Individual response and recovery:  
A learning experience from Hurricane María

Verónica Díaz-Pacheco, MS
Frederick González-Román
Clara Isaza, PhD
Thomas Richardson, MS
Robert Whalin, PhD
Mauricio Cabrera-Ríos, PhD

ABSTRACT
Situations faced in the advent of powerful hurricanes can be stressful for individuals due to the uncertainty they bring along. The consequences of these phenomena can leave individuals’ recovery in their own hands until order is re-established, and support can reach out to them. This work aims to develop a tool to guide individuals through their decision-making during a hurricane disaster and recovery, using the experience of Hurricane María. The tool is a classic inventory model adapted to monitor individual’s wellness through 48 hours after a hurricane arrival. This article presents the three stages followed in the development in this work: the assessment of individuals’ sentiments toward Hurricane María via an online questionnaire, the development of the mathematical model, and the creation of a prototype in the form of a mobile application. Each phase presents an important contribution: a summary of first-hand knowledge obtained from the reactions of individuals who survived Hurricane María, a novel modeling approach to the problem, and a convenient framework that synthesizes both previous components.

Key words: individual emergency decision-making, disaster decision-making behavior, inventory model applications, Hurricane María response and recovery

INTRODUCTION
The increase in frequency and the magnitude of natural disasters over the last few years has highlighted the importance of developing decision support tools for disasters. Some of the reasons why crisis managers need these include the inherent difficulty in coordinating efforts, time sensitivity, and lack of information during these events. Still, while efforts at higher levels become coordinated, individuals are the ones making decisions in their homes and communities to ensure their safety, survival, and well-being. Observing this, in this study, we develop a decision support tool for individuals’ well-being during hurricanes—by using the experience during Hurricane María as a case study.

LITERATURE REVIEW
Hurricane María hit Puerto Rico on September 20, 2017. The stressful circumstances during its aftermath were numerous: shortages of food and medicine, major flooding and wreckage, infrastructure damage, lack of electricity and water services for at least 3 months, lack or unpreparedness of shelters, landslides, and—in the misfortunate cases—even loss of life. The poignant memory of the event puts the death toll at approximately 3,000 and quotes structural damages between 16 and 20 billion dollars. From María, we learned that until help can reach out, individuals are often the ones making decisions in their homes to guarantee their own safety and survival. This places crucial importance on the quality of their decisions.

Traditionally, decision-making is regarded as the process of selecting “rationally” between prospects a
choice that will maximize utility and minimize consequences.\textsuperscript{10} Some factors involved in decision-making include the current state of information and the capacity to project outcomes for a choice.\textsuperscript{11} Evidently, the state of all these factors can fluctuate even more during disasters due to uncertainty and stress. Stress and worry are commonly mistaken for one another and although they are both anxiety related phenomena, they refer to different things. Stress is the “non-specific response of the body to a demand for change,” ie, a physiological reaction.\textsuperscript{12} Worry, on the other hand, refers to a negative thought intrusion that occurs especially in conditions of ambiguity or possibility of negative outcomes.\textsuperscript{13} Since anxiety affects individuals in different ways,\textsuperscript{14} we would expect worry to affect decision-making in an individual manner too.

Interestingly, another factor that affects decision-makers, especially in positions of power, is overconfidence.\textsuperscript{2,11,15} Berner,\textsuperscript{16} for example, explores the idea and, in effect, finds overconfidence as a cause of medical misdiagnosis. As it turns out, safety checklists provide a simple yet effective solution for this problem—a cognitive aid—especially for helping medical professionals avoid costly mistakes in operating rooms, where stress can be overwhelmingly present. The use of this tool has been so successful that World Health Organization has even intended to introduce the use of Surgical Safety Checklists worldwide.\textsuperscript{17}

While efforts directed to develop cognitive aids exist for decision-makers at higher levels of emergency management, close to none are directed at helping individuals avoid suboptimal decision-making during events. Furthermore, consultation of any resource on decision-making for emergency management will show that the objectives are safety and survival.\textsuperscript{2} On the other hand, there is a range of literature linking mental health\textsuperscript{18-20} and even well-being\textsuperscript{21-23} to natural disasters. Disaster recovery should, therefore, consider the well-being of individuals as an objective to consequently achieve a healthier, more resilient response and recovery as individuals, and as communities.

For this reason, in this work, we use the experience during María to develop a tool—a mathematical model—to enhance individuals’ decision-making for well-being during the aftermath of a hurricane. To the best extent of our knowledge, this is the first documented attempt to approach this task. The purpose of the tool is to provide a cognitive aid for individuals in moments of omnipresent uncertainty and stress. The advantage of using our prescriptive approach—as opposed to a descriptive one—is that it is centered on detrimental events and key and manageable possible solutions, which renders it independent of the people’s individual approaches. Since the model uses real-time information during disasters, a mobile app prototype was developed to support its use.

The following sections discuss the modeling approach’s three distinct phases of development: (i) data gathering through an online questionnaire, (ii) model creation, and (iii) mobile application development. The results section synthesizes what was learnt from each phase. Finally, conclusions and future work are discussed.

**STAGE 1: THE INDIVIDUAL EMERGENCY RESPONSE AND RECOVERY QUESTIONNAIRE**

In the first stage, a preliminary study was carried out to understand decision-making and perceptions during Hurricane Maria. The Individual Emergency Response and Recovery Questionnaire measured (i) worry levels about several categories, (ii) decisions made, and (iii) the amount of informal information received by individuals at four different time points regarding María: during, 8 hours into, a day after, and a week after. Sociodemographical variables, like age, geographical region, etc., were also assessed. From the survey results, we only present the set of data used to construct the model. Worry levels were measured on a five-point Likert scale and inquired about 11 categories, as shown in Figure 1. After survey design, a sample (n = 52) was collected, and an exploratory data analysis was executed. It should be noted that the majority of respondents were in the age group of 20-30 years old (79 percent). Also, for the purpose of analysis, time was grouped as follows: worry during and worry after the event.

Results indicate that during María, individuals were mostly worried about communications, friends and relatives, utilities, and plans for future. Two observations were consistent through time: this ordering by categories and an overall decrease in each worry. The
worries that least changed through time were communications and utilities, which seemed reasonable since it took so long for these to be re-established after María. In contrast, the worries that most changed over time were for the house, for vehicles, and for pets. These observations were consistent through age groups. The worry levels of respondents seemed to be composed significantly of their worry about relatives and family. Interestingly, anxiety related to uncertainty about friends and relatives was a consistent finding in literature.24,25 Also consistent with literature,25 an inverse relationship was found between worry and age group: younger individuals reported higher levels of worry than older ones. Also, age groups seemed to worry somewhat differently about some categories. For example, worry about studies was a large proportion of the total worry reported by younger individuals, and older people reported having worried more than younger ones about friends and relatives. Indeed, the exploratory data analysis yielded interesting findings. It is our wish to address these associations with more significant statistical power in a follow-up study, by increasing the sample size and through the development of a more robust sampling strategy. Nonetheless, with this information at hand, it was be possible to marshal an initial model.

**STAGE 2: MODEL DEVELOPMENT**

**Proposed framework**

This work proposes that an individual’s level of wellness during a hurricane can be seen as an inventory to be maximized. Classical inventory control models are used in manufacturing to maintain a level of inventory that minimizes production costs while meeting production demand.26 Using this framework for the problem at hand, a detrimental event, eg, losing a window in your place of shelter, carries a detrimental effect—a reduction—on an individual’s wellness (well-being), while working on a restorative action, ie, a solution, would carry the opposite effect. A wellness monitoring system during hurricane emergencies was envisioned of this model that could query individuals periodically—every 2 hours, for instance—to register events that occurred since the last time of query and reflect individuals’ live wellness levels. Once events were reported, the system would provide simple solutions, in this sense, in a prescriptive manner, to help mitigate detrimental effects and restore the wellness level in the near future.

**Notation**

The following mathematical notation was adopted in order to discuss the wellness control model:

**Indices**

| i | Time period | $i = 1, 2, 3, \ldots, I$ |
| j | Detrimental event in time period $i$ | $j = 1, 2, 3, \ldots, j_i$ |
| k | Detrimental event’s category | $k = 1, 2, 3, \ldots, K$ |
| l | Detrimental event’s subcategory | $l = 1, 2, 3, \ldots, l_k$ |
| m | Suggested solution to a detrimental event | $m = 1, 2, 3, \ldots, m_{kl}$ |
| n | Solution in a particular time period $i$ | $n = 1, 2, 3, \ldots, n_i$ |

**Constants**

| I | Number of time periods |
| $j_i$ | Number of detrimental events in the $i$th time period |
| K | Number of categories |
| $l_k$ | Number of subcategories for the $k$th category (event $ID$ in category) |
The way the system works is that individuals can report any problem from a list of detrimental events, and this event will be classified at that moment using a classification function:

\[ f(e_i) = klm \]

Once reported by the user in time period \( i \), the classification function will identify the \( j \)th event using its respective subindices \((klm)\). This characterization will help identify the event’s restorative effect, and its respective lead time, that is, the time (in hours) after which the restoration would take effect. Figure 2 illustrates how the mathematical notation defined earlier comes together in the proposed model.

**Events and solutions list**

To develop a comprehensive listing of events and solutions for the system that could represent scenarios after hurricane arrival, we surveyed individuals who experienced Hurricane María first-hand. Because the first period of impact can be the most significant,24 scenario development was constrained to the first 48-hours after hurricane arrival. The main objective was to get the user to focus on critical decisions and feasible actions with a positive impact, so the model took a prescriptive approach: it would only suggest solutions that restored wellness. The number of solutions for each event was limited to a maximum of three \(( \max\{m_{kl}\} = 3 \) ). Furthermore, when pertinent, only solutions that complied with standard safety and health practices were adopted. For example, during the hurricane, an event like “Trapped in a flooded building” would have only one solution: “Go to buildings highest level,” as is suggested by standard safety practices.27

The idea for the tool is to, eventually, enhance already existing emergency management systems: areas of collective lowered wellness could indicate areas that need attention. Hence, some of the solutions provided by the system should be revised and supervised by emergency managers, to ensure that what the system suggests also aligns with their interests for the collective.

**Detrimental effects, restorative effects, and lead times**

In order to determine their detrimental effect on wellness, every event on the list was

i. classified in terms of whether it could happen during or after the event, following the stratification developed in the “Stage 1: the individual emergency response and recovery questionnaire” section, and

ii. matched with a category of worry from the questionnaire.

| \( m_{kl} \) | Number of suggested solutions for the \( k \)th event |
|\( n_i \) | Number of restorations to take effect in the \( i \)th time period |
|\( d^{kl} \) | Detrimental effect of the event in the \( k \)th category and the \( l \)th subcategory |
|\( d_{ij}^{kl} \) | Detrimental effect in the \( i \)th period of the \( j \)th event in the \( k \)th category and the \( l \)th subcategory |
|\( r_{klm} \) | Restorative effect associated to the \( m \)th solution in the \( k \)th category and the \( l \)th subcategory |
|\( r_{in}^{klm} \) | \( n \)th restorative effect taking place in the \( i \)th time period associated to the \( m \)th solution in the \( k \)th category and the \( l \)th subcategory |
|\( l_t^{klm} \) | Lead time for the restorative effect of the \( m \)th solution in the \( k \)th category and the \( l \)th subcategory |

**Text variables**

| \( e_{ij}^{kl} \) | Detrimental event, reported by user |
|\( s_{ij}^{klm} \) | Solution suggested by model |

**Numerical variables**

| \( d_i \) | Total detrimental effect assigned to the \( i \)th time period |
|\( r_i \) | Total restorative effect taking place in the \( i \)th time period |
|\( W_i \) | Wellness level in the \( i \)th time period |

\[ d_i = \sum_j d_{ij}^{kl} \]

\[ r_i = \sum_n r_{in}^{klm} \]

\[ W_i = W_{i-1} - d_i + r_i \]
Afterwards, the magnitude of the detrimental effect on wellness of events, $d^{kl}$, was defined as

$$X: \text{(Level of worry about } ) \times \varphi$$  \hspace{1cm} (1)

Once each query in (1) is answered using a time point and a category, a value can be retrieved from Figure 1. The detrimental effect of an event was defined as the product of this value retrieved and a provisional arbitrary value of 20 ($\varphi = 20$). This value was introduced for scaling purposes. In this sense, the impact an event would have on wellness would be subjective to what individuals reported to have worried about most.

The magnitude of the restorative effect, $r^{kln}$, of the $m$th solution was determined as follows: if the solution was provisional, i.e., did not fix the problem entirely, the magnitude of the restorative effect was lower than its detrimental effect. If the solution did fix the problem entirely, the magnitude of the restorative effect was as large as the event’s detrimental effect. For example, the event Y “Lost electricity service” was associated with utilities and necessarily occurred during the event. Using (1) and observing Figure 1, $d^{kl}(Y) = 3.32 \times 20 = 66$, rounded to the nearest integer. Solution #3 for Y “light candles” was provisional; this solution’s restorative effect magnitude was only 30. The net effect on wellness of reporting these instances would be a state of lowered wellness, which is representative, to some extent, of the circumstances of lacking electricity.

In manufacturing settings, a lead time is the amount of time between order placement and the arrival of goods to customers. Using the proposed framework, it follows that a solution’s lead time is the estimate of the task’s completion time. This time was estimated for every event on the list. When events occurred during the hurricane, but a solution could not be worked upon immediately, a lead time estimation looked as follows

$$\text{Lead time (hours)} = \lambda + \text{estimate of solution completion time}$$  \hspace{1cm} (2)
where $\lambda = 8$ hours, an approximation of the amount of time of Hurricane María’s duration.

**STAGE 3: THE MOBILE APPLICATION PROTOTYPE**

During the third stage of this work, a mobile application was developed for the wellness inventory model. It was intended for this app to serve as the primary interface between individuals and the decision-making wellness monitoring system. The application, called *iWILL* (Individual Wellness Inventory Level Log), was created using Microsoft’s Power Apps online platform. *iWILL* contains the decision support model described previously, a revisable history of decisions made by the user, and provides a source of continuous real-time information during disasters along with visual aids. *iWILL* utilizes drop down menus with predefined lists of events and solutions, as defined and discussed previously in this manuscript (Figure 3). The idea is to have a convenient interface that can warn users when their wellness state is low in order to avoid cognitive biases and bad decision-making, which is very common during emergencies. It also has the capacity to work online and offline, as long as there is battery in the hosting cell phone.

**RESULTS: MODEL VERIFICATION AND VALIDATION**

To test the system, we collected the personal accounts—scenarios—of five individual’s experience during Hurricane María. By verification, we mean assessing the comprehensibility and sufficiency of the events and solutions list to each case. The objective was to assess if the model could represent their scenarios with reasonable fidelity. Figure 4 shows an instance of the resulting timed wellness profiles, as a proof of concept.

To test the model’s sensibility, a protocol driven by random numbers was undertaken to create five decision-making scenarios, ie, “random” profiles. The protocol consisted of assigning each event in the list an ID (45 in total) and generating a set of 4-7 random integers between 1 and 45 for each profile. For each profile, simulations were run adopting two different decision-making strategies: pick the option with shortest lead time or pick the highest restorative effect, respectively. These can be regarded as two strategies—policies—with contrasting objectives that individuals could very well adopt. Furthermore, for validation, several assumptions were made regarding the simulation's decision-making strategy. First, only one solution for each detrimental event would be selected. Second, in the case that solutions had the same lead time, the one with the highest restorative effect was selected. Third, and last, if both restorative effects and lead times were the same, any of the solutions would be selected. Figure 5 shows the results of the validation strategy.

**DISCUSSION**

Considerations in the first stage of the development include the time lapse that has come to pass since the moment of occurrence of Hurricane María and the survey: worry level can be subestimated due to the amount of time that has passed since the event. Nonetheless, the data still hold value in the comparative differences between worry categories. The authors agree that operationalizing something as subjective as a level worry may be difficult, which is why the model keeps its prescriptive nature.

Results from scenario development show the model reflected the five individuals’ experience during Hurricane María sufficiently. Two important observations arose with this exercise: (i) the initial wellness level must be assessed systematically on every instance and (ii) it is expected that after 48 hours, the individual wellness level differs from the initial level. Testing of the tool with more users should continue to refine the model and ensure its usability.

Validation results show that adopting a decision-making policy resulted in a different outcome; this trend was observed consistently. The observed effect was the following: adopting Policy I, shortest lead time, led to a higher wellness level than Policy II for some (short) time after the start of the simulation. However, adopting Policy II, the highest restorative effect, eventually led to a higher wellness level, for all runs. A limitation for validation is that it was assumed that an individual would select a maximum of one solution for each detrimental event. The way the prototype is currently configured, and the reality, is that it may be possible for individuals to choose more than one solution.
The outcomes of the verification and validation stages evidence that the model provides at least enough information to differentiate between individuals' decision-making profiles and separate distinct decision-making behaviors.

CONCLUSION AND FUTURE WORK

In this work, a tool to support decision-making during hurricane disasters was developed using Hurricane María as a foundation. The tool's implementation during a real emergency could provide a valuable source
of insight into decision-making behavior during emergencies. Because the model has a prescriptive nature, it is our judgement that the tool as is could serve as a cognitive aid to help individuals make better decisions by allowing them to work toward solutions that increase their well-being in situations where decision-making can be, not only at its most uncertain, but at its most critical.

It is undeniable that a larger sample, better representation across age and geographical groups, and a revised questionnaire are important to arrive to stronger conclusions in the future. We also believe that the model logic can be further developed to capture the complexities of human decision-making and its effect on well-being. The authors are currently undertaking these expansions to follow-up this project: a revised questionnaire and a target sample size will be achieved.

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The Applied Optimization Group, University of Puerto Rico-Mayagüez, Puerto Rico. ORCID: https://orcid.org/0000-0002-2582-4597.

Verónica Díaz-Pacheco, MS, Department of Industrial Engineering, The Applied Optimization Group, University of Puerto Rico-Mayagüez, Puerto Rico. ORCID: https://orcid.org/0000-0001-5399-2566.

Frederick González-Román, Department of Industrial Engineering, The Applied Optimization Group, University of Puerto Rico-Mayagüez, Puerto Rico.

Clara Isaza, PhD, Basic Sciences Department, Public Health Department, Ponce Health Sciences University-Ponce, Puerto Rico. ORCID: https://orcid.org/0000-0001-5399-2566.

Thomas Richardson, MS, Department of Civil & Environmental Engineering, Jackson State University-Jackson, Mississippi; Coastal Resilience Center of Excellence, University of North Carolina-Chapel Hill, North Carolina.

Robert Whalin, PhD, Department of Civil & Environmental Engineering, Jackson State University-Jackson, Mississippi; Coastal Resilience Center of Excellence, University of North Carolina-Chapel Hill, North Carolina & Director Emeritus, Engineer Research & Development Center-Vicksburg, Mississippi.

Mauricio Cabrera-Ríos, PhD, Department of Industrial Engineering, The Applied Optimization Group, University of Puerto Rico-Mayagüez, Puerto Rico. ORCID: https://orcid.org/0000-0002-2845-7147.

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