Improving Community Resilience through Post-Disaster Temporary Housing Optimization

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Abstract: Since the 1990s, there has been a significant increase in severity and frequency of natural disasters, and the numbers of post-disaster displaced people has followed a similar increasing trend. Most recently, devastation from Hurricane Harvey resulted in the prolonged displacement for nearly 40,000 people, with 8,000 families occupying all vacant rental options/hotels and an additional 30,000 in emergency shelters. Such an increase in the number of displaced people results in an increased importance for disaster relief housing, focused around transitional housing in post-disaster settings. The variety in temporary housing creates an ambiguity within the supply chain which dissembles the resource dynamics that were established as essential for communities to function and adapt successfully in the aftermath of disasters. To overcome such challenge, demand forecasts and a newsvendor supply chain optimization model for manufactured temporary housing are utilized to provide the affected region with the ability to prepare in advance for their displaced population, producing a reduced length of recovery, and therefore, increasing the resilience of the community. This optimization model provides a potential reduction between $119 million and $243 million in expected loss in comparison to the baseline inventories that U.S. response agencies historically stock.

Keywords: Community Resilience, Temporary Housing, Natural Disasters, Optimization, Supply Chain

1. INTRODUCTION

When a natural disaster strikes, any affected population will feel the adverse effects of these events on human life. Disaster relief and recovery efforts play a pivotal role in the recovery from such events, the reduction of future devastation, and wellbeing of impacted communities [9]. Historically, housing assistance provided to disaster victims has been touted as unsafe and mentally traumatizing, even causing various levels of post-traumatic stress through-out all ages [4, 5, 10, 11]. Unfortunately, the documented rise in the frequency and severity of natural disasters is a trend that is only expected to continue as the human population grows, coastal cities continue to expand, and climate change becomes a reality. As a result, the numbers of prolonged displacement of people after disasters continues to reach unmanageable levels, leaving emergency response managers to struggle with adopting the best response and recovery decisions [1, 2]. For example, Hurricane Harvey's devastation resulted in prolonged displacement for nearly 40,000 peoples, with 8,000 families occupying all vacant rental options/hotels and an additional 30,000 in emergency shelters [3].

Beyond Harvey, examples of these decisions and policies that have gone awry are evident in past disaster efforts during Hurricanes Katrina and Sandy. More specifically, Federal or State control mismanagement led to disagreements between temporary housing methods, which can be in the form of emergency repairs under the Sheltering and Temporary Essential Power (STEP) program, hotels or rental properties, and manufactured housing units, creating a lack of effective planning [12, 13, 14]. These dilemmas caused by an absence of effective planning are most visible during Katrina's recovery, when the temporary housing in the form of trailer homes had traces of the chemical formaldehyde which has negative human health effects, and during Sandy's response where manufactured temporary housing was overlooked leaving 11,000 families without a place to live during the plummeting temperature six weeks after the storm [15, 16].

The proposed solution for this housing dilemma is to improve community resilience using a data-driven supply chain model, which accounts for disaster severity and available inventory of manufactured temporary housing units. The model will enable the reduction of emergency purchasing of manufactured housing at the last minute; a process that relies on excessive expenditure and housing delay. In doing so, response agencies will be able to withhold a baseline inventory that minimizes the expected loss and produces a faster implementation rate amid a disaster event. This paper begins by providing a background of necessary information in section 2, an explanation of the solution methodology in section 3, a discussion of the results in section 4, and ends with a conclusion of the results and a determination of future required work within the topic in section 5.

2. BACKGROUND

2.1 Community Resilience

A community's resilience refers to its ability to successfully respond to and recover from a disaster. Resilience was originally defined as a system's capacity to return to equilibrium after a displacement, whether this entity is an individual, neighborhood, company, university, or state. As community resilience has become integrated within disaster recovery, it has added its own aspect to the accepted definition of resilience [6]. If a community desires to be resilient, the goal is to reduce risk biases between occupants. Reducing these biases by engaging locals in mitigation/recovery efforts, designing a flexible disaster plan, preserving social supports, and providing linkages that support communication between citizens and officials will allow the community to recover together both physically and mentally [6,17]. Furthermore, community resilience can vary demographically. For a disadvantaged community with higher rates of violence, further resources are required to increase communal hope, the safety of residents, and buffer adversity to encourage recovery while preventing violence within the community [18].

The fulfilment of these requirements is necessary for a community to become resilient, and with regards to natural disasters, housing assistance plays a crucial role in their ability to do so. A community's post-disaster resilience is built off the citizens' ability to return to the devastated area. If the temporary housing is limited or located outside of city limits, then that community's ability to rebound will be reduced; as seen in the aftermath of Hurricane Katrina when an absence of proximal temporary housing discouraged the return of residents and hindered the city's ability to recover [19]. However, the variety in temporary housing, which includes but is not limited to trailer or manufactured homes, vacant rentals/hotels, and essential repairs of the damaged properties, generates both financial and political disputes regarding the required housing assistance and correlating supply chain. These disputes between invested parties cause the dissolution of any potential organizational structure and results in delays between shelter and housing. As an example, during Hurricane Sandy's post-disaster housing attempt, only 118 units were provided, and thousands of victims left in shelters [16, 20]. Without an established supply chain and organization structure for temporary housing, the mandatory resource dynamics that are essential for community resilience and efficient post-disaster recovery cannot be achieved [6, 21].

2.2 Temporary Housing

In the aftermath of a disaster, individuals and families require shelter and protection from the devastation that presents itself in the form of structurally damaged buildings, a lack of public services, and further disaster events such as flooding and aftershocks. This shelter will be utilized by the victims for a few days or up to a few years, depending on the severity of the devastation. Disaster relief accommodation has been broken down in the past to represent four different categories, including emergency shelters, temporary shelters, temporary housing, and permanent housing; further explained in Table 1 [22].

Table 1: Summary of Utilized Data

Shelter Type	Expected Use Timespan	Examples
Emergency Shelter	1 to 3 Nights	A safe dry location or building
Temporary Shelter	2 to 3 Weeks	Tent or public mass shelter
Temporary Housing	6 Months to 3 Years	Rental houses or prefabricated units
Permanent Housing	-	A new, upgraded or refurbished home

As seen above, the shelter type that has the most significant transitional role from a mass public shelter to permanent housing is temporary housing, with an expected use timespan between six months and three years. This extended period spent in temporary housing makes the availability of units crucial to the efficiency and success of the recovery; if the units are delayed or arrive as an insufficient amount, then the recovery effort will be delayed. Additionally, as the trend of increasing displaced people continues, the larger demand for temporary housing will add more emphasis on the role of transitional phase [22, 23]. Focusing further on this significant phase, temporary housing is tucked within FEMA's Individuals and Household Program (IHP) which dates to 1951. The IHP program provides financial assistance and direct services for eligible families and individuals after a presidentially declared disaster event. The focus for the assistance provided through this program is for temporary housing, which is comprised of three main types. One of the first types of temporary housing considered post-disasters, consists of making emergency repairs to the victim's home and residence while more trivial repairs are finished; a process outlined through FEMA's Sheltering and Temporary Essential Power (STEP) Program. The next version requires the utilization of the existing rental properties and hotels, which will then be leased out for the entirety of the transitional housing process. The last resort is a prefabricated temporary housing unit which requires large upfront investment [24, 25]. On a global scale, prefabricated temporary housing units vary in design and purpose, from prefabricated kit supplies that must be assembled to ready-made shelters that can be utilized on arrival. The existing and extensive infrastructure in the U.S. can support prefabricated shelters in the form of trailer and manufactured homes [1, 26].

2.3 Temporary Housing Optimization Methods

In the past decade, a series of temporary housing optimization models were created. The first of these temporary housing optimization models is an exploratory model focusing on structural safety, economic impact and proximity of the temporary housing to the destroyed property; however, its downfall is lacking the inclusion for various social, environmental and economic aspects [27, 28, 29, 30]. An expansion of this model enables the accountability for certain social, economic, environmental; while also identifying safety objectives and the optimal location and specific type of temporary housing. The model was further developed to enable the selection of family preferred locations to be considered; though, the increase in complexity produces a prolonged and infeasible run-time [29, 31, 32].

It was not until 2012 that the first model began to account for victim need and apply a focus on the minimization of expenditure. This web-based model relied on the development of a post-disaster temporary housing management system and a customized Hungarian Algorithm to reduce overall runtime; a problem that plagued the models before 2012. Negotiation tactics between emergency management agencies and housing providers were noted as area of future interest [29]. One of the latest articles details designs for a model which minimizes distance to both preferred location and support services; however, this model again makes no stride between the negotiation tactics response agencies use with housing providers and the cost dilemma continues [33].

Although these studies and their different optimization considerations are necessary for further advancement and provide valuable insight into the future requirements of temporary housing, they all fail to answer the delay and lack of housing that plagues the response agencies in the United States. The answer to these gaps within the literature for temporary housing optimization is an optimization model focused on the temporary housing supply chain. A more resilient supply chain results in a reduction within the risk for delay and lack of temporary housing. Through this reduction, complaints and un-satisfaction from occupying residents and families will follow the diminishing trend. Moreover, the model reduces the overall financial risk of the temporary housing application due to the probabilistic approach that provides optimal inventory levels based on demand which in turn contributes to improve a community's resilience and effective recovery during disasters.

3. METHODOLOGY

This study reveals the absence of an organizational structure behind temporary housing implementation, while further revealing the adverse human and communal affects resulting from this delay or lack of housing. A partial solution to this housing dilemma comes in the form of a more resilient supply chain; which for this study relies on the application of the newsvendor model to identify the optimal allocation of temporary housing inventory. By providing an optimal manufactured temporary housing inventory amount, based on historical post-disaster usage of manufactured housing, the financial risk and danger of individuals' prolonged housing displacement is reduced. Although this work revolves around the usage of an applied newsvendor model, the challenge of gaining an accurate preliminary forecast is troubled by the lack of historical data on post-disaster manufactured housing usage. Due to the limited data, a conservative forecasting method is selected to account for variation and reduce potential heightened benefits. While a more sophisticated forecasting method can help overcome this challenge, this does not constitute the main objective of this work. Forecasting is merely a means objective towards the fundamental contribution of this paper which is the optimization of temporary housing supply chain.

3.1 Forecasting model

An accurate forecast, which is the main challenge in supply chains, is needed to avoid overstocks and shortages [34]. For this study, Hurricane Harvey's forecasted requirement of manufactured temporary housing units has been calculated using a moving average of the ratio between required manufactured temporary housing units (THUs) and Consumer Price Index (CPI) adjusted losses. This method disregards non-linear aspects between the specified ratio, and therefore will produce a lower unit requirement. More complex analytical methods can be developed and used to obtain accurate estimates of the number of temporary housing units needed, however, this does not constitute the main goal and contribution of this work and could be the subject of another research study.

The study forecasts displaced people who would require manufactured housing by utilizing prior historical data of manufactured housing supplements for the landfall of a hurricane hitting the United States. Each event considered was declared as a "Major Disaster" within the FEMA database, and contained an estimated cost exceeding ten billion dollars. Due to the increased frequency and severity of natural disasters within the past decades, only hurricanes from the year 2000 or later are considered, as an effort to appropriately consider this increasing trend. The method utilized to complete this forecast is a moving average which focuses directly on the recent increases from historical data. Additionally, the "Florida Four" was a series of four major hurricanes in 2004 which had their recovery effort grouped together in FEMA's five-year summary. Therefore, a "disaster cluster" is used to represent the recovery data for Hurricane Ivan, Charley, Frances, and Jeanne in this study. Another exception is that the support provided for Hurricane Sandy is not considered for the forecast due to New York's objective to disregard manufactured housing usage and instead promote and focus on the flagship STEP program; a decision that made Hurricane Sandy's effort an outlier when considering the THUs and adjusted-CPI ratio. The last exception of consideration for this study included deeming the response for Hurricanes Katrina and Rita an outlier due to the increased severity, exposure, and magnitude of the response.

The forecast for Hurricane Harvey's required number of manufactured temporary housing units is calculated by first finding the ratio of CPI to manufactured THU for each disaster. From here the average of these incident ratios is calculated to produce the average THU per CPI. The CPI for the disaster event of interest, is multiplied by this average THU per CPI to produce the THU for that specified event and the corresponding CPI. This procedure produces Hurricane Harvey's forecasted manufactured THU demand in this study; the historical data and bolded forecast can be seen in Table 2 [35, 36, 37, 38, 39, 40, 41].

Table 2: Summary of Utilized Data with Forecasted Demand

Hurricane	Year	Rank	Category	Temp. Housing Units	CPI-Adjusted Losses (in billions)
Katrina, Rita	2005	1	3	+200,000*	$ 185.2
Harvey	2017	2	4	**5,283**	$ 125.0
Ivan, Charley, Frances, Jeanne	2004	3	4	17,000	$ 71.6
Sandy	2012	4	1	118*	$ 70.9
Ike	2008	5	2	3,692	$ 35.1
Wilma	2005	6	3	1,182	$ 24.5
Irene	2011	7	1	784	$ 15.1
Mathew	2016	8	4	161	$ 10.4
* Not considered for this study					

The forecasted demand for Harvey, which has an adjusted CPI Losses of $125 billion, was approximately 5,300 temporary housing units. When comparing this prediction (forecasted demand is bolded) to the historical demands for temporary housing during previous disasters, there is visible discrepancy within the forecasted value compared to the historical demands. This conservatism within the expected demand can be contributed to the assumption within the forecasting process that the required amount of temporary housing units has a linear trend when represented with CPI. Therefore, the forecasted demand for the Hurricane Harvey is a conservative value that represents the lower end of the preliminary reports [42].

3.2 Forecasting model validation

The validation of this forecasting process is completed below by producing forecasts for each disaster that the data is utilized from and comparing these estimates to the historical manufactured THU required for each disaster. These forecasted values are seen below next to the historical values.

Table 3: Validation of Forecasted Demand

Hurricane	Year	Rank	Category	THUs	Forecast THUs	CPI-Adjusted Losses (in billions)
Katrina, Rita	2005	1	3	+200,000	**7,827**	$ 185.2
Ivan, Charley, Frances, Jeanne	2004	3	4	17,000	**3,026**	$ 71.6
Sandy	2012	4	1	118	**2,996**	$ 70.9
Ike	2008	5	2	3,692	**1,483**	$ 35.1
Wilma	2005	6	3	1,182	**1,035**	$ 24.5
Irene	2011	7	1	784	**638**	$ 15.1
Mathew	2016	8	4	161	**439**	$ 10.4

As expected, the forecasted levels accurately predict the lower adjusted CPI disasters; however, as the CPI loss increases, the forecasts skew and become much more conservative. As discussed previously, a more complex analytical method must be developed and used to obtain accurate estimates of the number of temporary housing units needed as CPI increases, however, this does not constitute the main goal and contribution of this work and could be the subject of another research. For this study, the conservative forecast will only hinder the positive affect of the supply chain model; one where positive attributes are already evident from the smaller value.

3.3 Supply Chain Model

It is well known that disruptive events like natural disasters can result in a supply chain disturbance and delay of necessary materials [43]. The newsvendor model has been historically used as a method of inventory control, with a focus on maximizing the expected profit or minimizing the expected loss and the delay for temporary housing. In the past, there have been conversations regarding the model's inadequate ability to analyze the inherent risks of supply chains and lack of stock to satisfy peak demand; which has been argued to cause adverse side effects to the retailer in the forms of a tarnished reputation and profitability [44]. However, the profitability side of this argument is irrelevant since relief agencies do not aim to make a profit, and only strive to reduce expected losses. A tarnished reputation from a delay and emergency order caused by the understocking of the manufactured temporary housing units would only occur if the suggested inventory is lower than the baseline that the response agencies currently hold. Although, a statement from FEMA in 2011 reveals that the baseline inventory for readied-units is 4,000, a figure less than the forecasted demand; and therefore, is lower than the newsvendor optimized inventory [7]. Additionally, the model will not only reduce costs but also create a resilient and time efficient implementation method through an increased baseline inventory.

The updated baseline inventory information will allow response agencies to make an educated plan, enabling them to order manufactured housing at a wholesale price from the manufacturer instead of the current process that causes a substantial financial loss, housing implementation delay, and an overall lack of housing. The model provides a conservative optimal quantity of temporary housing that response agencies should stockpile to ensure families will be provided the psychological, physical, and social requirements they need to achieve maximised community resilience. Furthermore, by following simple sustainability ideology such as re-use of materials, these manufactured homes can be maintained and placed in storage for only $1,000 dollar per year [45, 46]. If this baseline was purchased at the wholesale price of around $35,000, the storage costs would pay for themselves if the temporary housing units is used once in 35 years; however, with the increasing severity and frequency of natural disaster, the usage of this housing is expected to be significantly more than this ratio of 1:35.

The newsvendor model commonly used within supply chain optimization relies on the maximization of the expected profit; however, in the case of humanitarian aid and federal response agencies, the goal is not to maximize the profit but rather reduce the overall expenditure while providing sufficient aid to the victims. Therefore, for this study the newsvendor model has been formatted to instead minimize the expected loss. For this study the expected loss that is being minimized is a summation of each probabilistic incidence where either there is an unutilized wholesale manufactured unit or a lack of housing resulting in an emergency purchase. In turn, the more accurate the forecasted demand was, the higher chance of a minimized expected loss. This type of newsvendor relies on the minimization of equation 1, which represents the critical fractile for standardized normal loss.

$$L(Z^*) = \frac{Cu}{Co + Cu} \qquad (1)$$

When solving for the critical fractile for standardized normal loss in equation 1, the C_u variable represents the cost underage of one manufactured housing unit. On the contrary, the C_o variable represents the cost overage of purchasing an extra manufactured housing unit. For this study, the cost overage values were established based on a manufactured housing industry professional who estimated the bulk price for the FEMA model trailer home would be around $25,000 with the additional fees ranging about $2,000 for installation and $6 dollars per mile for delivery; however, to account for unknown fees a value of $35,000 per unit was considered for bulk purchasing. As for the cost underage values, a FEMA professional quoted a price estimate of over $90,000 for current emergency purchases; a price that includes installation and transportation [47].

The second step to this model is to apply the critical fractile and obtain the optimized inventory amount. This fractile is then multiplied by the standard deviation of the manufactured temporary housing demand to produce a safety stock, which is then added to the mean demand of manufactured housing to produce the optimized inventory levels. This process is outlined in equation 2.

$$Q^* = \mu + \mathrm{Z} \times \sigma \qquad (2)$$

Using these cost values, the forecasted demand, and the methodology behind the newsvendor model using equations 1 and 2, an inventory of 9,563 temporary housing units is calculated to be the optimal solution with an expected loss of approximately $164 million dollars. In addition, the model also calculates the fill rate (demand fulfilled by wholesale purchasing) to be approximately 76.5%. In 2011 FEMA released a statement that the baseline inventory for readied-units was 4,000; although, FEMA more recently stated that they had 1,700 homes in its current inventory [7, 48]. For comparison, these cases, and a case with a larger inventory, are shown in figure 1 to compare their expected losses and in figure 2 to compare their fill rates.

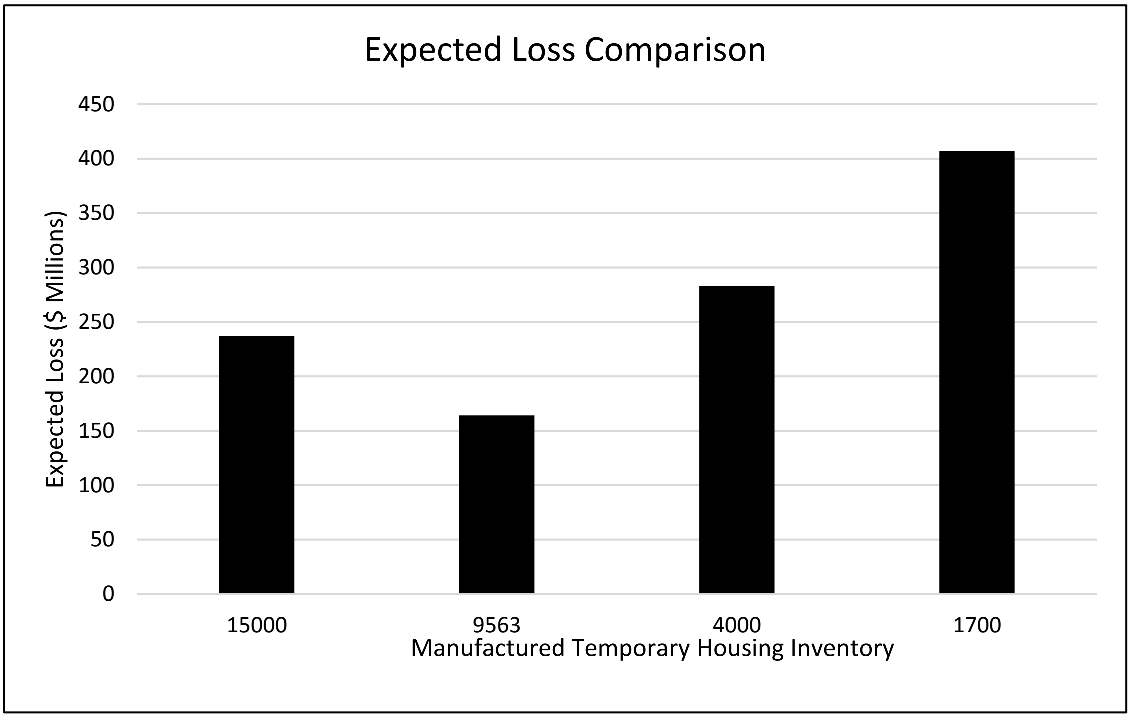

Figure 1: Comparison of expected loss in millions of dollars of the optimized manufactured housing inventory of 9,563 with the other inventories of 1,700, 4,000, and 15,000 (value used as an upper bound comparison).

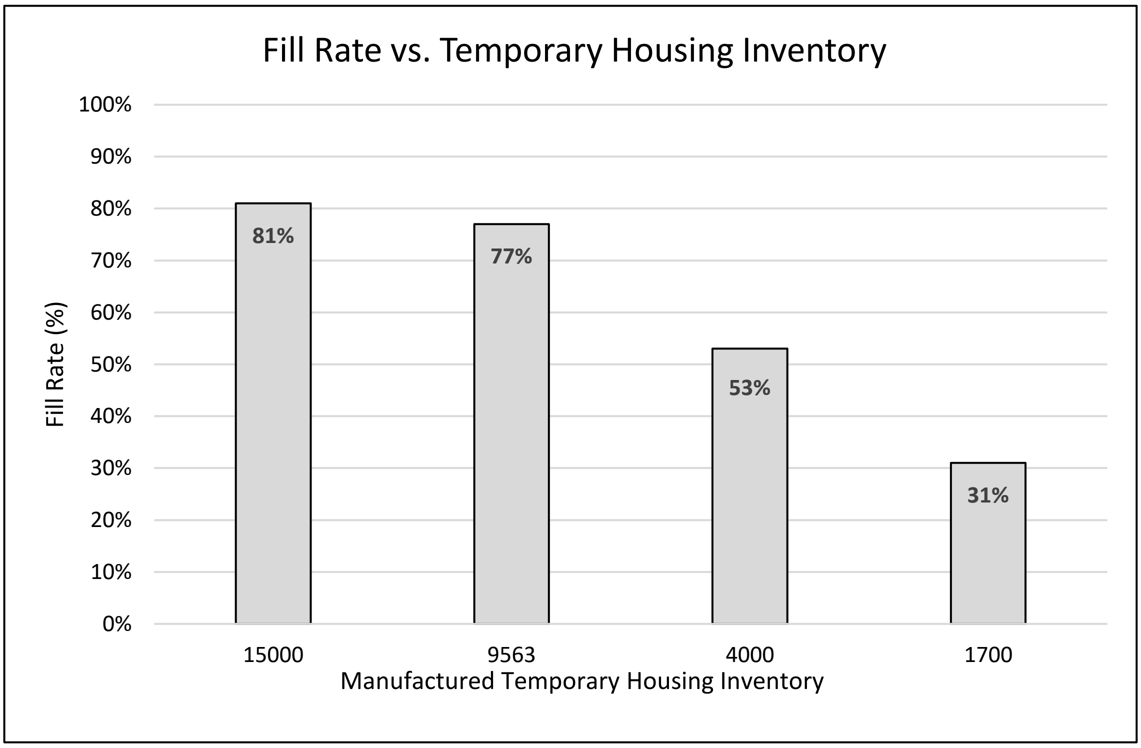

Figure 2: Comparison of the fill rate percentage of the optimized manufactured housing inventory of 9,563 with the other inventories of 1,700, 4,000, and 15,000 (value used as an upper bound comparison).

4. DISCUSSION

As the severity and frequency of natural disasters trend upward and the number of displaced people follows, the different methods of temporary housing will grow in importance. To estimate this future demand, this study presents a validated forecasting method that has deemed itself accurate at lower level adjusted CPI disaster events; while as the CPI increases the forecasts become conservative estimate compared to historical demands. Although, the conservative estimate is larger than the United States response agencies' baseline inventories, allowing for the gain of valuable information from the conservative forecasts. Overall, the forecasted Hurricane Harvey demand for manufactured temporary housing is established at a unit amount of 5,283. If a non-linear regression is completed on the data, a forecast of higher accuracy could be obtained; however, that is out of the scope of the focus for this research.

The supply chain model that is presented in this study enables the optimization of manufactured temporary housing inventories. This optimization provides an amount for expected loss and a wholesale fill rate percentage, describing what percentage of housing demand will have to be provided using an emergency order. The resulting optimized inventory from the model contains an expected loss which is less than the United States' baseline inventories and a larger inventory that was included for comparison; a representation that is shown in figure 1. In addition to this optimized inventory's lower expected loss, it also contains a higher wholesale fill rate. However, as seen in figure 2, the optimized inventory does not have the highest fill rate; the largest wholesale fill rate resides with the 15,000-unit inventory which contains a larger expected loss than the optimized inventory. As expected due to the probabilistic approach to expected loss, the optimized inventory did not contain a full fill-rate. From these comparisons in figure 1 and 2, the optimized inventory is considered reasonable.

This study provides a step forward that has been absent within temporary housing optimization models. The model focuses on the resilience of the supply chain as an effort to increase community resilience and reduce the overall duration of recover; through the reduction of expected loss and expenditure in the manufactured housing's post-disaster role.

5. CONCLUSION

As the frequency of and destruction from natural disasters rises, the number of post-disaster displaced people will follow. The levels of post-disaster displaced people have already proven to be unmanageable in the most recent events and the demand continues to increase. As such, the cost and quality for the efforts are expected to be adversely impacted by this trend. In this paper, we employ a supply chain optimization model to guide planning for a baseline inventory of manufactured temporary housing to minimize overall losses. Using the applied newsvendor model and the conservative forecasted demand, an inventory of 9,563 manufactured temporary housing units was found to be optimal for hurricane Harvey. This solution would reduce the expected loss by over $119 million from FEMA's baseline inventory of 4,000 set in 2011; while over $243 million can be saved when the result is compared to the reported actual inventory.

While this study focuses on reducing the expected loss in dollars with regards to temporary housing, other variables can be considered in the objective function that account for social and health aspects of temporary housing. An opportunity to expand this work in the future will include the utilization of an analytical model of higher complexity for the forecasted demands to provide more accurate estimates in response to the outcome of the validation phase of this study.

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