurricane tracks and intensities are used, most of which come from the U.S. National Hurricane Center database HURDAT, or the North American Hurricane Database [15], [27]. Organizations, such as the National Oceanic and Atmospheric Administration (NOAA) acknowledge the variance and potential bias in its data collection [24]. Overall, hurricane loss models use input data with the acknowledgement that all inputs simply cannot be correct.

Wind models within hurricane loss models include various components. Generally, most models used in industry are parametric models using storm parameters such as minimum central pressure, radius of maximum winds, forward speed, etc. [15]. The overall output of these models are wind speeds at the surface level or wind speeds above the ground level, called gradient winds [15].

Winds produced by the wind models generally need correction due to the surface friction or topography of the area being analyzed. Some models use a simple multiplication factor, however the correction factor often debated within literature [28], [29]. Values ranging from 0.5 to 1.1 have been suggested depending on surface roughness [15].

Moreover, more robust models use different terrain types, trajectory of wind, ridge and valley effects [15], [30], [31].

Damage models within hurricane loss models include multiple components. The damage model associate's winds induced in an area to the damage projected in that same area. Damage functions can be grouped into three types: claims-based, engineering judgment, or theoretically based [15]. Research from actual claims submitted to insurance companies establish claims-based functions [15]. Though it may seem like a logical and an optimal method, administrative, political and other considerations vary from storm to storm [15]. As an example, a damaged structure maybe valued differently based on the storm, region, adjusters experience, and homeowner's determination. Engineering-based functions are based by engineering surveys [15]. Here also, individual interpretation may vary and conversion of observed damage to the amount it costs to reconstruct takes special attention [15]. For instance, a structural engineer may determine a building to be partially damaged, however due to case specific reasons, such as zoning, it becomes impractical to repair and the claim then would be 100% of the value [15]. Theoretical based functions use academia of structural behavior. While this method does reduce the influence of human judgment, it still needs to capture such human influence [15].

HAZUS Hurricane Loss Model

The HAZUS Hurricane Model estimates four different sections, wind induced loads, building response, damage and then economic loss[22]. Economic loss model needs the inputs of wind induced loads, building response, and damage models in order to predict the dollar amount of damage caused by a given hurricane. Understanding how the four components were derived and interact provide insight on how HAZUS works.

The hurricane hazard model is comprised of a 100,000 year simulation of storms in the Atlantic Basin and is based on the original model developed by Vickery et al.[32], [33]. It has a storm track and wind field model and has even extended its capabilities to estimate rainfall [27]. It has all historical storms in the Atlantic Basin from the years 1886 to 2001, a new model outputting the radius of winds associated with the central pressure and latitude, and other minor limitations [27]. The hurricane hazard model also has periodic updates and the most recent one includes storms from 2018. The simulation model categorizes landfalling intense hurricanes (category three or higher storms) by both central pressure and the estimated wind speed with a 95% confidence interval [27]. In order to estimate losses, the loss model saves all storm simulations in excess of 50 km/h at the location of the centroid of each on the 31,142 census tracts in the coastal states and inputs those wind speed values into the loss model, which is described later on [22], [27].

The terrain model is another component that is implemented into loss modeling. The evaluation of ground roughness, used in HAZUS, helps explain wind effects which in turn impacts the physical damage of buildings [27]. Fundamentally, the wind rate closer to the ground is slower than the upper level winds when the terrain is rougher and buildings experience higher wind loads in open field areas such as beachside locations [27]. In order to categorize ground surface roughness, z_0, HAZUS developed with its own values due to the disagreement from various studies among researchers like Wieringa, Simiu and Scalan [27]. HAZUS used land use/land cover (LULC) data and aerial photos of the same area to assign a z_0. The values of z_0 where assigned based on judgement, use of prior roughness categories found in literature and a method developed by Lettau [27]. Though there is range of $z_0$values, only the mean value of z_0 is used for each LULC category in HAZUS [26]. The z_0 values used in HAZUS are 0.03, 0.35, 0.7, and 1.0 for open terrain, typical suburban terrain, suburban terrain with some trees or densely spaced homes and treed suburban terrain respectively [26].

When it comes to physical damage, the HAZUS-HM model estimates damage to exterior components and cladding, to include, windows, roof cover, roof deck, joint failures and wall failures [22]. Furthermore, the model also estimates the damage caused from debris carried by winds [26]. The model implements a resistance and load approach to assess the damage a structure has when exposed to winds from hurricanes [22]. Structures were developed in the HAZUS-HM model to represent various building types found in industry. The model includes anything from multilevel-single family homes to low/high rise retail buildings and even industrial buildings [22]. Laboratory test data, engineering analysis, and in special cases engineering assessment has been used in statistical models in order to define the resistance of each building components [26]. The resistance values are then assigned to all the components that can fail in any given simulation carried out. Roof cover, roof trusses, metal panels, window, doors, walls and roof sheathing are some of the building components that are modeled [22]. The HAZUS-HM technical manual elaborates how each building component's, such as wood framed walls, resistance value was found. All of the assumptions pertaining to each component resistances within the model are also given in the technical manual. As an example, masonry walls resistance values, stem from the fundamentals and main assumptions of yield-line theory in structural analysis of pressure failures [26], [34]. Once the estimated loads and resistances are modeled for a structure, the wind speed and direction are observed every fifteen minutes over the entire length of the storm in order to predict the damage to the building. Using directionally dependent pressure coefficients the wind loads felt by all the components of the building are estimated such as windows and doors [22], [27]. Simultaneously, missile impact models are used to find the probability of windborne debris impact [27]. As any given fifteen minute interval completes, the resistances of the components are compared to the wind loads induced by the building and fail all components where the load exceeds the resistance [22]. Ongoing, the calculation of damage by windborne debris is executed. Should any door or window fail, the difference in internal pressure is calculated and then loads acting on all the other components, which have not failed, are recalculated with the effect of the internal pressure accounted for [22],[26]. During that same time interval, the failure of additional components are calculated [22]. Once there is no more change in internal pressure and enough building simulations have been completed the damage loss statistics are compared to the given storm [22]. The modeling approach for damage is exhibited in figure 1.

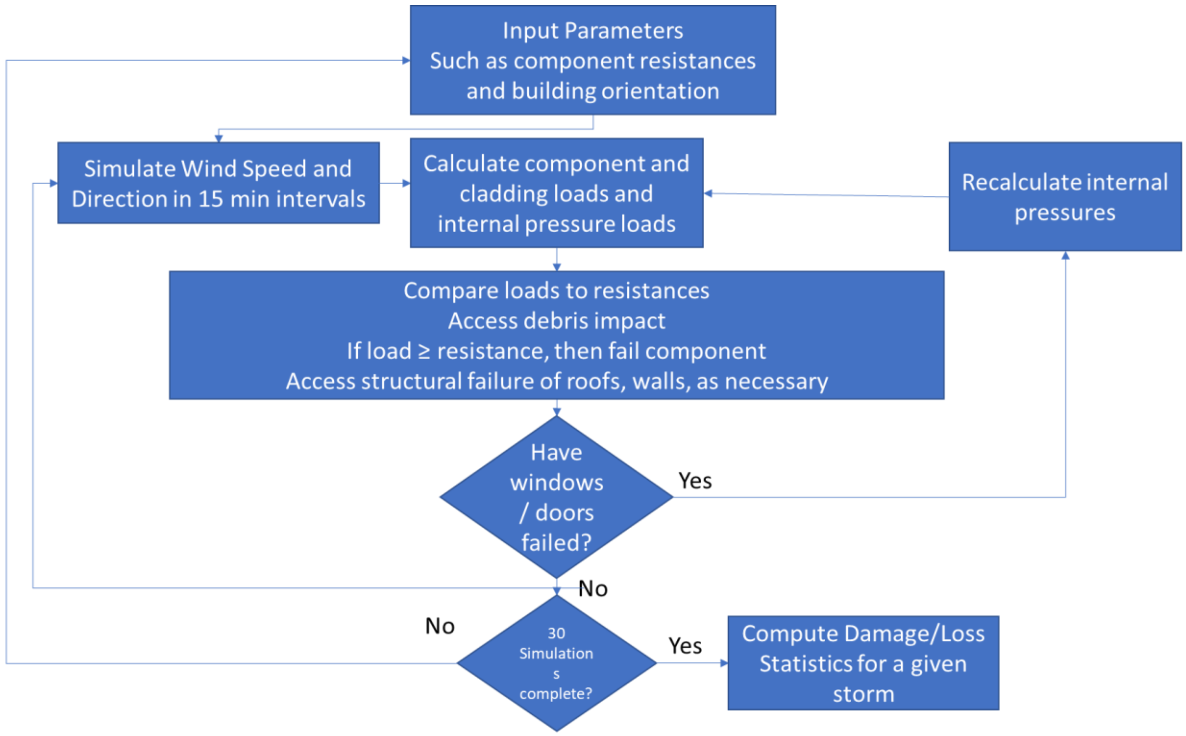

Figure 1. HAZUS hurricane damage estimation approach [derived from, 22].

Of note, the error statistics for the resistance values and model related to the wind loads are taken before the storm passes the structure and do not change for the length of the storm [22][26]. The component resistances and loading error statistics are recalculated and a new damage model simulation is redone using the same storm in order to acquire the damage statistics for any storm [22]. Thirty damage simulations are ran and every tropical cyclone used comes from a 20,000-year hurricane simulation model that has been validated comparisons of simulated and observed hurricane data in Vickery et al. published work [32], [33]. Voluminous information pertaining to building damage, rainfall breach, and peak wind speed is saved after every simulation and is used in the damage and loss analyses.

Once all the data for the simulations was collected, the HAZUS model categorized the damage states of all building types within the program. The method toward defining damage states resembled the methodology used by Vann and McDonald [35]. There were five damage states defined. The range goes from 0, or no damage, to 4, or destruction [22]. Once the damage state definitions were developed for all building types in the HAZUS HM model, damage state curves were established with the probability of the structure undergoing a given damage state against the peak gust wind speed [22].

The ability of the damage model to predict a structures state was validated by comparing the simulated data to the observed damage states for a given building type from various hurricanes from the past. What was compared includes roof cover damage, roof sheathing damage, and window damage from Hurricanes Andrew, Erin and Fran [22]. The data was pulled from various sources to include the U.S. Department of Housing and Urban Development (HUD) [22], [26], [36]. As an example, the HUD study from Hurricane Andrew was comprised of 466 random homes situated in nine distinct groups in the areas that were classified as high damage areas [36]. The results between the observed and modeled damage was acceptable, all uncertainties considered [22], [26], [36]. Figure 2 better conveys the results for various building types from Hurricane Andrew [22].

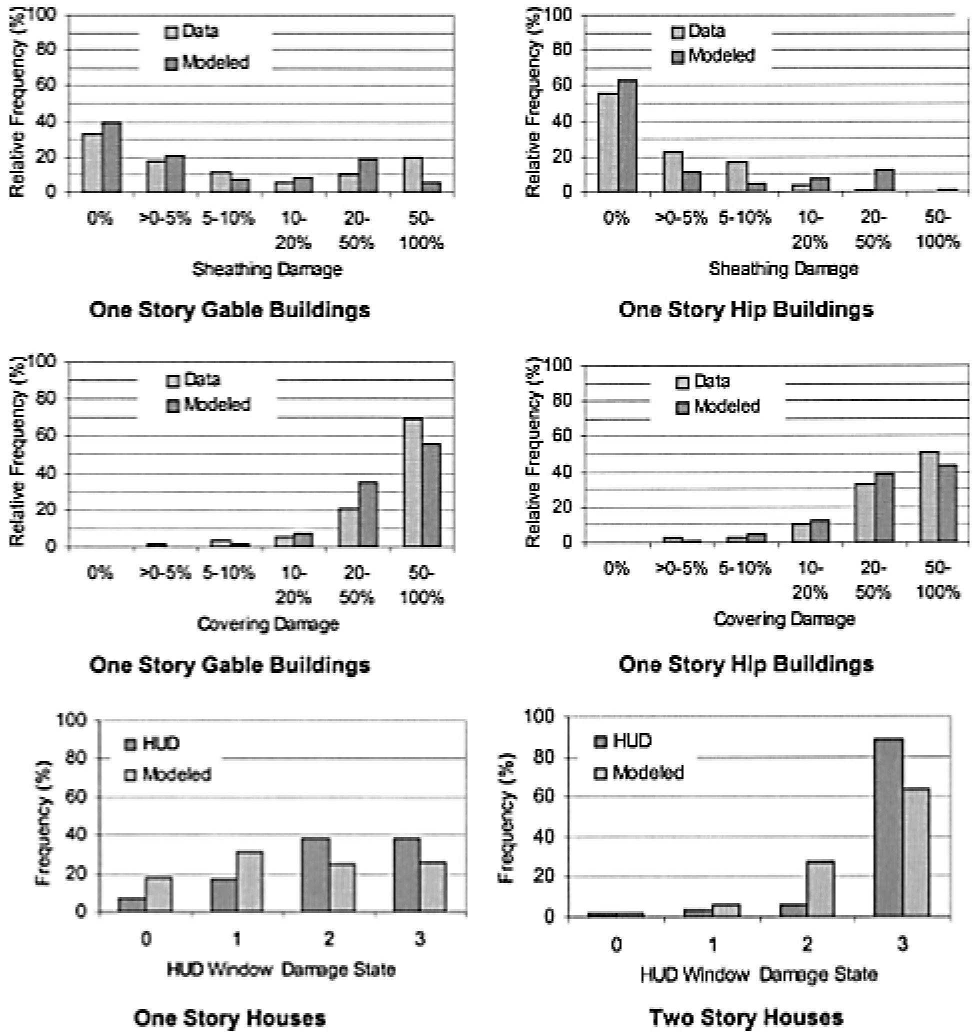

Figure 2. Modeled versus actual building damage [directly from, 22].

Finally, economic reports were created. Due to the damage models outputs, which derived from wind induced loads and building response data, the model output losses related to building, contents, and even inventory losses [22], [26]. Furthermore, if a building's use is lost, the model estimates cost related to inoperability [22]. Of note, the following description is for residential homes, however, a similar approach is used for all types of buildings such as manufactured homes, commercial buildings and essential facilities [26].

In order to figure out the dollar amount of a given building modeled in HAZUS, RS Means is used [22], [26]. The RS Means cost information is entered for all of the components a building requires and using a mixture of explicit and implicit loss functions the cost of reconstructing is calculated based on the damage of the building [22]. More specifically, the explicit cost functions output the replacement cost for the components related to the exterior of a building such as roof, walls and windows [22]. The implicit cost functions in the model were used to estimate the repair cost of interior of a building [22].

Beforehand, however, the loss model subdivides the building into costing subassemblies so that the model allows for various building types, specific configurations, and estimate flexibility. The schematic in figure 3 represents the loss model and conveys all the parameters that are needed to come up with the direct economic loss.

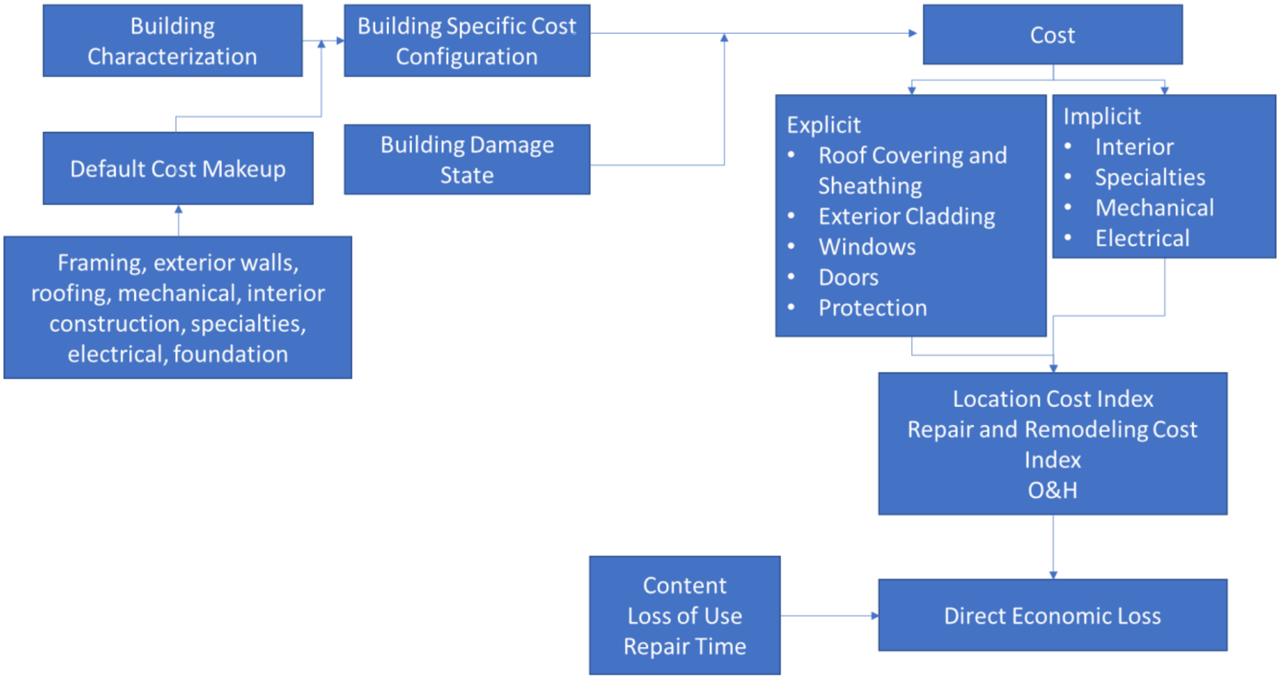

Figure 3. Schematic of the Loss Model for Residential Buildings [derived from, 26].

As seen in the schematic there are several inputs that the loss model considers before it outputs the economic loss. The model uses nine default subassemblies seen throughout the industry of construction [26]. Of note, the materials and workmanship data used from RS Means for these nine subassemblies is only sufficient to satisfy the minimum building codes, and low costs is prioritized over distinctive features [26]. Building cost configuration can be changed based on the selection of various characteristics a building typically has. Additionally, the damage state of a building is introduced. This includes the information from the damage model, which is window damage, building missile hits, water penetration, etc. [26]. The cost ratios are calculated and are defined as the ratio of the cost to complete the subassembly to the total cost of the whole building [26]. Once the cost ratios are computed for the building, equation 1 is used to find the cost to repair any of the nine subassemblies [26].

$$C = D \cdot C_R \cdot V \tag{1}$$

Where C is the base cost to repair, D is the fraction of the subassembly to be replaced, C_R is the cost ratio for the subassembly, and V is the building value. Equation 1 only produces the cost to repair without taking into consideration other factors such as city index, repair and remodeling adjustments and overhead and profit [26]. However, once all subassembly costs are computed the adjustment factors from RS Means are introduced. The model recognizes costs generally increase due to a reduction in labor output when dealing with repairs, remodeling, and existing work conditions. The way it accounts for this cost is by implementing a factor of 1.25 that was derived from subject matter experts, field observation and RS Means [26].

Furthermore, the model uses explicit costing method to calculate the repair and replacement costs for components such as roof covering, roof sheathing, windows, entrance doors, etc. [26]. There are damage replacement thresholds that the model considers so that once a component goes past the thresholds, the given component needs to be replaced. It is set for 0.5% for asphalt roof covering and 5% for roof sheathing for example [26]. Additionally, for those components that did not fail, serviceability considerations are taken into account. This means if the component experience a load exceeding 85% of their ultimate capacity, the component is replaced [26]. All fenestration, uses conceptual similar continuous deterministic functions like the one in equation 2 [26].

$$Standard\ glass: Replacement\ Cost\ =\ 10.00\ \cdot\ (AREA - 12.00) + 225.00 \quad (2)$$

Where *AREA* is the overall area of the window unit (sf) [26].

In terms of replacement cost for the building interior, implicit equations are used. Of note, the simple functions developed stem from the basis of experience and judgment [26]. The cost to the interior is a function dependent on the damage to roof cover, roof sheathing, roof structure, windows, and doors. Essentially, if they fail, damage will occur to the interior of a building due to water penetration [26]. If interior damage is related to roof cover, L_{RC}, loss equation 3 is used.

$$\boldsymbol{L_{RC} = f_1(R_{RC})\big(1 - f_2(A_{RC})\big)f_3(R_{RC})V_1} \quad (3)$$

Where, R_{RC}, is the fraction of failed roof cover, A_{RC}, is the area of failed roof cover (sf) and V_1 is the value of the interior of the building. The functions, f_1, f_2, and, f_3 are described in equation 4. The function f_1 is expressed as:

$$\begin{aligned} f_1(R_{RC}) &= 1.11R_{RC}, && for\ R_{RC} \leq 0.9 \\ f_1(R_{RC}) &= 1.0, && for\ R_{RC} > 0.9 \end{aligned} \quad (4)$$

Where, $f_1(R_{RC})$, denotes the fractional quantity of the interior area disturbed by the loss of a fraction of the roof cover. The function, f_2, is expressed as:

$$\begin{aligned} f_2(A_{RC}) &= 1 - 0.005\,A_{RC}, && for\ A_{RC} \leq 200\ ft^2 \\ f_2(A_{RC}) &= 0, && for\ A_{RC} > 200\ ft^2 \end{aligned} \quad (5)$$

where A_{RC} is the area of failed roof cover. The function f_2 represents a term that accounts for small roof cover damage in which in many occasions, water does not penetrate the building since the underlayment stays intact, or no disparities in the roof sheathing are revealed [26].

The function, f_3¸ is expressed as:

$$f_3(R_{RC}) = 0.1, \qquad for\ R_{RC} \leq 0.05$$

$$f_3(R_{RC}) = 2.0R_{RC}\ , \qquad for\ 0.05 < R_{RC} \leq 0.5$$

$$f_3(R_{RC}) = 1.0, \qquad for\ R_{RC} < 0.5 \qquad (6)$$

The function f_3 denotes a term that considers the fact that the interior damage increases in severity as the area of the interior damage increases. Some of the severe damage includes sheet rock failing and impacting interior components like flooring or cabinets or water getting inside walls and impacting the electrical systems.

If damage to the interior is caused by roof sheathing the economic damage is modeled by equation 6 [26].

$$L_S = (3.6R_S + 0.1)V_1 + (R_S V_{RF}), \quad for\ 0 < R_S < 0.25 \qquad (7)$$

Where L_S is the cost associated with the loss of roof sheathing, R_S is the percentage of missing roof sheathing and V_{RF} is the price of roof framing [26]. Based on experience, historical data, and the assumption that the interior needs replacement when 25% of the roof sheathing has failed, equation 7 accounts about 10% to 15% of interior’s cost [26].

Lastly, if damage is caused by window or door failure, equation 8 is used.

$$L_F = (4D_W)V_1, \qquad for\ 0" \leq D_W \leq 0.25" \qquad (8)$$

Where D_W is the depth of water, in inches, average over the floor area of the building [26]. This equation was created with the assumption that losses increase linearly as more water goes into a structure and that once 0.25 inches of water enters, 100% of the interior is lost [26].

The HAZUS model has results that agree with actual economic losses. The data used to validate the loss model was from Hurricanes Erin, Opal, Bertha and Fran [26]. The average prediction error ratio was 0.83, which is defined as the actual loss divide by the predicted loss [26]. Recent use of the model for Hurricane Ike, estimated a damage of $8.4 billion with the actual value being $8.5 billion [37]. In another case, Hurricane Harvey, the model did not accurately represent the damage cost [38]. This was because the county that was studied received damage from floods. Once the flood model of HAZUS was used, the model reasonably agreed [38].

Risk Management Solutions (RMS)

As the research within this thesis progressed to the RMS model, it is important to note and reiterate that the RMS model is a legitimate model to analyze because it is approved by the Commission of Florida on Hurricane Loss Projection Methodology and thus making it one of the few valid model options for insurers to use. However, it is owned by a private company. This limits the literature review on the analysis of the RMS model. Largely because the company must hold proprietary information in order to maintain a competitive edge against other models or competition. Moving forward, this sections rather finds peer reviewed examples where the RMS model uses the major components expressed in the literature review of this thesis. Literature shows records of detailed results and analysis pertaining to wind, surge, flood, etc. [7], [39], [40]. More importantly, the literature conveys RMS attempts to capture economic loss.

Like the HAZUS model, the RMS model uses a similar approach to model losses by using input databases. With the input of information such as meteorological data, buoy measurements, and wind speed measurements, output of hurricane characteristics are possible [7], [41]. The model quantifies all the historical data and uses a random-walk technique to create simulations for any of the five categories of hurricanes [41]. Each simulation it tracks wind speed, location, forward speed and direction, central pressure and radius of maximum wind. The random-walk technique is frequently utilized in environmental fluid mechanics as its core functionality is to predict the direction of the next point based on a random sampling of previous points [42]. The model then runs frequency of historical hurricane landfalls probabilities and uses that information to calibrate the simulation models landfall rates. The model repeats this process in order to calibrate pressures for each of the same simulations calibrated for landfall rates. [41]. Finally, importance sampling is performed via Monte Carlo simulation in order to provide a set of storms that is used for loss and cost determination.

The RMS model, like the HAZUS model, has a wind hazard module. Though specifics are not clearly stated in literature, what limited information is out there conveys that wind damage is taken into account since there is claims of losses attributed only to wind fields [39]. An example of the outputs is the estimated peak gust winds that were developed from Hurricane Katrina, 94 mph [7]. Noted, wind speed observations were small, but the wind speed patterns from the model coincided with them [7]. The module estimates wind speeds using central pressure, radius to maximum wind, wind profile, forward speed, direction, landfall location, and track at a given location. The module considers surface roughness or topography, and other attributes that affect winds in order to treat the wind speed simulations in a more realistic manner. Hurricane Katrina is an example where topography was considered [40]. Additionally, an analysis on territorial rating within Florida has been conducted [43].

Furthermore, the RMS model has a damage module. The estimated damage is measured in terms of wind speeds or flood depth (for the optional surge component). The module computes damage ratios, dollar amount to replace divided by the assets total value, and relates them to either wind speeds or flood depth to get a vulnerability function [41]. It has base vulnerability functions due to wind, and due to surge for 536 building classifications. The functions change based on a combination of the following characteristics: (1) Construction class; (2) Building height (number of stories); (3) Building occupancy; (4) Year built; (5) Square footage (single family residential only); (6) Region of state (vulnerability region). The 6 characteristics affect the development of vulnerability functions. As an example, the model classifies the unknowns for home characteristics as zero for the appropriate category. Consequently, there is not a change to the base vulnerability curve made [41].

Following all the output from its multiple modules, losses are computed. For Katrina, the RMS model calculated a loss of $900,000 million related to winds [7]. Additionally, the model was able to estimate insurance losses which were between $2 to $5 billion dollars [7]. The model was also able to create estimates in terms of the direct damages and expected loss of production [7]. The way RMS calculates losses is by multiplying the damage ratios from the damage module, the value of the property, and a post-event loss Amplification (PLA) component when appropriate [41].

RMS's PLA component attempts to account for demand surge impacts. Demand surge impacts are defined as elements that escalate losses by a combination of economic, social and operational conditions that follow after a given event [41]. The PLA component helps explain three factors. One, economic demand surge (EDS) which is the escalation of building materials and labor costs as demand exceeds supply. Two, claims inflation (CI) which is the cost inflation due to the difficulties in fully adjusting claims following a catastrophic event. Three, Super CAT scenarios which is coverage and loss increase because of a complex collection of factors [41].

Florida State University Model

A study conducted at Florida State University examined Florida's hurricane statistics from 1900 to 2007, variability of various hurricane characteristics and then considered distributions of direct damage cost associated with the Florida hurricanes [9]. The approach within the study was to record the historical record of hurricane strikes and their associated damage cost. From there the study, looked at the statistics of occurrence, intensity, and size and examined their relation to losses [9]. Though this study is different than the other two, it is the first of its kind to solely focus on the state of Florida with a linear regression approach that has been used before [9], [44]–[46].

The study took a list of all the hurricanes affecting Florida from the Florida Commission on Hurricane Loss Projection Methodology and data from the U.S. National Hurricane Centers archive HURDAT [9]. The study emphasized on only examining hurricanes that directly hit Florida. In order to find those hurricanes, it define a hit to be when part, if not all, of the hurricane's eye wall made it to the coast [9]. Additionally, the study makes it clear that it only used the landfall characteristics of the highest intensity if the hurricane landed more than once. Lastly, the study began to find the losses associated with the direct strikes on Florida. Those losses came from normalized damage data already established in previous research [46]. The data of the hurricane damage estimates had been previously put in 2005 dollars.

The FSU study first looks at frequency of Florida hurricanes. With the Florida specific data, the study was able to output graphically the annual hurricane counts for 108 years (1900-2007). Additionally, it was also able to convey the amount of years with various numbers of hurricane events. The figure portrayed two things. One, the annual hurricane counts remained relatively similar until the 21st century and two there was a little over 60 years with no hurricane strikes [9].

Using the tailored data for Florida only, the study portrayed graphs pertaining to minimum central pressure and maximum wind speed over the 108-year time span. The distribution of those graphs conveyed no long-term trend and an average intensity of 966 millibars or 90 knots [9]. Additionally, the study was able to categorize all the hurricane landfalls on a map of Florida by hurricane intensity and the Saffir-Simpson scale. The figure conveyed that most hurricanes hit in the southern region of the peninsula, particularly the regions near Miami [9]. As exploratory data analysis continues, it finds that most hurricanes have a radius of max winds to be between 20 to 60km [9].

The study then ran similar analysis for damage losses based on the data taken from the previous studies [46]. The study caveats the data set used had some coastal landfalls that did not have damage losses associated with them prior to 1940 [9]. It recognizes there should be some though due to the hurricane statistics convey at least one hurricane strike every two years and that this lack of data produces an undercount of loss damage to statistics prior to 1940 [9]. The study found the ten hurricane events with the most damage in 2005 dollars putting the Great Miami storm of 1926 at the top with a value of $129 billion in 2005 dollars [9]. Totaling the all cost within the 108-year timespan would have been $459 billion of which 77 percent came from the top ten hurricanes. The study's distribution of losses by hurricane event was highly skewed towards smaller losses. However, it examined the same information using a logarithmic scale in an attempt to respond to skewness. Using the logarithmic scale, the distribution conveyed an increasing trend in losses which was similar to that of hurricanes increase in intensity and size [9]. Once the study had hurricane and loss statistics, the study began to find trends and associations. The study processed trends using the flowing techniques, ordinary least squares regression and quantile regression [47]. With such techniques, the study was able to show statistically significant relationships between intensity of hurricanes and the amount of damage using both minimum central pressure or max wind speeds as the indicator [9]. Of note, the relationship between hurricane size and damage was unclear since larger hurricanes seemed to be correlated with less damage [9]. The study somewhat attributed that to the inverse relationship between hurricane intensity and hurricane size. Associated with the 95% confidence interval, the correlation of the intensity estimates, minimum central pressure and max wind speeds, to damage cost where great with values of r to be -0.59 and 0.52 respectively [9].

As a final step, the study used equations discussed in literature to find the potential losses. Literature, conveys that losses from hurricanes stem from intensity and size characteristics [48]. The study looked at two equations. One was the Carvill Hurricane Index (CHI) and the other was the Florida hurricane loss index (FHLI) [9], [48]. The following equation, CHI, is based on wind speeds and storm radius.

$$CHI = \left(\frac{v}{v_o}\right)^3 + 1.5\,(\frac{r}{r_o})\left(\frac{v}{v_o}\right)^2 \tag{9}$$

Where v is the max wind speed (kt), v_o is the threshold hurricane-wind speed (64kt), r is the radius of threshold hurricane-wind speed or greater (km), r_o is the threshold radius (97 km).

To get r, a form of the Rankine vortex equation is used in order to get the decay of winds from its maximum value by equation 10 [49].

$$r = r_{max}\left(\frac{v}{v_o}\right)^{1.5} \tag{10}$$

The CHI equation brings about a positive and significant correlation of 0.53 with losses, indicating that the incorporation wind speeds, and storm radius is a valid method for calculating losses. The study however, notes that the relationship in the CHI equation is not as strong as the minimum central pressure and max wind speeds correlations on their own [9]. This suggests that the best variables for potential loss are either one of the single variables, minimum central pressure or max wind speeds. Due to a marginally improved correlation, the study reasons to use central pressure as a single variable for potential loss calculations [9].

The study regressed losses onto the minimum central pressure and the equation representing damage estimates in dollar amounts, Florida hurricane loss index (FHLI), was expressed [9].

$$FHLI = 10^{40.912-0.0329pmin} \quad (11)$$

Where $pmin$ is the minimum central pressure (millibars) forecast at landfall. Once landfall minimum pressures were inputted, for Florida hurricane events, the expected loss was computed. The study tabulated the approximate losses based on the minimum central air pressure, Pmin., in table 2.

Table 2 Expected loss in Florida based on different Minimum Central Air Pressure Values, Pmin [derived from, 9]

Hurricane Category	Pmin. Values	Cost in 2005 US Dollars
1	989-980	250M-499M
2	979-965	500M-1.49B
3	964-945	1.50B-7.99B
4	944-920	8.00B-49.99B
5	<920	>50.00B

This study's approach to loss estimation, though different, attempts to show correlation between hurricane characteristics and damage loss. Unfortunately, the equation derived from the regression model only explains 40 percent of the variation. It is however better than the CHI equation which only explains 28 percent according to the study [9].

Choosing the Hurricane Loss Models

The models were chosen for potential analysis for the following reasons. The first model, RMS, is used by the Congressional Budget Office (CBO) [50]. The CBO is a federal agency within the United States government that provides independent assessments of budgetary and economic issues. They depend on the commercially available models from Risk Management Solutions (RMS). The RMS model was chosen because it is one of five models approved by the Florida Commission on Hurricane Loss Projection

Methodology under Florida Statute 627.0628 which provides the specific guidelines and standards on hurricane loss models [51]. Additionally, the insurance industry, specifically, uses RMS reports to compute the impact of hurricanes in terms of risk. Following that understanding, insurers takes steps to manage the risk [40].The second model is HAZUS-HM Hurricane Model. This model was chosen because is used by the Federal Emergency Management Agency (FEMA). FEMA, under the Department of Homeland Security, is authorized by the President to provide financial and technical help to states and local resources once the disaster becomes overbearing [52]. Additionally, 75% of the cost that is used to provide aid stems from the HAZUS model assessment. The last option is the Florida State University (FSU) model. This model used data used by the Florida Commission on Hurricane Loss Projection Methodology. Specifically, data of historical hurricanes that affected Florida only. The research was also endorsed by Florida Office of Insurance Regulation. Under Florida Statutes Section 20.121,(3)(a)1, Florida Office of Insurance Regulation responsible for all that concerns insurers and any risk bearing units [9], [53].

Although all three models had some validation. Only the HAZUS model was used moving forward. The reason for that stemmed from RMS being extremely costly to analyze and the FSU model having little to no use past its publication. RMS was not a publicly available method and all of its information was proprietary. Thus, there was a lack of existing literature on RMS performance. RMS was available as a service for a minimum of $5,000 meaning there would not be a chance to use the program and merely just use the results for comparison. There was the option to buy in at a minimum of $250,000 a year. That would grant full access for the entire Air Force, however with such a high procurement cost and the possibility that it would not perform better than the others made the risk not worthwhile. Additionally, the entire Air Force does not need the program and it would only be used when needed.

Summary

This literature review finds all relevant research on hurricanes, the economic losses incurred over the years and the components used in industry when developing a hurricane loss model. Hurricane loss models attempt to do some sort of simulation and predict how, where and when hurricanes form, their wind speeds, intensity and sizes, their tracks. They try to model how wind speeds are affected by the terrain after landfall, how the winds interact with topography and how much it will cost to rebuild the damage.

The HAZUS, RMS and FSU models were explained. The models where chosen for comparison because each model has stakeholders who are directly involved with policy that governs and other unique attributes, like modeling costs for historically vulnerable states. However, due to feasibly and reliability concerns, HAZUS was analyzed to see if it proved to be of use for future replacement cost estimates.

III. Methodology

Chapter Overview

This chapter provides the approach applied to answer the research questions regarding the HAZUS model. The chapter is separated into sections that explain the data, how the data was cleansed, and initial exploratory data analysis. Furthermore, it conveys the three different ways HAZUS was used to compare replacement cost results. Lastly, an explanation as to how results were turned into an attempt to correlate age and replacement value is provided.

Data Description

Data received was prepared by the AFCEC CO Assessment Team include a preliminary estimate of the damages sustained by Tyndall AFB. There were results from 63 building estimates in the report. Out of those, 17 were removed because they did not fit the profiles of the wind building type that HAZUS uses in the general building stock already provided or imports user defined facilities. As an example, some of those omitted data points were gate entrances, blast-proof bunkers and radar towers. Furthermore, another five data points were omitted because the cost of replacement was more than the Plant Replacement Value (PRV). The reasons for that varied, but according to the reports the expenses surpassed the PRV because of work was related to mold, asbestos, roof system or structural failure, and rare work such as installation of a lightning protection system. In total, there was 41 data points that were included for comparisons with the HAZUS model. Of note, there was two buildings that were used, but also omitted in initial exploratory data efforts because they were outliers due to high cost. However, these data points are building types common to military installations and thus acknowledgement that there are buildings such as a, in this case, flight simulator training center and base engineering maintenance shops that are costly and require special construction should be taken into account. The total estimated cost at the time of assessment was $10,977,942. Figure 4 shows the estimated building repair cost of the 41 buildings, and the two outliers can be observed outside of one standard deviation from the mean.

It is important to note that the actual awarded replacement estimates were not available for analysis. At the time, Tyndall AFB had just started assessing the damage sustained throughout the base and was not in the process of receiving and awarding contracts for the work that needed to be done.

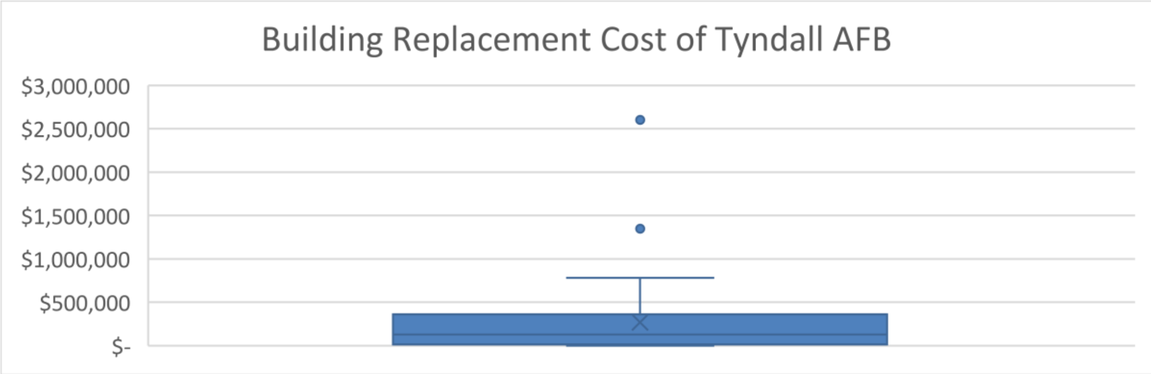

Figure 4. Box and Whisker Plot of the 41 Tyndall Air Force Base Building Replacement Cost Estimates

Once the 41 buildings were accepted as data points to analyze, they were categorized into their respective wind building types. As explained in the literature review section, this categorization is a strong determinant on the level of damage a building might receive in a hurricane event. Based on the brief descriptions in the reports provided, there was eight categories of buildings identified. Table 3 displays the 41 data points and all the categorizes of information collected in order to implement the data into HAZUS.

Table 3 Data Collection from the 41 Buildings at Tyndall Air Force Base used for Comparison Analysis

Building Type	**Description**	**Wind Building Type**	**Area**	**Cost**	**PRV - Cost**	**PRV**	**Code Number**	**Building Number**	**Age**	**Wind Building Scheme**	**Year Built**
CONCRETE	Concrete Res 1-2 story	CERBL	8612	$39,295	$2,397,742	$2,437,037	1	472	75	Florida_North	1943
CONCRETE	Concrete Res 1-2 story	CERBL	2350	$39,413	$1,752,999	$1,792,412	2	493	15	Florida_North	2003
CONCRETE	Concrete Res 1-2 story	CERBL	669	$2,521	$179,850	$182,371	3	494	10	Florida_North	2008
CONCRETE	Concrete Res 1-2 story	CERBL	324	$13,492	$168,880	$182,372	4	495	15	Florida_North	2003
CONCRETE	Concrete Res 1-2 story	CERBL	6936	$356,239	$948,058	$1,304,297	5	745	76	Florida_North	1942
CONCRETE	Concrete Res 1-2 story	CERBL	10778	$213,429	$1,813,347	$2,026,776	6	747	76	Florida_North	1942
CONCRETE	Concrete Res 1-2 story	CERBL	11574	$363,364	$2,122,679	$2,486,043	7	916	76	Florida_North	1942
CONCRETE	Concrete Res 1-2 story	CERBL	8942	$431,344	$2,528,879	$2,960,223	8	1015	76	Florida_North	1942
CONCRETE	Concrete Res 1-2 story	CERBL	6936	$352,677	$1,228,502	$1,581,179	9	1016	20	Florida_North	1998
CONCRETE	Concrete Res 1-2 story	CERBL	1550	$129,281	$309,340	$438,621	10	1287	64	Florida_North	1954
CONCRETE	Concrete Res 1-2 story	CERBL	7597	$703,352	$641,782	$1,345,134	11	1305	75	Florida_North	1943
CONCRETE	Concrete Res 1-2 story	CERBL	5228	$433,754	$1,147,425	$1,581,179	12	1476	75	Florida_North	1943
CMU	Masonry Com 1-2 story	MECBL	2010	$214,468	$171,119	$385,587	13	181	23	Florida_North	1995

CMU	Masonry Com 1-2 story	MECBL	1769	$52,809	$111,173	$163,982	14	481	11	Florida_North	2007
CMU	Masonry Res 1-2 Story	MERBL	6880	$90,514	$912,905	$1,003,419	15	484	15	Florida_North	2003
CMU	Masonry Res 1-2 Story	MERBL	23917	$2,601,885	$7,115,756	$9,717,641	16	546	63	Florida_North	1955
CMU	Masonry Multi-Unit 1 story	MMUH1	5498	$190,761	$1,439,431	$1,630,192	17	108	6	Florida_North	2012
CMU	Masonry Multi-Unit 1 story	MMUH1	9056	$44,439	$2,226,730	$2,271,169	18	487	14	Florida_North	2004
CMU	Masonry Multi-Unit 2 story	MMUH2	20240	$24,468	$313,307	$337,775	19	492	11	Florida_North	2007
CMU	Masonry Multi-Unit 2 story	MMUH2	20590	$1,347,358	$1,625,274	$2,972,632	20	1134	31	Florida_North	1987
CMU	Masonry single family	MSF1	144	$963	$26,567	$27,530	21	96	4	Florida_North	2014
CMU	Masonry single family	MSF1	1312	$6,395	$382,621	$389,016	22	98	5	Florida_North	2013
CMU	Masonry single family	MSF1	280	$4,844	$31,176	$36,020	23	404	28	Florida_North	1990
CMU	Masonry single family	MSF1	426	$17,605	$105,604	$123,209	24	406	32	Florida_North	1986
CMU	Masonry single family	MSF1	222	$10,216	$53,992	$64,208	25	408	32	Florida_North	1986
CMU	Masonry single family	MSF1	960	$11,308	$172,853	$184,161	26	526	17	Florida_North	2001
CMU	Masonry single family	MSF1	517	$6,973	$319,224	$326,197	27	1722	35	Florida_North	1983
CMU	Masonry single family	MSF1	1102	$61,347	$35,704	$97,051	28	1723	74	Florida_North	1944
CMU	Masonry single family	MSF1	317	$10,868	$34,898	$45,766	29	1724	69	Florida_North	1949
CMU	Masonry single family	MSF1	460	$20,081	$20,430	$40,511	30	1725	33	Florida_North	1985
CMU	Masonry single family	MSF1	610	$129,605	$158,861	$288,466	31	1766	38	Florida_North	1980

CMU	Masonry single family 2 or more stories	MSF2	1187	$11,761	$159,609	$171,370	32	489	16	Florida_North	2002
CMU	Masonry single family 2 or more stories	MSF2	13654	$514,299	$2,778,923	$3,293,222	33	1801	44	Florida_North	1974
STEEL	Steel pre-engineered <15000 sf (small)	SPMBS	11700	$779,773	$2,595,653	$3,375,426	34	333	15	Florida_North	2003
STEEL	Steel pre-engineered <15000 sf (small)	SPMBS	13125	$152,977	$1,741,914	$1,894,891	35	1141	18	Florida_North	2000
STEEL	Steel pre-engineered <15000 sf (small)	SPMBS	4189	$142,465	$1,143,957	$1,286,422	36	1142	8	Florida_North	2010
STEEL	Steel pre-engineered <15000 sf (small)	SPMBS	7500	$151,395	$931,400	$1,082,795	37	1144	18	Florida_North	2000
STEEL	Steel pre-engineered <15000 sf (small)	SPMBS	7500	$573,043	$1,549,319	$2,122,362	38	6070	14	Florida_North	2004
STEEL	Steel pre-engineered <15000 sf (small)	SPMBS	3000	$16,307	$369,620	$385,927	39	6072	10	Florida_North	2008
STEEL	Steel pre-engineered <15000 sf (small)	SPMBS	7110	$422,177	$1,235,947	$1,658,124	40	7042	2	Florida_North	2016
STEEL	Steel pre-engineered <15000 sf (small)	SPMBS	6000	$288,677	$712,176	$1,000,853	41	9432	9	Florida_North	2009

HAZUS Modelling

HAZUS has the ability to run analysis on default data programed within the model. In order to compare the generic building stock within the model, the most up to date version of HAZUS was utilized (HAZUS 4.2 service pack 03). Once HAZUS was installed, the first results explored was a rapid estimate that HAZUS is able to provide based on the generic building stock already within the program. To get those results, input parameters included the hazard region, hazard type (hurricane), hurricane scenario (Hurricane Michael), the aggregation level of analysis which is state, county and/or census tract. In this case, the state was Florida, in Bay county, in census tract 12005000700. Figure 5 conveys the study region which is where Tyndall AFB is located.

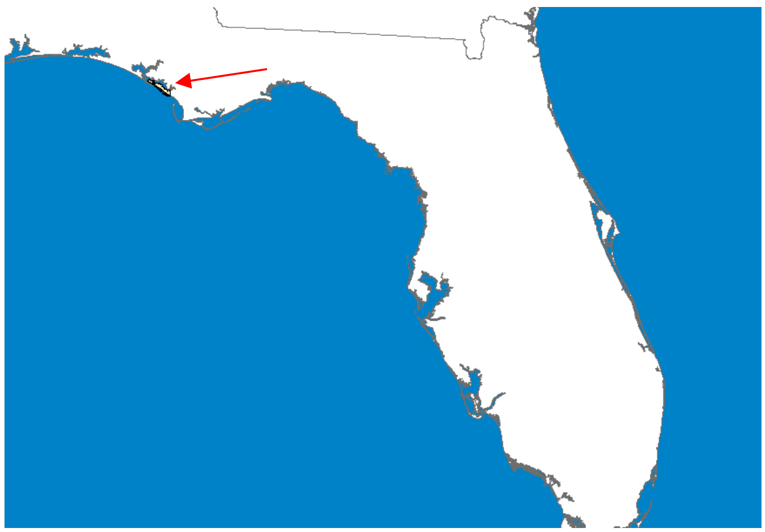

Figure 5. The Study Region analyzed in Florida, Bay County, Census Tract 12005000700 (HAZUS Direct Output)

After the program was run, HAZUS provided a report for the number of damaged buildings and direct costs associated to those specific building types. Since the program only provides totals of each, direct costs and number of buildings damage, the average of each wind building type was calculated in order to be able to compare the results to the dataset from Tyndall. The percent differences between the estimate cost estimates and the HAZUS results was calculated. A paired t-test statistical analysis was conducted to check if there was a statistical difference between the estimate and modeling results.

Another second approach was attempted that might improve upon the first approach. That method involved investigating at the building loss functions within HAZUS. Table 4 displays the assumptions made when choosing the appropriate loss function for each wind building type. The reasoning behind assuming the characteristics conveyed in table three stems from the notion that those specific characteristics for the buildings were not available in the Tyndall reports. Additionally, because of that unavailability the characteristics chosen were worst case scenario, also known as the least expensive way to build. Though not always true, it does tend to happen when awarding government contracts.

Table 4 Building Characteristics Assumed for the 8 Wind Building Types in the Tyndall Dataset

Wind Building Type	Assumption Descriptions
CERBL	Single-Ply Membrane Roof No Shutters Wind Debris: Res/Comm
MECBL	Single-Ply Membrane Roof No Shutters Wind Debris: Res/Comm
MERBL	Single-Ply Membrane Roof No Shutters Wind Debris: Res/Comm
MMUH 1	Gable Roof No Shutters Roof-Wall Connection: Strap Masonry Reinforcing: Yes
MMUH 2	Gable Roof No Shutters Roof-Wall Connection: Strap Masonry Reinforcing: Yes
MSF 1	Gable Roof No Shutters Roof-Wall Connection: Strap Masonry Reinforcing: Yes
MSF 2	Gable Roof No Shutters Roof-Wall Connection: Strap Masonry Reinforcing: Yes
SPMBS	New or Average Roof Deck Age No Shutters Standard Metal Roof Deck Attachment

Following the assumptions, eight different loss functions were used from the HAZUS model. For each loss function the peak wind speed of Hurricane Michael was used, which was a reported value of 138 mph according to the results from the hurricane simulation within HAZUS. However, in order to facilitate graph function interpretation a wind speed of 140 mph was actually used.

Using the graphs from Figure 6, the total loss/ total value ratio was estimated for open terrain, suburban terrain and light trees terrain. These graphs can be found under the analysis tab. HAZUS conveys the terrain type for the study region so it was conjectured that the light trees terrain loss function cost ratios would produce optimal results. With the ratios captured, the value for each of the 41 buildings in the Tyndall dataset was multiplied to the ratio corresponding to the specific building type. This was done for all three terrain types. Once those results were attained, they were compared to the replacement cost estimates from the assessment done by AFCEC. Again, a paired t-test statistical analysis was done in order to see if there was a statistical difference between the HAZUS results and the Tyndall estimated costs.

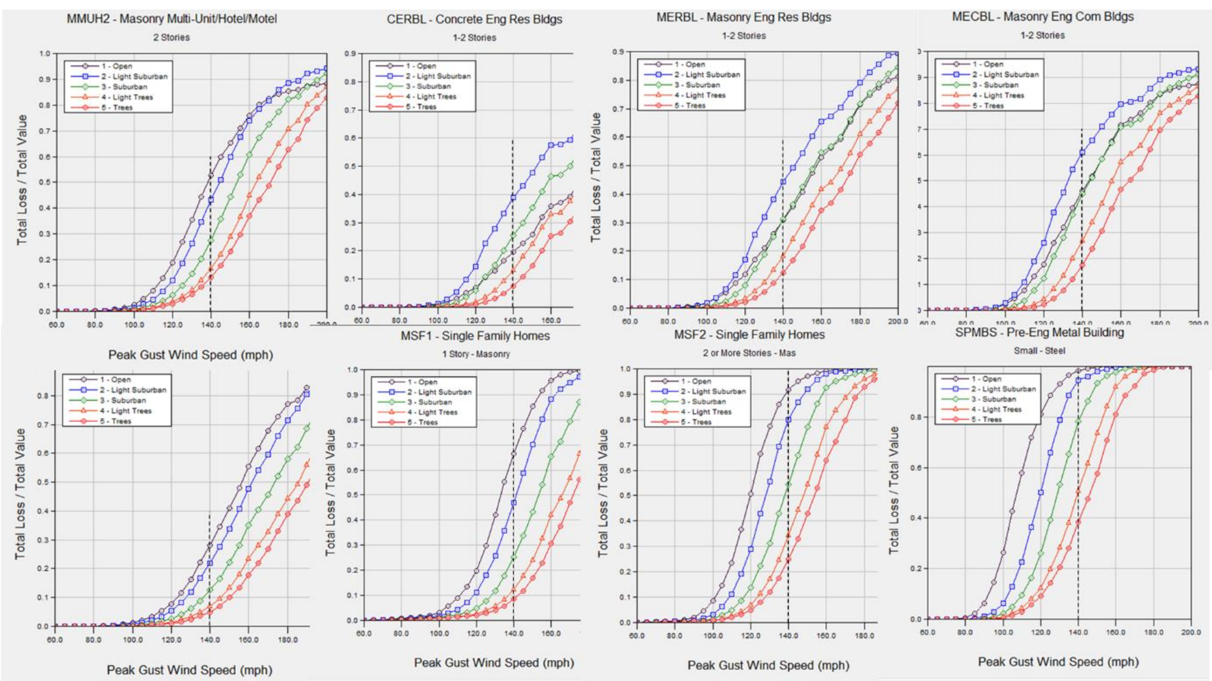

Figure 6. Loss Function Curves for all 8 Wind Building Types (Direct Output from HAZUS)

There was a third approach used to compare the Tyndall replacement cost and HAZUS ability to estimate costs. This method involved inserting the information gathered from the Tyndall dataset into the user defined facilities tab under the inventory section of the

HAZUS model and running the program again for the same study region in question. Under the results tab in HAZUS, the building damage probabilities for each of the 41 buildings were reported. Though it cannot at this moment output direct building costs, using the building damage probabilities and simplified cost probabilities for the four levels of damage (minor, moderate, severe and destruction) the cost ratio for the associated level of damage was found. The cost probabilities were 0.08, 0.3, 0.7 and 1.0, respectively. This was done using the multiplication rule which calculates the probability of one event and another event happening. The following equation, derived from the multiplication rule, was used:

$$BldgDamage = Minor * 0.08 + Moderate * 0.3 + Severe * 0.7 + Destruction * 1.0 \quad (13)$$

Were minor, moderate, severe and destruction are the HAZUS probability results for minor damage, moderate damage, severe damage and destruction of each building. A paired t-test analysis was done for this comparison as well.

All the different approaches were then compared. They were compared by the paired t-test statistic results. The null hypothesis was that there was no difference between the approach and the Tyndall AFB preliminary estimates. If any of the different approaches failed to reject the null hypothesis then that indicated that the approach had no statistical difference in cost estimates. The paired t-test was conducted using excel.

Lastly, the study attempted to conduct further analysis on the method with the best results. The research attempted to predict how far off an estimate will be based on age and based on PRV. This was only done for the light tree terrain comparison as it showed the best results for replacement cost estimates. The difference between the HAZUS results and the Tyndall dataset was calculated for each building. Then the difference was plotted against the age of each building. Similarly, the difference was plotted against the plant replacement value. In both plots the linear predictive equation was found and so was the R squared in order to see how well the correlation was. Additionally, there was an attempt to uncover trends by plotting replacement cost estimates for the different building types.

Summary

This research attempted different methods to investigate the relationship with estimate replacement costs of 41 buildings at Tyndall AFB. Once the replacement cost estimates were calculated, they were compared to the replacement cost estimated provided by the AFCEC assessment team. A paired t-test was done for each of the different methods in order to see which method provided the best results. Furthermore, the research looked to see if age or PRV can help predict how far off cost estimates will be using the results from the best method. It also identified cost estimate trends based on different building types.

IV. Results and Discussion

Chapter Overview

In this chapter, the results from the HAZUS model are described and then compared to the Tyndall dataset provided by AFCEC. The chapter conveys the HAZUS model results for the general building stock. Next, the chapter goes into detail with respect to the loss function results for open, suburban, and light tree terrain. Lastly, replacement cost results using the building damage reports for user defined facilities are explained. The chapter compares the results of each method to the data set and explains the variation. Additionally, further analysis is done for the light tree terrain building loss function results. The chapter also conveys the application within the DoD and gives suggested improvements.

Results and Discussion

Figure 7 conveys the number of buildings within the generic building stock and direct cost to the buildings in the area after a simulation of Hurricane Michael runs.

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Building Damage by Count by Building Type: RiskMAP Increasing Resilience Together

May 11, 2020

	# of Buildings					
	None	Minor	Moderate	Severe	Destruction	Total
Florida						
Bay						
Concrete	3	4	24	18	0	50
Masonry	52	153	191	90	23	509
Manufactured Homes	0	0	0	0	0	0
Steel	3	3	13	13	1	33
Wood	25	91	96	35	10	258
Total	84	252	324	156	34	850
Total	84	252	324	156	34	850
Study Region Total	84	252	324	156	34	850

A.

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RiskMAP Increasing Resilience Together

Direct Economic Losses For Buildings:

May 11, 2020 *All values are in thousands of dollars*

	Capital Stock Losses				Income Losses				
	Cost Building Damage	Cost Contents Damage	Inventory Loss	Loss Ratio %	Relocation Loss	Capital Related Loss	Wages Losses	Rental Income Loss	Total Loss
Florida									
Bay	52,832	21,617	168	19.87	7,568	1,726	1,963	4,204	90,078
Total	52,832	21,617	168	19.87	7,568	1,726	1,963	4,204	90,078
Study Region Total	52,832	21,617	168	19.87	7,568	1,726	1,963	4,204	90,078

B.

Figure 7 A. Generic Building Stock Building Damage Count B. Generic Building Stock Direct Economic Loss (HAZUS Direct Output)

There were 850 buildings according to the generic building stock data within the HAZUS model and of those 84 did not sustain any damage. The total estimated value of damage to the buildings was $52,832,000. Of note, residential structures data is derived from Census 2010 and non-residential structures data is derived from Dun & Bradstreet (D&B) and all valuations were updated to RSMeans 2018 values.

In order to compare the Tyndall dataset to the HAZUS results, the breakdown of direct building loss report was observed for the eight categories of buildings. Figure 8 displays the estimated cost HAZUS reports to repair the damaged buildings.

Loss - CERBL: Concrete Eng Res Bldgs, 1-2 Stories ($K)

Census Tract	Total	Building	Content	Inventory	Relocation Cost	Income	Rental	Wage
12005000700	1.552	873	332	0	257	0	89	0

Loss - MECBL: Masonry Eng Com Bldgs, 1-2 Stories ($K)

Census Tract	Total	Building	Content	Inventory	Relocation Cost	Income	Rental	Wage
12005000700	4,639	2,124	1,314	18	415	290	212	266

Loss - MERBL: Masonry Eng Res Bldgs, 1-2 Stories ($K)

Census Tract	Total	Building	Content	Inventory	Relocation Cost	Income	Rental	Wage
12005000700	413	193	95	0	22	18	44	41

Loss - MMUH1: Masonry Multi-Unit/Hotel/Motel, 1 Story ($K)

Census Tract	Total	Building	Content	Inventory	Relocation Cost	Income	Rental	Wage
12005000700	752	514	83	0	71	0	83	0

Loss - MMUH2: Masonry Multi-Unit/Hotel/Motel, 2 Stories ($K)

Census Tract	Total	Building	Content	Inventory	Relocation Cost	Income	Rental	Wage
12005000700	1,122	763	256	0	48	0	55	0

Loss - MSF1: Single Family Homes, 1 Story - Masonry ($K)

Census Tract	Total	Building	Content	Inventory	Relocation Cost	Income	Rental	Wage
12005000700	23,972	14,853	5,217	0	3,013	0	889	0

Loss - MSF2: Single Family Homes, 2 or More Stories - Mas ($K)

Census Tract	Total	Building	Content	Inventory	Relocation Cost	Income	Rental	Wage
12005000700	6,382	4,071	1,829	0	372	0	110	0

Loss - SPMBS: Pre-Eng Metal Building, Small - Steel ($K)

Census Tract	Total	Building	Content	Inventory	Relocation Cost	Income	Rental	Wage
12005000700	1,991	1,160	713	11	55	2	42	7

Figure 8. Generic Building Stock Direct Building Losses Report of the Eight Wind Buildings Types (HAZUS Direct Output)

The numbers in figure 8 are for all damaged buildings within each respective category. Furthermore, the specific wind building type reports the number of damage buildings. That report was then used to calculate the average replacement cost for each of the eight building categories. The generic building stock results in Table 5 A. convey the inventory for each building type, how many buildings are damaged, how many were not damaged and the average cost to replace. Table 5 also conveys the inventory for each building type, number of damaged buildings and the average cost to replace for the Tyndall AFB dataset with and without the two buildings flagged as outliers.

Generic Building Stock

Wind Building Type	Total Buildings	Non-Damaged Bldgs	Damaged Bldgs	Direct Losses	Loss Average per Bldg
CERBL	37	3	34	$ 873,000	$ 25,676
MECBL	11	1	10	$ 2,124,000	$ 212,400
MERBL	2	0.2	1.8	$ 193,000	$ 107,222
MMUH1	26	3	23	$ 5,148,000	$ 223,826
MMUH2	17	5	12	$ 763,000	$ 63,583
MSF1	396	40	356	$ 14,853,000	$ 41,722
MSF2	46	5	41	$ 4,071,000	$ 99,293
SPMBS	5	0.5	4.5	$ 1,160,000	$ 257,778
Total	540			Average	$ 128,938

A.

Tyndall AFB Data with Flight Simulator Room and Base Engineering Maintenance Shop

Wind Building Type	Total Buildings	Non-Damaged Bldgs	Damaged Bldgs	Direct Losses	Loss Average per Bldg
CERBL	12		12	$ 3,078,161	$ 256,513
MECBL	2		2	$ 267,277	$ 133,639
MERBL	2		2	$ 2,692,399	$ 1,346,200
MMUH1	2		2	$ 235,200	$117,600
MMUH2	2		2	$1,371,826	$ 685,913
MSF1	11		11	$280,205	$ 25,473
MSF2	2		2	$ 526,060	$ 263,030
SPMBS	8		8	$ 2,526,814	$ 315,852
Total	41			Average	$ 393,027

B.

Tyndall AFB Data without Flight Simulator Room and Base Engineering Maintenance Shop

Wind Building Type	Total Buildings	Non-Damaged Bldgs	Damaged Bldgs	Direct Losses	Loss Average per Bldg
CERBL	12		12	$ 3,078,161	$ 256,513
MECBL	2		2	$ 267,277	$ 133,639
MERBL	1		1	$ 90,514	$ 90,514
MMUH1	2		2	$ 235,200	$ 117,600
MMUH2	1		1	$ 24,468	$ 24,468
MSF1	11		11	$ 280,205	$ 25,473
MSF2	2		2	$ 526,060	$ 263,030
SPMBS	8		8	$ 2,526,814	$ 315,852
Total	39			Average	$ 153,386

C.

Table 5 A. General Building Stock Average Results B. Tyndall AFB Dataset Average Results with Outliers C. Tyndall AFB Dataset Average Results without Outliers

The averages between each type of building category shared some interesting results in Table 5. In terms of concrete engineered buildings, both datasets with and without the outliers estimated a higher loss at $256,513 when compared to the $25,676 for the generic building stock in the HAZUS results. That is an underestimate of around a factor of 10. Other building types like masonry engineered commercial buildings, the results were $133,639 for the datasets with and without outliers to $212,400 for the generic building stock results in HAZUS. The difference here is now an overestimate of less than a factor of 2. Furthermore, the outlier within the masonry engineered residential building was removed and the generic building stock average replacement cost was $107,222 compared to a cost of $90,514 from the Tyndall AFB dataset. That is an overestimate by a factor of about 1.2. Looking at the removal of the other outlier in masonry multi-unit 2 story buildings, the generic building stock average replacement cost overestimated $63,583 to the $24,468 from the Tyndall AFB dataset. That is an overestimate by a factor of about 2.6. Table 6 conveys with a negative value if the generic building stock underestimated and by what percent for each wind building type. A positive value indicates an overestimate of the generic building stock results. It also conveys that with or without the outliers, the generic building stock results are off by either an under or overestimate of approximately 70%.

Table 6 A. General Building Stock Percent Increase Results without Outliers B. General Building Stock Percent Increase Results with Outliers C. General Building Stock Paired T-Test Results Without Outliers D. General Building Stock Paired T-Test Results with Outliers

Without Simulator and Mx Shop

Wind Building Type	Diff in Estimate	% Increase
CERBL	$(230,837)	-90.00
MECBL	$78,762	58.94
MERBL	$16,708	18.46
MMUH1	$106,226	90.33
MMUH2	$39,115	159.86
MSF1	$16,249	63.79
MSF2	$ (163,737)	-62.25
SPMBS	$ (58,074)	-18.37
Average		70.25

A.

With Simulator and Mx Shop

Wind Building Type	Diff in Estimate	% Increase
CERBL	$ (230,8367)	-90.00
MECBL	$78,762	58.94
MERBL	$ (1,238,977)	-92.03
MMUH1	$ 106,226	90.33
MMUH2	$ (622,330)	-90.73
MSF1	$ 16,249	63.79
MSF2	$ (163,737)	-62.25
SPMBS	$ (58,074)	-18.39
Average		70.81

B.

t-Test: Paired Two Sample for Means

	Without Simulator and Mx Shop	*Generic Building Stock*
Mean	153386.1049	128937.5605
Variance	12522460395	8065797843
Observations	8	8
Pearson Correlation	0.326017476	
Hypothesized Mean Difference	0	
df	7	
t Stat	0.583697204	
P(T<=t) one-tail	0.288869556	
t Critical one-tail	1.894578605	
P(T<=t) two-tail	0.577739112	
t Critical two-tail	2.364624252	

C.

t-Test: Paired Two Sample for Means

	With Simulator and Mx Shop	*Generic Building Stock*
Mean	393027.4174	128937.5605
Variance	1.87721E+11	8065797843
Observations	8	8
Pearson Correlation	-0.174609147	
Hypothesized Mean Difference	0	
df	7	
t Stat	1.632425743	
P(T<=t) one-tail	0.073304462	
t Critical one-tail	1.894578605	
P(T<=t) two-tail	0.146608924	
t Critical two-tail	2.364624252	

D.

A paired t-test compared the average cost of generic building stock to the average costs of the Tyndall dataset without the outliers and with the outliers. When looking at the t statistic for the comparison without the outliers the value is 0.584 meaning that the results are occurring about 0.6 standard deviations away from the mean. Since the t critical for a two-tail test is 2.364 one fails to reject the null hypothesis and suggest that there is no difference between the generic building stock replacement cost averages and the Tyndall AFB replacement cost averages when the two data points are excluded. Of note, there are only eight observations (the average estimate for each type of building). Looking at the paired t-test statistics that include the two outliers, the t statistic is 1.632, meaning that the results are occurring about 1.63 standard deviations away from the mean. Since the t critical for a two-tail test is 2.364, one fails to reject the null hypothesis and suggest that there is no difference between the generic building stock replacement cost averages and the Tyndall AFB replacement cost averages when the two data points are included.

If one were to apply this method of estimation for a future hurricane strike, the results should not necessarily be reliable given that 766 out of 850 buildings, according to the generic building stock, received $52,832,000 worth of damage when just 41 buildings in Tyndall AFB dataset accumulated a preliminary replacement estimate of $10,977,941. The near eleven-million-dollar estimate is for eight different wind building types and comparing the average cost for each of these wind building types between the generic building stock results and the Tyndall AFB dataset may give a little more insight. Comparing the averages was a better way to look at replacement estimate results as the Tyndall assessment data only had information on 41 buildings and not the entire study region. The generic building stock results under or overestimate by about 70% once the average cost comparison is made given that the paired t-test suggests that the null hypothesis has not been disproven. Thus, calculating an estimate shortly after a hurricane strike, with as many uncertainties as there are during such natural disasters, being able to support a claim that an estimate will be over or under 70% may be acceptable in hindsight. The reason for such variance can be attributed to several factors. The generic building stock data is from census 2010 for example, though only four buildings in the dataset were reported to be built past 2010. Similarly, it has also been documented that the generic building stock over or underestimates in various study regions. Some literature reported differences between 15% to 40% and convey that the general building stock inventory data has variation [54]–[56]. Furthermore, though it is a feature within HAZUS, the military installation inventory section is empty. This may suggest that the general building stock inventory data for military installations may not reflect what is there. Part of that is intuitive; however as disclosing information like that to the public databases can increase national security risk. Additionally, the variance can come from item costs due to unique construction that the general building stock data may not capture. Buildings that require unique construction such as sensitive compartmented information facilities or a flight simulator training center require more expensive construction. These types of buildings may only be treated as standard wind building facility type within the HAZUS direct building loss functions.

Overall, this method would not be the best way to get replacement cost estimates. The general building stock data for the study region does not seem to represent the military installation in the study region. It may, however, be a reliable method to get the average cost per wind building type in the region given that the t-test statistic for the averages compared proved to show no statistical difference. There were only eight wind building type averages compared within the t-statistic and increasing the sample size should be done. In doing so, it is a possible that the difference improves, represents differences seen in literature and a more concrete conclusion can be made as to whether average replacement cost derived from the general building stock are reliable estimates.

The second method involved looking at the building loss functions from HAZUS in order to get the loss ratios for each building type. Table 7 conveys the ratio results for each building depending on the type of terrain being analyzed. Looking at the results the ratios tends to decrease as there is more terrain.

Table 7 Loss Ratios Attained from HAZUS Building Loss Functions for Open, Suburban and Light Tree Terrain

Wind Building Type	Open Terrain	Suburban Terrain	Light Trees Terrain
CERBL	0.2	0.25	0.125
MECBL	0.455	0.45	0.275
MERBL	0.3125	0.3125	0.1875
MMUH1	0.2875	0.125	0.075
MMUH2	0.525	0.275	0.175
MSF1	0.675	0.25	0.125
MSF2	0.9125	0.55	0.35
SPMBS	1	0.7875	0.5

With the loss ratios available, a simple multiplication between the plant replacement value and the loss ratio amounted to the estimated replacement cost for each building in the dataset. Figure 9 compares the results for open terrain replacement estimates versus the Tyndall replacement dataset.

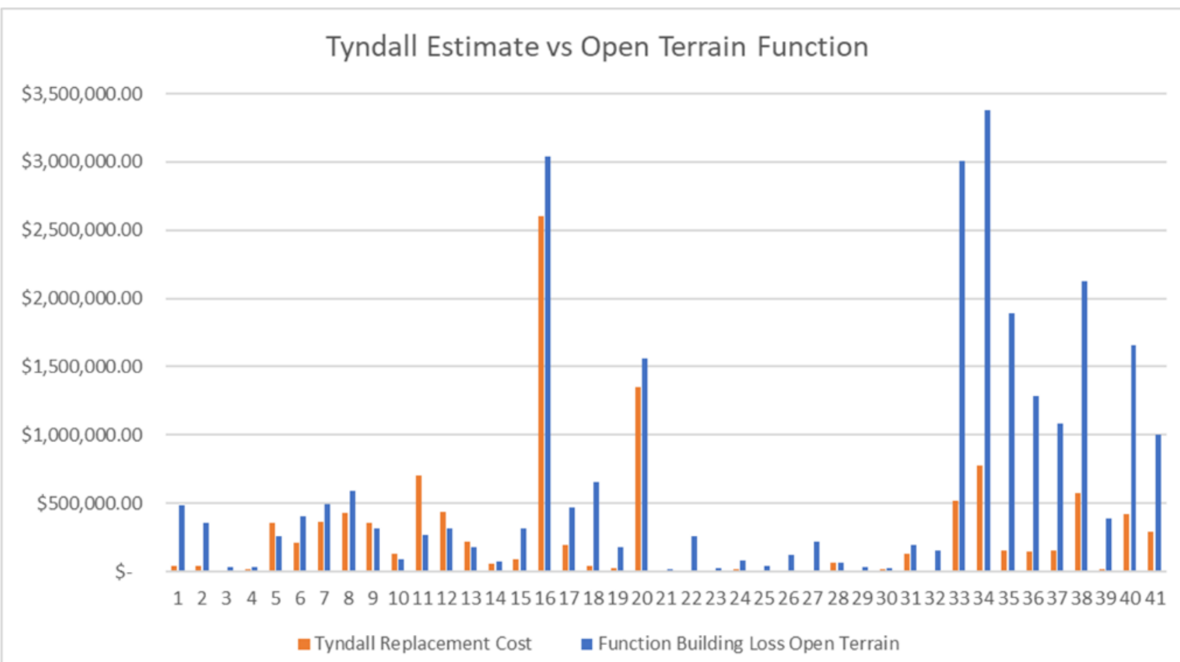


Figure 9. Tyndall Replacement Estimate and Open Terrain Estimate Results Comparison

Looking at figure 9 one can see that buildings 33-41 tend to be grossly overestimated by the open terrain building loss function. Those buildings are pre-engineered steel. Buildings 5-12 are concrete engineered residential buildings and their estimates seem to align better, though still overestimated.

Moreover, the suburban terrain results were compared to the Tyndall dataset. As one can see in figure 10, similar trends occur. The steel buildings are overestimated and the concrete ones have a closer resemblance. Buildings 21-32 are masonry wind type buildings and their costs seem to be comparatively lower than the rest of the dataset.

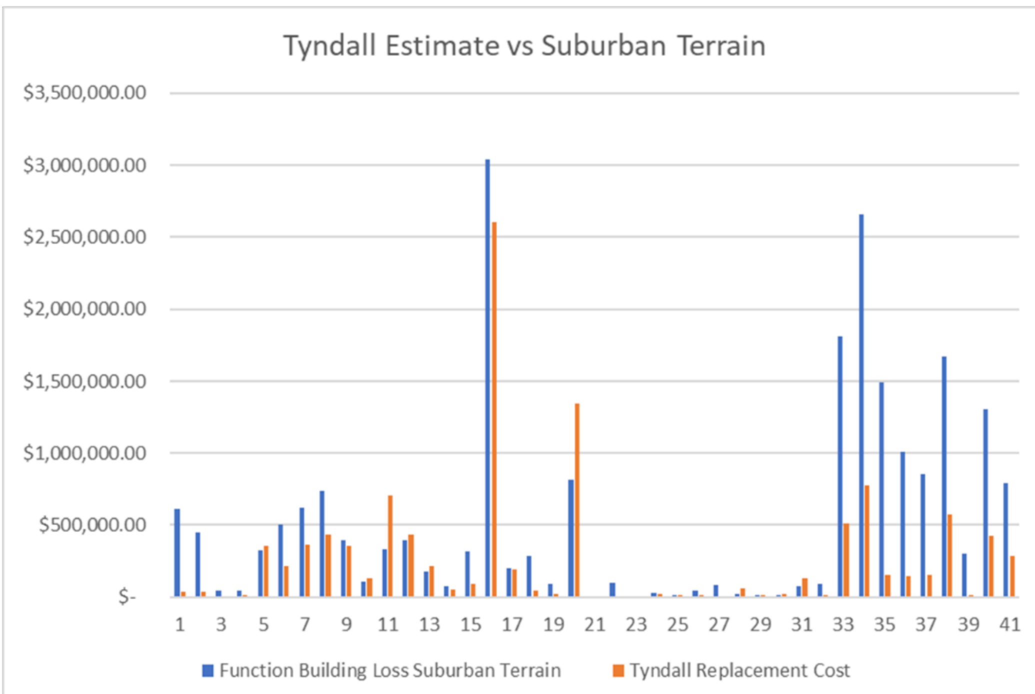


Figure 10. Tyndall Replacement Estimate Suburban Terrain Estimate Results Comparison

Lastly, the comparison between light tree terrain and the Tyndall estimates showed some similar results. With HAZUS conveying that light tree terrain resembled the region the best an expectation for better results was anticipated. Within literature, a difference of less than 10% in loss ratios was observed for the resembled open terrain conditions of

Hurricane Andrew [26]. The delta between estimates improved in figure 11 when using the represented terrain. However, figure 11 still shows in similar fashion that steel is overestimated by HAZUS and underestimated for concrete.

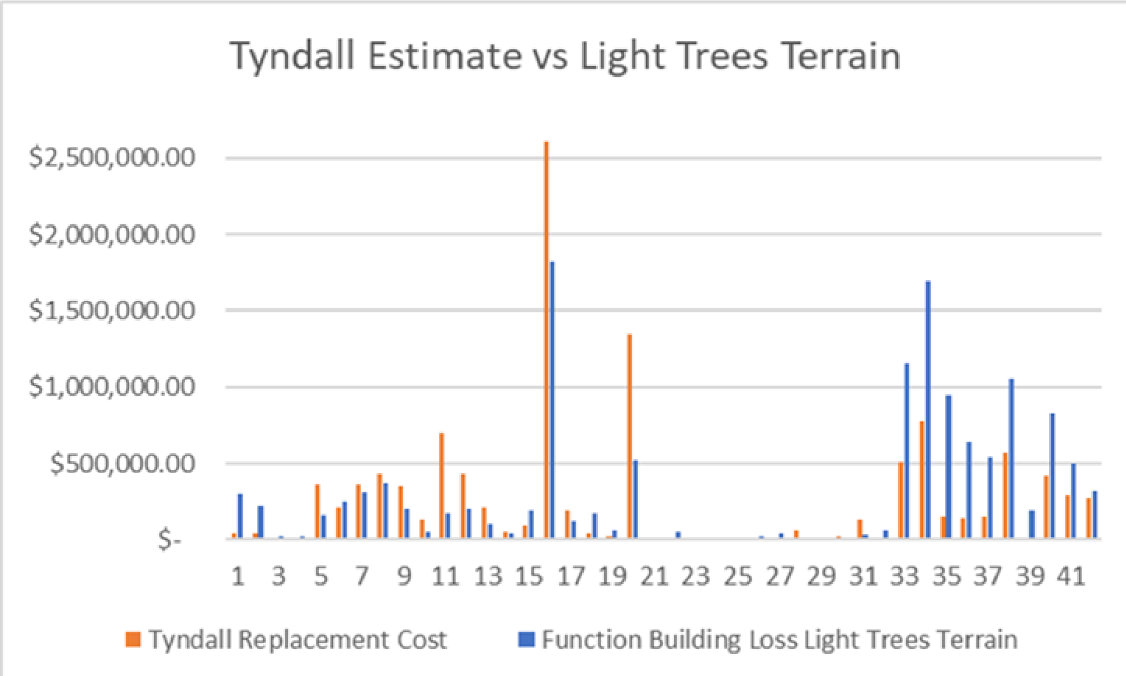


Figure 11. Tyndall Replacement Estimate and Light Trees Terrain Estimate Results Comparison

This method of replacement cost estimate conveyed various information. Within all three comparisons, masonry buildings seemed to have the lowest replacement cost. This could convey that masonry type buildings are the most resilient buildings when faced with a hurricane strike. The building loss function results also conveyed that the concrete buildings are underestimated and that the steel pre-engineered buildings are overestimated by HAZUS. Looking at the statistics in table 8 C one can see that the light tree terrain comparison is the only comparison that failed to reject the null hypothesis. The light tree terrain t statistic is 1.0068 meaning that the results are occurring about 1.01 standard deviations away from the mean. Since the t critical for a two-tail test is 2.021

one fails to reject the null hypothesis and suggest that there is no difference between the light tree terrain replacement cost and the Tyndall AFB replacement costs. This method was off by approximately 195% when comparing building to building estimates to the Tyndall AFB dataset as shown in table 9. Comparing these results to those in literature, the results from this research were not as representative to the actual models. However, the estimate results in this research did improve when the terrain was best represented. This agreed with conclusions found in literature conveying that surface roughness influences building damages [15], [30], [43]. The difference in performance within this research could be attributed to the assumptions made in table 4 and only having 41 buildings available to compare.

Table 8 A. Paired T-Test for Open Terrain B. Paired T-Test Suburban Terrain C. Paired T-Test Light Trees Terrain

t-Test: Paired Two Sample for Means

	Function Building Loss Open Terrain	*Tyndall Replacement Cost*
Mean	663090.253	267754.6805
Variance	7.84465E+11	2.15269E+11
Observations	41	41
Pearson Correlation	0.674109701	
Hypothesized Mean Difference	0	
df	40	
t Stat	3.791732102	
P(T<=t) one-tail	0.000247553	
t Critical one-tail	1.683851013	
P(T<=t) two-tail	0.000495107	
t Critical two-tail	2.02107539	

A.

t-Test: Paired Two Sample for Means

	Function Building Loss Suburban Terrain	*Tyndall Replacement Cost*
Mean	535890.1173	267754.6805
Variance	5.06611E+11	2.15269E+11
Observations	41	41
Pearson Correlation	0.747831713	
Hypothesized Mean Difference	0	
df	40	
t Stat	3.596024948	
P(T<=t) one-tail	0.000438967	
t Critical one-tail	1.683851013	
P(T<=t) two-tail	0.000877934	
t Critical two-tail	2.02107539	

B.

t-Test: Paired Two Sample for Means

	Function Building Loss Light Trees Terrain	*Tyndall Replacement Cost*
Mean	320530.0773	267754.6805
Variance	1.98613E+11	2.15269E+11
Observations	41	41
Pearson Correlation	0.728413226	
Hypothesized Mean Difference	0	
df	40	
t Stat	1.006837472	
P(T<=t) one-tail	0.16003249	
t Critical one-tail	1.683851013	
P(T<=t) two-tail	0.320064981	
t Critical two-tail	2.02107539	

C.

Table 9 Percent Increase Results for Light Tree Comparison

Light Tree Comparison

Building Code number	Diff in Estimate	% Increase
1	$ 265,335	675
2	$ 184,639	468
3	$ 20,275	804
4	$9,305	69
5	$ (193,202)	-54
6	$ 39,918	19

7	$(52,609)	-14
8	$(61,316)	-14
9	$(155,030)	-44
10	$(74,453)	-58
11	$(535,210)	-76
12	$(236,107)	-54
13	$ (108,432)	-51
14	$ (7,714)	-15
15	$97,627	108
16	$ (779,827)	-30
17	$ (68,497)	-36
18	$ 125,899	283
19	$34,643	142
20	$ (827,147)	-61
21	$2,478	257
22	$42,232	660
23	$(342)	-7
24	$ (2,204)	-13
25	$ (2,190)	-21
26	$11,712	104
27	$33,802	485
28	$(49,216)	-80
29	$ (5,147)	-47
30	$(15,017)	-75
31	$(93,547)	-72
32	$48,219	410
33	$638,329	124
34	$907,940	116
35	$794,469	519
36	$500,746	351
37	$390,003	258
38	$488,138	85
39	$176,657	1083
40	$406,885	96
41	$211,750	73
	Average %	**195**

One acknowledges that assuming worst case scenario characteristics will produce worst case scenario replacement cost results. It can be seen in figure 12 how characteristic selection changes the loss function curves. The only characteristic changed was the inclusion of shutters and the curve changed. Touched on earlier however, it is not unusual for government contracts to be built while meeting the minimal requirements.

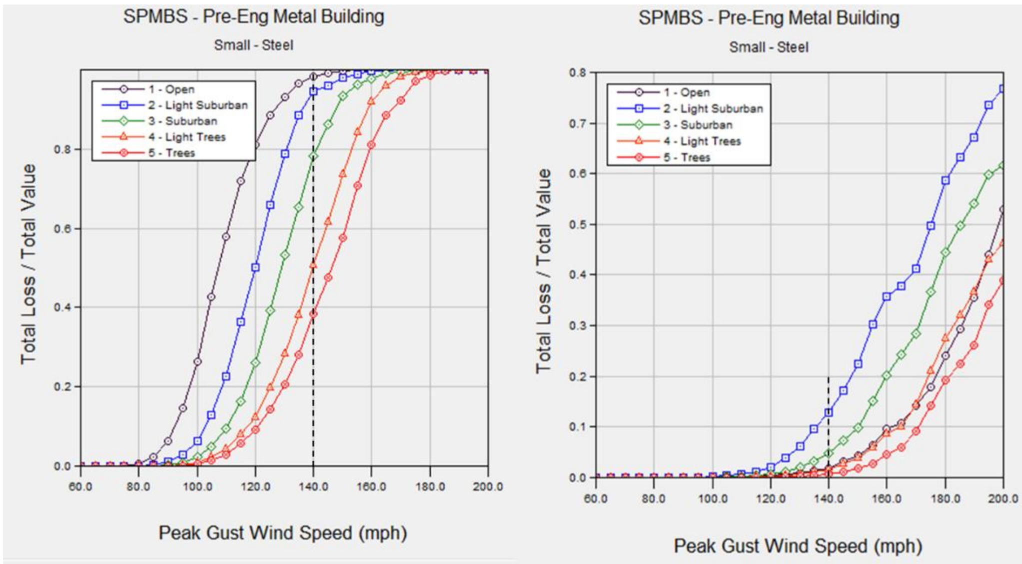


Figure 12. Example in Loss Function Curve Difference when Characteristics Change (Direct Output from HAZUS)

Overall, using the building loss functions seems like a feasible way to get replacement cost estimates. The loss function curves loss ratios seem to correspond to damages incurred when the wind, terrain and building characteristics are representative of the study region. Though the results convey that this method is off by 195%, the t-test statistics show that there is no significant difference between the ACEC assessment estimates and the light tree terrain estimates. Furthermore, the loss functions were validated using hurricanes Erin, Opal, Bertha and Fran when the software was developed [26]. The average prediction error ratio, which was identified as the actual loss divided by the predicted loss, was 0.83 [26]. The total predicted cost, using the light trees terrain loss function, was $13,141,733 while the actual, according to the preliminary estimates, was $10,977,942. That was a prediction error of 0.835, which falls right in-line with the average. Furthermore, Hurricane Ike was modeled using HAZUS and the actual value of damage was $8.5 billion compared to the predicted estimate of $8.4 billion [43].

The last method used the damage results from the user defined facilities capability in HAZUS. The damage result probabilities results for all 41 buildings are shown in table 10. The building loss estimates for each building were also included in table 10.

Table 10 Damage Probability Results from HAZUS, Building Damage Percent and Building Loss Estimates for the User Defined Facilities Method

Wind Building Type	Code Number	Minor	Moderate	Severe	Destruction	Bldg Damage %	Bldg Loss
CERBL	1	0.13	0.3	0.44	0	0.4084	$ 995,285.91
CERBL	2	0.13	0.3	0.44	0	0.4084	$ 732,021.06
CERBL	3	0.13	0.3	0.44	0	0.4084	$ 74,480.32
CERBL	4	0.13	0.3	0.44	0	0.4084	$ 74,480.72
CERBL	5	0.13	0.3	0.44	0	0.4084	$ 532,674.89
CERBL	6	0.13	0.3	0.44	0	0.4084	$ 827,735.32
CERBL	7	0.13	0.3	0.44	0	0.4084	$ 1,015,299.96
CERBL	8	0.13	0.3	0.44	0	0.4084	$ 1,208,955.07
CERBL	9	0.13	0.3	0.44	0	0.4084	$ 645,753.50
CERBL	10	0.13	0.3	0.44	0	0.4084	$ 179,132.82
CERBL	11	0.13	0.3	0.44	0	0.4084	$ 549,352.73
CERBL	12	0.13	0.3	0.44	0	0.4084	$ 645,753.50
MECBL	13	0.13	0.31	0.43	0	0.4044	$ 155,931.38
MECBL	14	0.13	0.31	0.43	0	0.4044	$ 66,314.32
MERBL	15	0.13	0.31	0.43	0	0.4044	$ 405,782.64
MERBL	16	0.13	0.31	0.43	0	0.4044	$ 3,929,814.02
MMUH1	17	0.37	0.4	0.13	0.01	0.2506	$ 408,526.12
MMUH1	18	0.37	0.4	0.13	0.01	0.2506	$ 569,154.95
MMUH2	19	0.37	0.4	0.13	0.01	0.2506	$ 84,646.42
MMUH2	20	0.37	0.4	0.13	0.01	0.2506	$ 744,941.58
MSF1	21	0.38	0.35	0.11	0.05	0.2624	$ 7,223.87
MSF1	22	0.38	0.35	0.11	0.05	0.2624	$ 102,077.80
MSF1	23	0.38	0.35	0.11	0.05	0.2624	$ 9,451.65
MSF1	24	0.38	0.35	0.11	0.05	0.2624	$ 32,330.04
MSF1	25	0.38	0.35	0.11	0.05	0.2624	$ 16,848.18

MSF1	26	0.38	0.35	0.11	0.05	0.2624	$ 48,323.85
MSF1	27	0.38	0.35	0.11	0.05	0.2624	$ 85,594.09
MSF1	28	0.38	0.35	0.11	0.05	0.2624	$ 25,466.18
MSF1	29	0.38	0.35	0.11	0.05	0.2624	$ 12,009.00
MSF1	30	0.38	0.35	0.11	0.05	0.2624	$ 10,630.09
MSF1	31	0.38	0.35	0.11	0.05	0.2624	$ 75,693.48
MSF2	32	0.38	0.35	0.11	0.05	0.2624	$ 44,967.49
MSF2	33	0.19	0.27	0.31	0.2	0.5132	$ 1,690,081.53
SPMBS	34	0.19	0.27	0.31	0.2	0.5132	$ 1,732,268.70
SPMBS	35	0.02	0.07	0.34	0.31	0.5706	$ 1,081,224.80
SPMBS	36	0.02	0.07	0.34	0.31	0.5706	$ 734,032.39
SPMBS	37	0.02	0.07	0.34	0.31	0.5706	$ 617,842.83
SPMBS	38	0.02	0.07	0.34	0.31	0.5706	$ 1,211,019.76
SPMBS	39	0.02	0.07	0.34	0.31	0.5706	$ 220,209.95
SPMBS	40	0.02	0.07	0.34	0.31	0.5706	$ 946,125.55
SPMBS	41	0.02	0.07	0.34	0.31	0.5706	$ 571,086.72

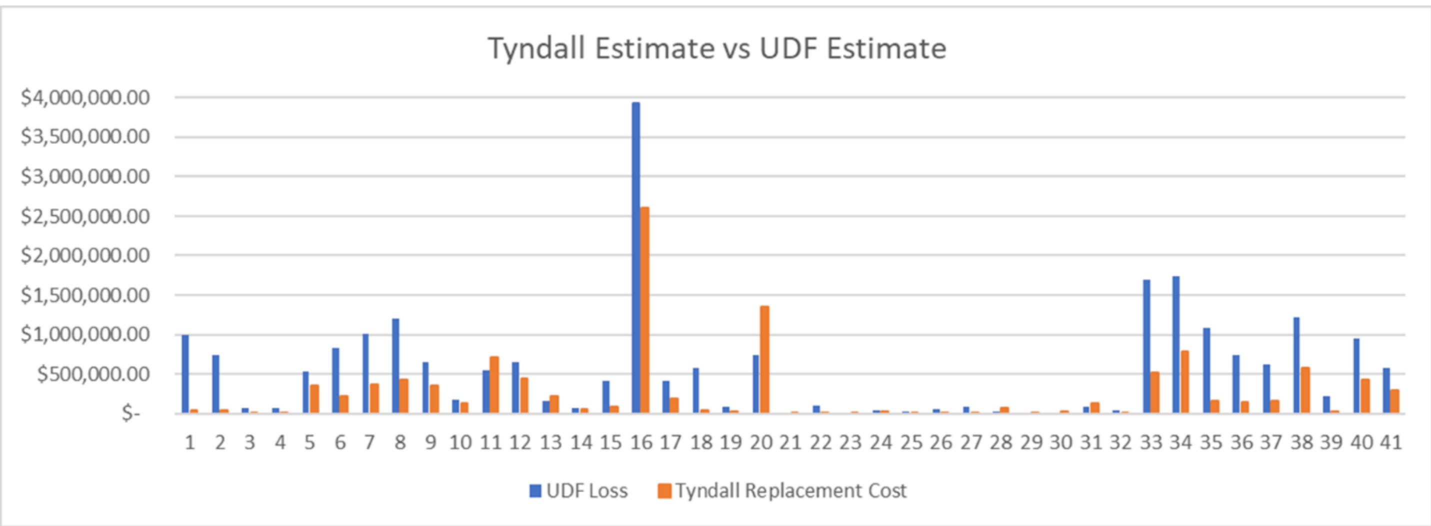


Figure 13. Tyndall Replacement Estimate and User Defined Facilities Results Comparison

Figure 13 conveys the comparison between the user defined facilities data and the Tyndall dataset. One notices that across the board all the user defined facilities estimates tend to be higher than the Tyndall dataset. Of note, the user defined facility feature within HAZUS only uses wind building type, census tract, wind building scheme and location in order to come up with the building damage probabilities. Square footage and age are solely for descriptive purposes within the user defined capability.

Looking at the statistics in table 11, one can draw that the user define facilities cost estimates are statistically different from the Tyndall estimates. This is because the t statistic is 4.704 and falls outside the t critical two tail value of 2.021.

Table 11 Paired T- Test Results for User Defined Facilities Comparison

t-Test: Paired Two Sample for Means		
	UDF Loss	***Tyndall Replacement Cost***
Mean	563915.7361	267754.6805
Variance	5.13292E+11	2.15269E+11
Observations	41	41
Pearson Correlation	0.851398353	
Hypothesized Mean Difference	0	
df	40	
t Stat	4.703760943	
P(T<=t) one-tail	1.51388E-05	
t Critical one-tail	1.683851013	
P(T<=t) two-tail	3.02777E-05	
t Critical two-tail	2.02107539	

Table 12 Percent Increase Results for User Defined Facilities Comparison

UDF Comparison

Code Number	Diff in Estimate	% Increase
1	$ 955,991	2433
2	$ 692,608	1757
3	$71,959	2854
4	$60,989	452
5	$176,436	50
6	$614,306	288
7	$ 651,936	179
8	$777,611	180

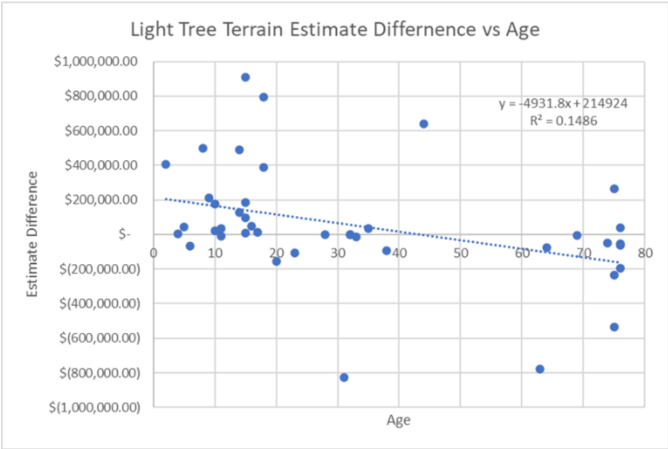
9	$293,077	83
10	$49,852	39
11	$(153,999)	-22
12	$212,000	49
13	$(58,537)	-27
14	$13,505	26
15	$315,269	348
16	$1,327,929	51
17	$217,765	114
18	$524,716	1181
19	$60,178	246
20	$(602,416)	-45
21	$6,261	650
22	$95,683	1496
23	$4,608	95
24	$14,725	84
25	$6,632	65
26	$37,016	327
27	$78,621	1128
28	$ (35,881)	-58
29	$1,141	10
30	$(9,451)	-47
31	$ (53,912)	-42
32	$33,206	282
33	$1,175,783	229
34	$952,496	122
35	$928,248	607
36	$591,567	415
37	$466,448	308
38	$637,977	111
39	$203,903	1250
40	$523,949	124
41	$282,410	98
	Average %	**438**

The user defined facilities method did not perform well when estimating the replacement cost of the buildings. Table 12 conveys that building estimate comparisons were off by an average of 438%. The method used attempted to use the damage probabilities of each building and the cost ratio probability associated with the damage. Though the method was valid, it makes sense that the results were inaccurate as cost ratio probabilities were not specific to each building and rather a generalized proportion based on the validation results in HAZUS. This method does convey the damage probability of the buildings which could be useful for decision makers. In past studies, the damage probabilities have shown acceptable results, one in particular had a mean difference of approximately 23% [57].

Given that the light trees terrain building loss function seemed to perform the best, further analysis was done to see if there was a correlation between building types and replacement cost estimates. Looking at figure 14 one can see a trend that concrete buildings are underestimated, and steel pre-engineered buildings are overestimated. All masonry related buildings seem to have conflicting results. For example, in the masonry single family homes graph building 22 is overestimated by the light trees terrain function but building 31 is underestimated. This suggests that future analysis may have similar results.

Figure 14. Light Trees Terrain Results and Tyndall Replacement Comparison by

Building Type



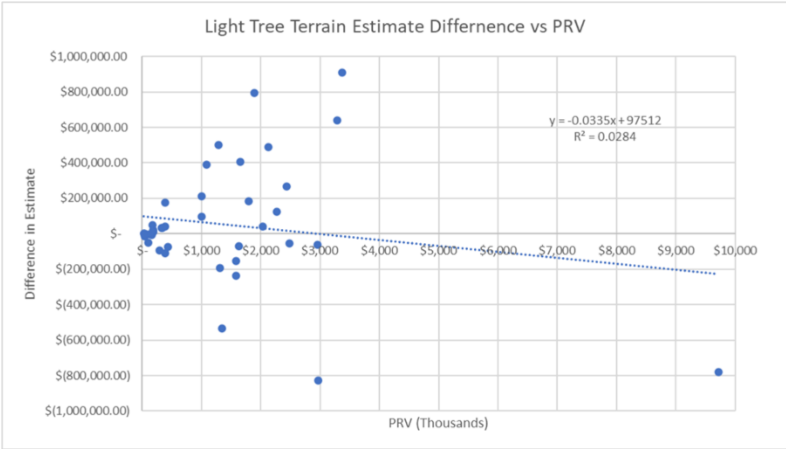


Figure 15A. Plot of Age versus the Estiamte Difference between HAZUS Light Tree Terrain and the Tyndall Dataset B. Plot of Plant Replacement Value (PRV) versus the Estiamte Difference between HAZUS Light Tree Terrain and the Tyndall Dataset

Furthermore, the plant replacement value and the age of each building was plotted against the difference between the light tree terrain estimates and the Tyndall replacement cost estimates. Figure 15 conveys that there is no reason to consider the value of a building or the age of it when calculating the cost to replace the damage. When looking at the plot with age, one can see that buildings with the same age have a wide range in estimate differences. With the r-squared only explaining 14.86% of the data, age also does not help predict well enough how far off from the actual estimate one will be. When looking at the PRV plot again there seems to be little correlation. When looking at the same PRV value one can see that there are multiple results in estimate differences. With the r-squared only explaining 2.84% of the data the PRV does not help predict how far off one can expect to be also. These results could improve if there were more buildings to compare.

Comparing the three methods, generic building stock, building loss functions and user defined facilities, the best method was the building loss functions method. The average cost for a building was $267,755 for the Tyndall dataset while the average cost was $320,530 for light tree terrain results. The paired t-test explained whether there was no difference in cost (null hypothesis) between the Tyndall dataset and the HAZUS comparisons. The generic building stock statistics and the light tree terrain statistics were the only two to failed to reject the null hypothesis indicating that these methods maybe feasible. Though the generic building stock method was inaccurate by about 70%, the generic building stock approach could only compare the averages of specific wind building types since the generic building stock reports only gave the total damage cost for each wind building type. The building loss function method compared building to building cost estimates and the statistics from all terrains showed representative results. It was expected for the estimates in open and suburban terrain to be different than the Tyndall AFB results, and the statistics showed that. Furthermore, the building loss functions have been validated and the projection error ratio for the light tree's terrain comparison aligned with the average.

Looking at other literature, the results in this research show similar findings. Though the loss ratio results are for building and content HAZUS modeled a total loss ratio of 16.9% compared to the actual loss ratio of 19.1% for the entire county of Dade using Hurricane Andrew [22]. This is an underestimate by the HAZUS model. For Hurricane Hugo the total modeled loss ratio was 3.64% compared to the actual ratio of 2.96% [22]. Here the model overestimated. Another study showed that the HAZUS model underpredicts risk by 31.3% and overpredicts risk by 9.5% [58]. Similarly, the Tyndall results had over and underestimates. This conveys that other studies have found to be HAZUS to be off, but not by much. Literature has also conveyed that the damage and loss models may underestimate the small losses that occur at lower wind speeds [22]. In a more recent study on Hurricane Harvey, the HAZUS results underestimated the actual losses and the difference was attributed to out of date data within the general building stock [38].

Application to AF and DoD

This research is applicable to the AF and the DoD as a whole. Inevitably a hurricane will strike DoD institutions. This will create the need to know the damage costs and many more information for reconstruction. HAZUS may be able to help with emergency management, community planning, recovery, guesstimating, budgeting, etc. Currently, the Air Force is fighting to rebuild Tyndall AFB after Hurricane Michael destroyed it. For future use, the HAZUS model suggest a reliable replacement cost estimate using the building loss functions. Since weather technology can gage the wind speeds of incoming hurricanes days in advance one can fix a predicted top windspeed and go from there. In order to get great results however, one should gather the wind building type for the military installation, building characteristics assumed in table 3 and the terrain type of the area. Using the HAZUS building loss functions may prove to be a much simpler and quicker method to calculate replacement cost estimates. More importantly, the estimates can be calculated before a hurricane strikes rather than after. This software may provide a standardized method to assess replacement cost due to natural disasters as it is known that methods change slightly from base to base.

Suggested Improvements

Of notice various data sources may cause inconsistency of damage/loss estimates. To date, not much effort has been done into centralizing a systematic, and comprehensive events and losses inventory. The Hazards Research Lab at the University of South Carolina developed the Spatial Hazard Events and Losses Database for the United States (SHELDUS) in hopes to solve this issue [7].

When looking at hurricane loss models there seems to be difficulty capturing demand surge metrics. RMS is one of the few models that attempts to do so and is even in developments of a model for super catastrophes, like Katrina [7]. If demand surge were captured, cost estimates would measure the economics of increased demand for reconstruction materials and labor and other causes of loss amplification.

Factors that contribute to the increase in the cost of reconstruction are important to consider after a hurricane disaster. Air Force officers at Tyndall AFB expressed that some cost estimates have come in with up to 300% inflation and others only 15% after hurricane Michael [14]. Inflation in the construction sector after the Sri Lanka natural disaster averaged around 30 to 40% [59]. Without understanding what factors are considered and which ones could possibly be left out, an explanation for the increase in the cost of reconstruction is difficult to give and accurate estimates cannot be done. Some of those factors are contractor fees, location, damage type, and resources availability [60]. Contractor fees are factor to consider. For example, the reconstruction projects in Panama City Beach have a large need for labor [61]. If the contractors are coming from out of state, mobilization costs are much higher and include housing and food [61]. Depending on the category of a hurricane, the cost of housing the contractors varies. If a category 5 hurricane hits, according to the Saffir-Simpson scale, one can expect a scarcity in hotels to house the contractors [8], [61]. This all falls under a category called services according to literature [62]. The issue with that becomes understanding what services entails. According to Olsen and Porter, service fees could literally be any expenses paid to companies at any distance from the disaster by any insured entity throughout the life of any time-element claim [62]. By that definition other aspects can fall under this category to include the increased overhead and profit contractors apply due to the risks that contractors take on [60]. Following Hurricane Katrina, the uncertainty lead to costlier bids in order to cover the new level of risk [62]. These contractor fees are tough to quantify as it is ultimately up to each contractor to charge whatever they want due to the circumstances of the natural disaster.

The damage type is a factor that affects the reconstruction prices. Each type, whether it is water, wind, structural, and the like comes with its own challenges and thus associated costs. Water damage in particular is an issue. This type of repair is very time sensitive as the longer it takes to repair the more money it costs to do so [62]. For example, hot and humid climates where water damage has occurred can be the perfect conditions for mold to prosper. Coupled with the realistic possibility that electricity is unavailable within the region for extended periods of time makes it difficult to cool and dry infrastructure [62]. Xavier College experienced just that after Katrina [60]. Depending on the type of damage, the cost is subject to change and it should be captured in the cost estimating method.

A factor that has perhaps been unnoticed is the incurred cost to build to current building codes. This may affect the scope of work which in turn increases the cost [60]. The most up to date building code maybe required in order to reconstruct a building that was greatly damaged. These requirements affect the type of materials, amount of material and skills needed to reconstruct [62]. Air Force Civil Engineering Center's (AFCEC) Arnaldo Vincenty expressed how this contributed greatly in the initial cost evaluation for Tyndall Air Force Base after Hurricane Michael [61]. However, there can be exceptions, as was the case with Hurricane Andrew. Building codes were not enforced in an effort to allow for a speedier recovery [62]. This factor alludes partly to the difficulty involved estimating the costs to reconstruct as there has been historical data that enforces new building code and others that choose not to.

The resources available to the area contribute to the price increase. Local materials, labor and material is what is typically used to reconstruct [62]. However, as supply and demand take its course prices increase [60]. In England, prices rose after an extratropical cyclone hit in 1703. Roofing tiles went from 21 shillings per thousand to 6 pounds (that was a 470% increase) [60]. Though not a hurricane, following the earthquake in Charleston 1886, the demand for labor increasingly exceed the supply from the local area [62]. Union bricklayers would not work for anything less than US $5 a day, which was a 67% increase compared to the prices before the earthquake [60]. After Hurricane Andrew, heavy equipment was needed to remove debris and the United States Army Corps of Engineers awarded contracts that were US $25 per cubic yard only after rejecting one-third of the bids that were even higher [62]. Months later contracts were coming in at US $7, when the demand had decreased drastically [62]. It is important to note that ultimately the price is set by the contractors which is based on what consumers are willing to pay, but only they have their reasoning's as to how they come up with their prices. Some contractor's drive to maximize profit explains the higher cost, but for others that is not the case. Some contractors after Hurricane Andrew elected to provide free or reduced materials and services and others just kept them the same as if the tropical cyclone did not happen [60]. Though the price for resources can be difficult to quantify for various reasons, this factor contributes to the demand surge after a hurricane.

Summary

The results and discussion went over the HAZUS model analysis. The generic building stock was compared to the Tyndall dataset and found that there is no statistical difference between the average cost for each specific wind building type. Following that, the wind speed was fixed to reflect the wind speed for Hurricane Michael and the specific wind building loss functions were used to get replacement cost results based on terrain. Light trees terrain had the best outcome statistically speaking making HAZUS a feasible option to use as the terrain within the study region is similar. The user defined facilities capability did not reflect great replacement estimate results, but it did output the probability of damage for user defined facilities. This could be of interest for matters like mitigation and used when considering what types of buildings to use for construction. What was revealing from the analysis was that concrete buildings tend to be underestimated, steel buildings overestimated. Additionally, PRV and age have no correlation with replacement cost estimates according to the data. Overall using HAZUS suggests that specific wind building type function curves may give acceptable results for replacement cost estimates.

V. Conclusions and Recommendations

Chapter Overview

This section covers the conclusions drawn from the analysis of HAZUS. It conveys what the results suggest and any insights that were able to be drawn. The significance of this research is that HAZUS may be able to provide acceptable replacement cost estimates if the building loss functions are used. Four recommendations for future research are conveyed within this chapter as well.

Conclusions of Research

The first question aimed to see what method, within HAZUS, was the most effective. Out of the three different approaches analyzed the building loss function approach is best way to get replacement cost estimates. Using the building loss functions one saw how the results got better and represented the Tyndall AFB preliminary estimates once the terrain was representative of the study region. Of caution, this method was off by an average of 195%, but only 41 buildings were available for analysis. The statistics for this method did convey, however, that there was no statistical difference between the HAZUS results and the preliminary estimates. The generic building stock approach may lack in its ability to represent military installations since the default data does not have information on them. Other research conveys that its default data may be inaccurate as well [22], [38]. Even though we failed to reject that there was no change in average cost estimates for the generic building stock and the method was off by 70%, identifying if this approach is effective will not be available until data for the entire base is collected. It can be said that the user defined facilities capability was not a feasible way to estimate replacement cost estimates. The UDF method rejected the null hypothesis and its estimates were off by 434%.

The second question this research aimed to answer was whether HAZUS was a reliable tool for replacement cost estimates. Based on the findings from this research and other literature review, HAZUS is not perfect. It will overestimate and it will underestimate. This can be attributed to multiple factors as hurricanes cause a multidimensional problem. However, within the light trees terrain results, the prediction error aligned with that of four different validated studies. Additionally, though results in literature have shown differences between actual and modeled cost, they were accepted as reasonable as no model can 100% predict actual cost. The results for this research too showed that HAZUS will overestimate or underestimate. If the dataset was larger, estimate differences are expected to decrease making the replacement cost estimates more accurate. With limitations and assumptions in mind, HAZUS does provide replacement cost estimates.

The research also attempted to show how the best method can be used within the Air Force and DoD. HAZUS can be implemented within the Air Force and DoD if one uses the building loss functions. The results and discussion section conveys a deeper explanation, but as long as one has a reliable wind speed for the hurricane in question, the terrain type, specific wind building classification and a description of the building characteristics replacement cost results should be acceptable. The results conveyed that no matter the terrain, HAZUS may underestimate concrete buildings and overestimate steel pre-engineered buildings. They also conveyed that rougher terrain reduces the damage to buildings and that masonry type buildings received lower repair estimates. The

HAZUS building loss functions approach would be a much simpler and quicker method to calculate replacement cost estimates. Additionally, the estimates can be calculated before a hurricane strikes rather than after. This software may provide a standardized method to assess replacement cost due to natural disasters as it is known that methods change slightly from base to base.

Significance of Research

The significance of this research is the insight gained from the HAZUS model analysis done. Furthermore, this research will help come up with a feasible replacement cost estimate in a much simpler fashion. Within industry, replacement cost estimates are built by making an itemized list of materials and labor for the damages to each building. It is also known methods from base to base vary slightly which may contribute to the accuracy of estimates. This method may serve as a standardized method throughout military installations and could possibly be extended to other types of natural disasters. Given that the replacement cost estimates trend towards a lower cost based on more terrain, it is also significant to acknowledge that having rougher terrain may be advantageous when planning the layout of building installations. Additionally, HAZUS can output damage probabilities which can be used by decision makers whenever the inevitable day comes that another hurricane strikes.

Recommendations for Future Research

First and foremost, if it becomes practical at the very least the RMS model should be analyzed and then compared to the HAZUS results. The model, alike a few more, are heavily used within industry and could prove to be have accurate results. HAZUS will be releasing a new tool called FAST that is designed to make cost assessments using imported information on a set of structure specific data. This may have better results since HAZUS user defined facilities tab does not estimate building cost damages. At the time this research was done, awarded contracts were still being given and thus that data was not available. It would be interesting to see what the results are repeating this research, but with the final replacement costs for each of the buildings. Those results would be more valuable given that the comparison is between HAZUS outputs and what was actually paid for the 41 buildings. Future research should also focus on the demand surge. NOAA has claimed they have not made an attempt to run economic analyses for long-term effects in the spike in local construction industry following a major event [63]. Capturing this type of phenomena may add another variable for hurricane loss models to implement.

Summary

Ultimately, hurricane loss models are tools, and the implementation of them can help predict, plan, mitigate, budget, forecast, etc. The analysis suggests that HAZUS may be of assistance when calculating replacement cost. This model could significantly help estimate cost due to hurricanes in a more standardized manner that is less time consuming and proactive. Applying the most suitable method for replacement cost will help generate improvement within project management and asset management for future hurricane strikes to come.

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14. ABSTRACT
Recent reconstruction of infrastructure and its associated cost due to hurricanes justify research into hurricane loss models that can provide a more robust cost estimate. Academic research indicates that hurricane disasters are becoming more frequent and are becoming costlier. This research intends to explore hurricane loss models used by Federal Emergency Management Agency (FEMA), Risk Management Solution (RMS) and Florida State University (FSU). Within the literature review, key components of hurricane loss models were identified. These models and the key components were explored in order to help bring an understanding of loss estimation. The research found that the implementation of the HAZUS model may aid in calculating the replacement cost of buildings using the specific building loss functions. The building loss functions are dependent on terrain type and building characteristics, however. HAZUS user define facilities capability reports the probability of specific building damage, however not the replacement cost. The generic building stock results prove to be off by approximately 70% when comparing building averages. The building loss functions results prove to be off by approximately 195% and the user define facilities proved to be off by approximately 438% when comparing building to building results. The limitations included unavailable awarded contracts, the analysis was only applied to 41 buildings and that default generic building stock data within the software. Within the DoD, HAZUS conveys that rougher terrain and masonry buildings can be advantageous when building near the shore. Using the building loss functions method is a simpler, quicker and standardized approach to get replacement cost results. Overall, this research determined that HAZUS may give valuable insight when looking at hurricane strikes in a study region.

15. SUBJECT TERMS
Hurricane Loss Model, FEMA, Construction Cost

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