A PRELIMINARY SUPPLY CHAIN MODEL TO HOUSING RECOVERY AFTER THE OCCURRENCE OF A NATURAL DISASTER

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ABSTRACT
Severe storm events adversely affect housing stock and regional capacity to produce them. Rebuilding this capacity takes time while the affected region faces an unexpected surge in the demand for housing. This research presents a simulation model that considers this problem from the supply chain and production perspective. It allows characterizing capital fluctuations over time and determining bottlenecks to recovery. The model enables an understanding of the dynamics of supply and demand as it pertains to producing housing solutions as part of the recovery process. The ability to anticipate the composition of the demand as well as understanding capital fluctuations is critical to a fast recovery process.

1. INTRODUCTION
Hurricanes are major catastrophic events that cause death and suffering when they hit a populated region. Sheltering before, during, and after a severe storm is an essential activity to preserve the life of residents of the affected communities. In the aftermath of the storm, authorities and communities engage in different activities to recover from the devastating effects of the disaster. Depending on the magnitude and location of the event, different segments of the population may be affected and the regional capacity to recover may be diminished.

Flooding and damage produced by winds may significantly affect existing dwellings. The displaced population remains in shelters and may transition to temporary housing solutions until reconstruction endeavors are able to provide more permanent residential solutions. However, these reconstruction efforts are not uniform among affected communities since the damage stemming from a hurricane may have a dissimilar impact on the housing stock (Nigg, Barnshaw et al. 2006).

The spectrum of recovering the housing stock is extensive. Some houses require some minor repairs while others involve demolition and reconstruction. While government assistance rapidly flows into the affected region, supplies, materials, and labor converge at different rates. In an effort to quickly respond to the displaced population's sheltering needs for those that cannot return to their residences, decision makers may rule to establish temporary housing. However, some of these policies may cause unintended consequences that may delay the rebuilding process. For example, the longer the distance between temporary dwellings and the affected neighborhood, the longer it takes to rebuild the housing stock for underserved communities (Green, Bates et al. 2007). The examination of the recovery process as well as additional examples have been developed by Cemea (1997), Levine, Esnard et al. (2007), Kovács, Matopoulos et al. (2010), Frimpong (2011), Nejat and Damnjanovic (2012) among others.

This paper suggests an innovative application of a stock management structure suggested by Sterman (2000) in the production of housing solutions viewed from the supply chain perspective. The proposed simulation model allows examining the implications of transitioning displaced population to intermediate and long-term housing in the demand side while exploring the effects of barriers and enablers during the housing reconstruction process.

2. RESEARCH QUESTION
Literature that explores and models the progression of housing stock recovery after a catastrophic event employing a supply chain view is limited. Local, State, and Federal authorities benefit from this knowledge since it allows understanding the demand for temporal and permanent housing solutions while identifying bottlenecks that may jeopardize the recovery process. Thus, the central objective of this research is to propose a generic model that characterizes the dynamics of the

recovering housing stock process viewed as a production process. This production process may be seen as a process in which a set of structures, resources, and processes are set in place to deliver an output to the customer who is, in this case, the displaced household. As the production of housing solutions progresses, important fluctuations in labor and material may affect regional capacity to produce them. Thus, the production process assumed in this model is influenced by material and labor availabilities as well as building permits and housing reassignments rates.

3. APPROACH

This abstract suggests using a System Dynamics approach to gain knowledge and understanding of the dynamics of housing stock reconstruction as recovery from a catastrophic event progresses. Größler, Thun et al. (2008) argue in favor of using System Dynamics structures for investigating operation management issues since this approach considers feedback loops, accumulation processes, and delays that actually exist and are commonly found in complex problems. The authors employ a generic System Dynamics modeling approach suggested by Sterman (2000). The methodology includes: (1) developing a causal-loop representation of the regional housing production system; (2) formulating a theory that underlies this model; and (3) formulating a simulation model to test the dynamic hypotheses created from the production model. A brief overview of the model follows.

4. THE MODEL

The model involves characterizing displaced population when progressing through several stages during the recovery process. This is best characterized by compartments, e.g. short term, intermediate, and long-term. Likewise, on the supply side, the production of housing solutions process is subdivided into stocks that represent the different stages in which residential solutions are generated. The production process is influenced by the flow of capital to the region, fluctuations in materials and labor, and the number of dwellings completed and reassigned. These are common characteristics of housing production activities during recovery (Green, Bates et al. 2007).

The model provides a mechanism to characterize the demand and supply of housing solutions considering the composition of the demand and the interplay between the demand and the supply over time. As the stock of housing increases via repairing or reconstruction, the displaced population decreases which leads to decelerating the demand for permanent housing. Figure 1 provides a snapshot sub-model of the core production process in which material, labor, and house assignment rates contribute to adjustments in production rate, and consequently, completion rates.

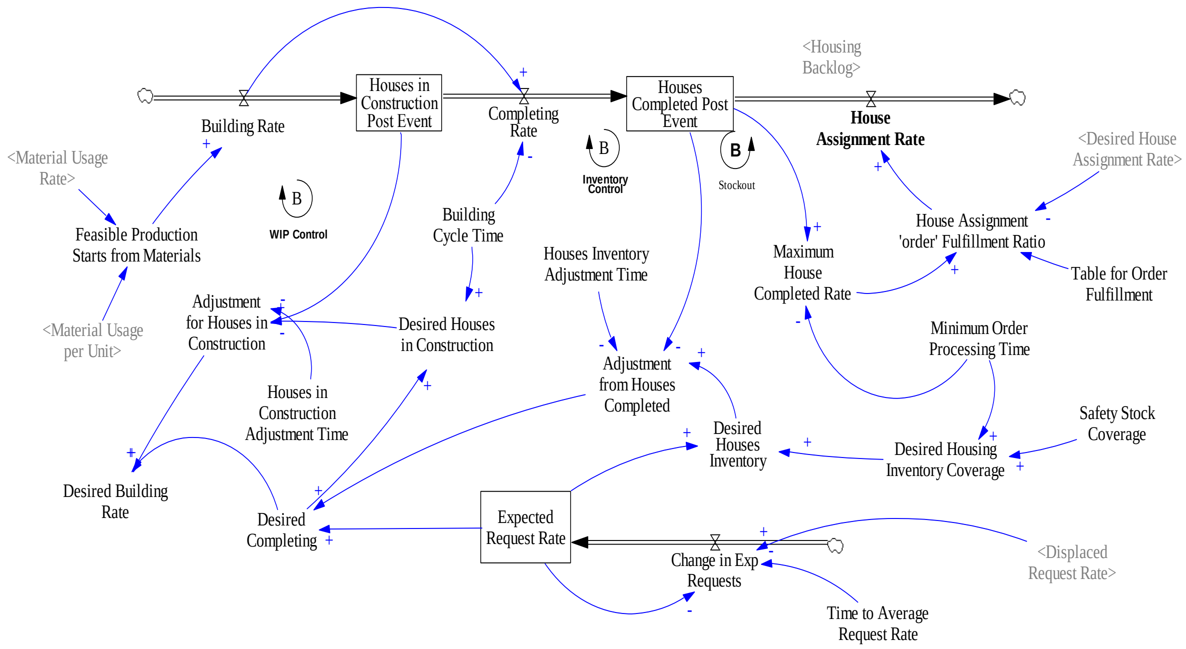

Figure 1: Production view of housing recovery

5. RESULTS

Theoretical data have been employed to mimic the behavior of a hypothetical scenario in which a hurricane hits a populated region. Figure 2 shows how displaced population stock declines as permanent housing solutions become available. Figure 3 exhibits how the number of people waiting for housing solutions first increases as more people become eligible for reconstruction, and then declines as permanent housing are produced and assigned to waiting people.

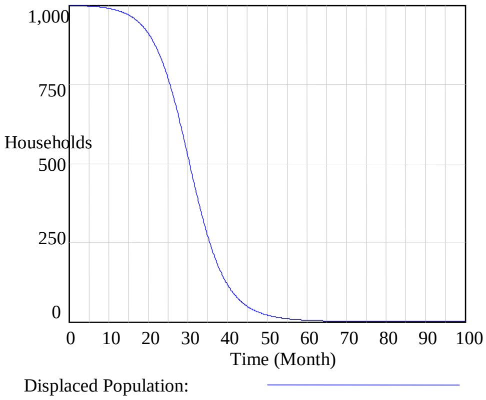

Figure 2: Displaced population volume

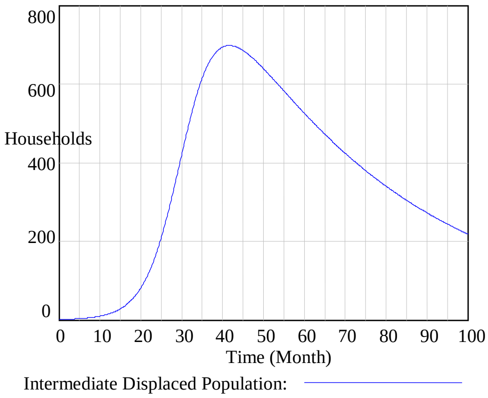

Figure 3: Intermediate displaced population

Figure 4 shows the labor flow where the hiring rate, vacancy creation, and quit rate are displayed. Right after the hurricane hits, the vacancy creation rate rises sharply since it reflects the immediate need of worker to perform the housing construction. This dictates the urgency and need to increase addition labor. Vacancies constitute the stock of potentially hired workers and is increased by the vacancy creation rate and decreased by the hiring rate. However, the hiring process takes time, e.g., considering interviews, background checks. All those activities constitute delays, necessary for the vacancies to be filled.

This delay is illustrated on the figure by the hiring rate, expectedly displaying a lag of time, compared to the vacation creation rate. The difference between the peaks of these rate curves – *vacancy creation rate* and *hiring rate* – illustrates the shortage of workers in need during this period. The quantity of workers available does not meet the need for reconstruction / repair. In the meantime, this severe lack of human resources causes a significant number of houses left without repair / reconstruction (Colten, Kates et al. 2008). Finally, this leads to the increase of the pressure on the small amount of construction builders already on duty.

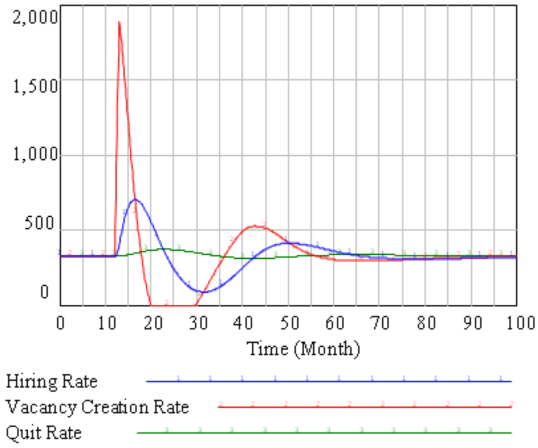

Figure 4: Labor flows

The *vacancy creation rate* remains at 0 for 10 weeks (between 20th and 30th). The 30th week corresponds to the time the *desired labor* raises from its minimum value and tries to adjust to the demand. The *vacancy creation rate* initiates its increase at the same time. An increase in *desired labor* indicates a need for workers, since the *Labor* and *hiring rate* have also gone down. The shortage having been created from those decreases need to be covered, which explains the rise of *vacancy creation rate*. The same cycle repeats until the forecasted demands match the demands.

Figure 5 shows an increase in pressure as to assure the emergency needs of population. The construction employees are pushed to work overtime in an attempt to clear the overload. Figure 5 also shows the sudden rise of the *desired labor*, similarly to the *vacancy creation rate*, as both behaviors are influenced by the demand. Thus, as the demand declines, both rates slowly regress. Given the delays involved in the hiring process, both *desired labor* and *vacancy creation rate* keep decreasing even after the demand is stabilized.

The *desired labor* depends on the *desired building start rate* (desired number of house construction starts), which is the desired *completion rate* of houses adjusted by the adequacy of the inventory of houses in construction, which depends on the demand. In other words, the behavior of *desired labor* is directed by the demand, with the presence of a lag time. In this sense, there is a constant attempt of the *Labor* to mimic the behavior of the demand.

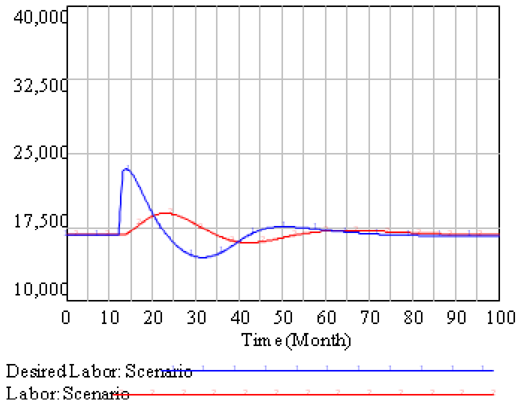

Figure 5: Desired labor

The *Desired labor* and *labor* meet at month 20, which indicates that the ideal needed number of workers is theoretically attained. There are thus no more vacancies to fill. This is illustrated by the curve of *vacancy creation rate* which takes the value of 0 at the same time. At that same time, the pressure is back to normal (value equals 1) and there is no need for overtime. The number of workers has become important enough to meet the demand. *Labor* is thus forced to stop its increase and start its decrease.

The schedule pressure is shown in Figure 6. This work schedule is also decreasing, given the diminishment of demand and the lowering of state of emergency. The vacancies are progressively being filed as the number of newly hired construction workers increases. The number of construction workers initiates its increase, but slowly as rather than local residents, mostly immigrants are the ones being hired (Petterson, Stanley et al. 2006). The *hiring rate* reaches its peak as it equals the *vacancy creation rate* and decreases.

Figure 7 shows another consequence of the labor shortage is the delivery delay, which goes up at the same time. This is due to the overwhelming demands which lead to the accumulation of orders in the backlog for some time, until they can be processed.

Figure 8 displays the behavior of housing after the shock. As expected, the *desired inventory* of houses increases right after the incident. This is happening because the *Desired Inventory is* directed by the behavior of the demand. In other words, an increase followed by a decrease of the demand causes the *desired inventory* to increase followed by a decrease. The *desired inventory* comes back down with the decline in the demand, but with a slower pace.

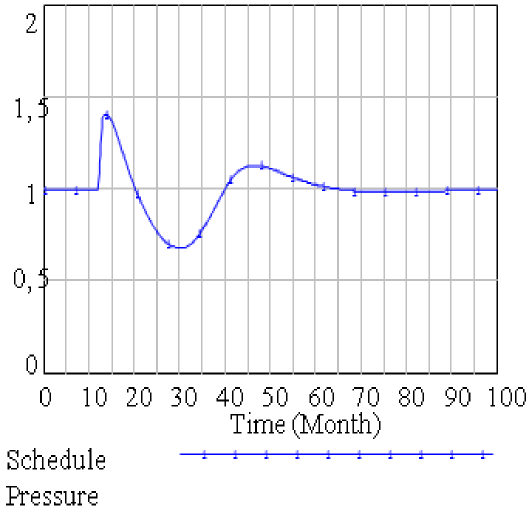

Figure 6: Schedule pressure

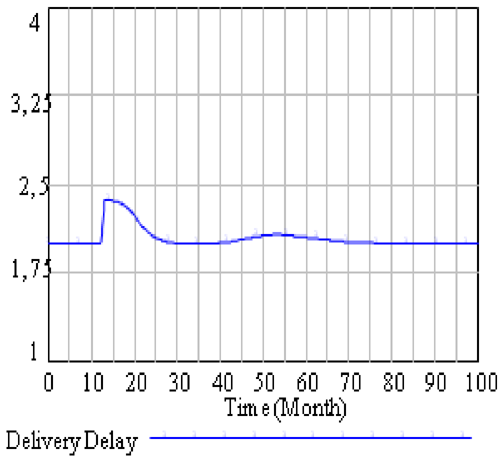

Figure 7: Delivery delay

The number of actual houses built decreases from its original value, given the unforeseen demands. The inventory stops diminishing around month 19th. This time coincides with the time when the *completion rate* equals the *expected demand* rate. At this point, the number of houses newly built equals the demand so the inventory of houses already built stops being used. The stock of built houses can get back up. The *completion rate* reaches its peak around month 28th, which provides the opportunity of more time for the inventory to re-build. By the 35th month, the demand takes over the building rate, which has been decreasing due to the drop in labor.

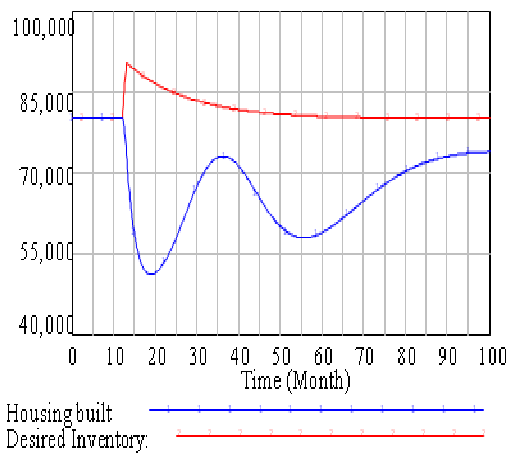

Figure 8 Housing after the shock

The houses are again in shortage and the inventory stops growing and declines back down again. This triggers the rise of the building start rate as there appears a shortage of houses to meet the demand. The inventory *housing built* is again used and the same cycle can repeat. Figure 8 also depicts the slow recovery in the area, should a hurricane event occur. The number of houses originally present does not seem to be reached anymore, given impediments in the reconstruction/recovery process. This is due to a structure in the model creating a delay for the *desired inventory*. This additional delay slows the adjustment of the *desired inventory* to the *expected demand*. That is, the *desired inventory* takes more time to follow the demand. Thus, the decrease of *desired inventory*, caused by demand declines, is more intensified. This causes the adjustment between the desired number of houses built and the actual number of those houses that take more time to occur. The *desired inventory* remains low and forces the inventory to adopt the same pattern. This behavior shows the problems of misplaced population and the struggle to recover from the disaster. From the governmental perspective, the lack of funding and the policy adjustment constitute a significant halt to post disaster recovery (Zhang and Peacock 2009).

It creates an important delay and causes negative impacts in the population and their ability to recover on the long run. From a socio-economic perspective, communities with limited resources bear most of the suffering and experience more complicated return conditions. More vulnerable victims opt for low-income rental homes, which have proved to be lengthy in construction, causing a shortage given the high demands (Dass-Brailsford 2008). The lack of shelter contributes to the slow return of the victims. The example of the locality of Lower Ninth Ward in New Orleans also confirms the behavior of the graph as it clearly shows the delay in recovery and the differences in housing after the disaster. The low and moderate income and minorities struggled the most and require more time to return (Green, Bates et al. 2007).

The presence of oscillation in all the graphs is the result of time delay and negative feedback. The structure of this model is designed to keep the inventories at their target level, which is used to compensate when faced with unexpected disturbances. The behavioral cycle described above is associated to the need for those values to pursue their target and bring the system to equilibrium.

6. CONCLUSIONS

This paper suggests using a System Dynamics modeling to understand the housing recovery process from a supply chain perspective. This model considers essential aspects of housing production systems in the presence of a highly disruptive event, namely, a severe storm. Hypothetical results indicate that the model theoretical behaves as expected, in terms of reflecting demand and supply changes as housing recovery progress. The ability to model and the housing production process when shocked by a major catastrophic event is important for decision makers. Scenario analysis provides opportunities to examine ripple effects and potential stumbling blocks that may jeopardize the recovery process. In addition, it provides a mechanism to test interventions that seek to reduce bottlenecks and increase housing production rates. Ongoing investigation involves calibrating the model and using real-world data to analyze likely scenarios for a major U.S. metropolitan region that lies in a low-lying coastal zone.

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Biographies

Rafael Diaz graduated from the Old Dominion University with a Ph.D. in Modeling and Simulation in 2007, and became a Research Assistant Professor of Modeling and Simulation at Old Dominion University's Virginia Modeling, Analysis, and Simulation Center (VMASC). He holds an M.B.A degree in financial analysis and information technology from Old Dominion University and a B.S. in Industrial Engineering from Jose Maria Vargas University, Venezuela. His research interests include operations research, operations management, healthcare and public health policy-making, dependence modeling for stochastic simulation, and simulation-based optimization methods. He is an Adjunct Assistant Professor in the program of Public Health, at Eastern Virginia Medical School.

Joshua G. Behr received his Ph.D. training at the University of New Orleans specializing in urban and minority politics. He has taught a variety of public policy, state government, and statistical methods courses at the University of New Orleans, Southwestern Oklahoma State University, Eastern Virginia Medical School, and Old Dominion University. His is now a research professor at the Virginia Modeling, Analysis and Simulation Center (VMASC), Suffolk. He has published on a wide range of topics including presidential approval, times series methodology, minority employment patterns, public health, and emergency department utilization as well as a recent book (SUNY Press) on political redistricting and a book chapter addressing discrete event simulation. Currently, his research interests include modeling and simulating smart grid, transportation systems, and the flow of patients within a regional healthcare system.

Ange-Lionel Toba is currently a second year Ph.D. student in Modeling and Simulation at Old Dominion University. He holds a MS. in Industrial & Systems Engineering from Colorado State University and a B.S. in Electrical Engineering from Cadi Ayyad University, Morocco. His research interests are operations research, Applied Statistics and Modeling and simulation of complex systems using System Dynamics (SD) and Discrete Event Simulation (DES). He is a Graduate Research Assistant at Old Dominion University's Virginia Modeling, Analysis and Simulation Center (VMASC).

Francesco Longo received his PhD in Mechanical Engineering from the University of Calabria; he is currently an Assistant Professor and Director of the Modeling and Simulation Center, Laboratory of Enterprise Solutions (MSC-LES). His research interests include modeling and simulation for training procedures in complex environments, supply chain management and security. He has published more than 120 papers in international journals and conferences. He is Associate Editor and Guest Editor of Simulation: Transactions of the SCS. He is Guest Editor of the International Journal of Simulation and Process Modelling. He is has extensively supported the organization of international conferences as General co-Chair, Program Co-Chair and Track Chair (MAS, EMSS, I3M, SCSC, etc.).

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