# Quality Engineering Methodology in Hurricane Mitigation Procedures

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## 1.0 Introduction

This paper discusses the role of *Quality Engineering* (QE), a collection of methodologies based on *statistical* procedures used in *industrial engineering, reliability, logistics, and operations research*, to hurricane disaster mitigation. We present QE methods in the analysis of several large hurricanes in *Louisiana, New York, Houston, Puerto Rico, North Carolina, etc*. The QE methodologies are effective in designing, implementing, streamlining and making hurricane and other weather related mitigation and control measures, easier to manage and implement.

Our paper pursues *three objectives*. *First*, to *present QE methodologies* in general. *Secondly*, to *provide practical examples* of their implementation to hurricane and weather disaster mitigation, so authorities become aware of their power to improve operations. Finally, to *showcase examples* developed by the students of MFE634 https://web.cortland.edu/matresearch/MFE634SylS17.pdf a graduate Syracuse University course. These students, under our guidance, developed several final projects that illustrate the present discussion. MFE634 students are trained in analyzing real life problems (https://web.cortland.edu/matresearch/PastProjectTopics.pdf) using QE tools, and may apply for positions in organizations seeking excellent young engineers with relevant skills.

In July of 2021 we wrote a paper on using QE methodologies in the design of Covid-19 Systems: https://www.researchgate.net/publication/352998703_Quality_Engineering_Methodology_in_Covid-19_Systems_Design_and_Improvement Previously, summary of *Covid-19 research papers*: https://www.researchgate.net/publication/349008991_Commented_Summary_of_a_Year_of_Work_in_Covid-19_Statistical_Modeling The material was well-received, as per LinkedIn, Research Gate hits: https://web.cortland.edu/matresearch/SELECTEDREADINGSRESEARCHGATE.pdf

The current paper *analyzes difficulties in implementing hurricane mitigation measures*. By *using QE approaches* and *improvement methodologies*, we are able to *detect, and avoid or minimize problems*, thence *identifying* and *correcting glitches and providing mitigating actions* where such difficulties are unavoidable. Recent hurricanes, such as Ida in Louisiana, constitute examples. *We want to offer some QE engineering and statistical tools* that may be of help, in such events.

## 2.0 General Hurricane Preparation Concerns

In this section we discuss some general hurricane preparation concerns. *QE tools* are overviewed in PPT https://web.cortland.edu/matresearch/QualEngGralMfe.pdf and in Sections 2.0 and 4.0 of https://www.researchgate.net/publication/352998703_Quality_Engineering_Methodology_in_Covid-19_Systems_Design_and_Improvement already mentioned.

Broadly speaking, *we need to address three different areas*, in order *to prepare for a hurricane* strike. These are: **before, during and after the hurricane lands**. We review them, below.

**Before**, *meaning up to several months or even a year*, requires an in-depth assessment of the terrain affected by the *three main fallouts of a hurricane*: *wind, rain and surge*. *Wind* affects tall structures. We need to assess and reinforce their strength, pull them down, protect surrounding structures from their possible collapse, etc. *Rain* will pour during hours; where will all that water go? If there is poor drainage there is only one possibility: up! There will be flooding, that will threaten lives and weaken structures. If the region is *close to the sea* there is a possible *surge*, adding to the rain water flooding. Then, we need to consider evacuating the inhabitants.

We then need to estimate the number of people to evacuate, and establish how this will be done (road, air, water?). It implies estimating the number of vehicles (buses, boats, planes) that will be used, including travel time, as well as the capacity of routes (roads, bridges, canals, airports, etc.) to ensure there is sufficient capability to move all evacuees out of danger, before the storm hits.

It is necessary to establish where all these evacuees will be lodged (for several days) and provide for them: food, water, beds, medical and safety personnel and equipment, electrical power (the first element lost as the storm hits), etc. We need to establish an array of warehouses, where such equipment and material will be stored, to minimize supply chains to provision them. We need to organize a contingent (firemen, medics, police, etc.) that will stay on location, to help those that will not be evacuated, as well as in the evacuation sites, including their support material.

All of *this information is obtained* from interviews, brainstorming sessions, studies, etc. done with subject matter experts, *before the hurricane hits* the site. And such information will be used *to draft a master plan* to be implemented at the time of imminent threat of a hurricane.

**During** the hurricane, said *master plan will be implemented*. For safety and precaution, *key parts* of it should have *back-ups or redundancy* –remember Murphy's laws: *if anything can go wrong, it will*! This period may last several days. For, after the hurricane passes through, this team must stay to *clean up the debris, re-establish* electrical power and water supply, and provide all other essential services before the evacuees can return and resume a semi-normal life, again.

**After** the hurricane is gone and evacuees are back, *reconstruction* and *root-cause analysis* needs to be done. In spite of all the planning and forward thinking, *some things may have not worked*, or *worked poorly*, or we may have *forgotten or miss-calculated* some issues. This is the time to *go back to the drawing* board and *revise, redo*, etc. the *plans, for the next iteration*.

All these activities will be illustrated in the following pages, through several student projects.

**3.0 Quality Engineering Student Group Projects Addressing Hurricane Problems.**

We now present applications of *QE statistics-based engineering methods* to the assessment and improvement of w*eather-related problems*. W*e use, as illustration*, some *MFE634 student group PPTs* discussing their group final projects, developed under our supervision. Projects address different aspects of the preparation phases mentioned, as these hurricanes are very different.

**3.1 Quality Engineering Study for Hurricanes in Louisiana and the Carolinas**

We first present a *Student Group QE final report PPT* based on the Katrina, LA and Sandy, NY hurricanes (https://web.cortland.edu/matresearch/2017WeatherDisasterMgmtFinPres.pdf). *Sandy* hits a *heavily populated urban area* (New York City) and *its surge floods* the city's underworld: subway stations, basements, streets etc., thus disabling electrical power stations and cutting the electricity off elevators of high rise buildings, public transportation systems, etc. *Katrina* hits a *smaller and low level* city (New Orleans), situated *in the delta of an immense river* (Mississippi), whose *levies yield to the surge* and allows *complete flooding* of the urban area.

As usual, the students start by providing a background for the study of these two weather-related storms. Then, they perform a *Brainstorming* session, to find areas problem areas (factors), and sub-areas (levels), that are organized through an *Affinity Diagram* and then built into a process *Flowchart* to better understand the basic needs and event flow of the situation at hand.

Based on such results, students *develop a quality assessment,* implementing *COPQ* (*Cost of Poor Quality)* analysis using the f*our problem categories*: *internal, external, appraisal and prevention*. With this information students create a *qualitative Ishikawa chart* where issues that affect overall objectives are measured through appropriate Performance Measures. This chart *eventually* serves as framework for *quantitative statistical procedures* (e.g., Regression, DOE, ANOVA).

Much information material, to find out the *key issues involved* in the system, is obtained from the *interviews of subject-matter experts*. Said *process flowchart* eventually yields *Value Stream Map* (VSM), which identifies *bottlenecks*, *non-value-added steps* and other problems that can then be modified or substituted, substantially improving the situation. An example will be provided later.

Before collecting any data (or measuring), we should implement an *MSA (Measuring Systems Analysis*) to determine if measurements taken include undesired elements, such as *operator or* *gage biases*. *Gage R&R* analyses are implemented to detect these problems. If an overwhelming percent of measurements (say 98% or above) come from the system and only a small percentage (say 2% or less) come from operator and/or gage bias, MSA is fine. Otherwise, we must first fix the measurement system, retest it, and if accepted, then we can safely measure variables.

Students next define a *Six Sigma (DMAIC*) improvement methodology to the existing hurricane mitigation procedures (as they already exist, and we want to improve on them). The five DMAIC phases (Define, Measure, Analyze, Improve and Control) are explained in detail in the PPT.

There may be specific design problems that we want to optimize. For example, we may want to assess the survival capabilities of New Orleans Levees, as a function of the wind, rain and surge. This can be done in a laboratory setting, implementing a Design of Experiments (DOE) analysis. Students present an example of such analysis using both statistical software, and Excel.

If there are design aspects that did not exist but we want to initiate, then we implement a Design procedure such as DFSS (Design for Six Sigma) or QFD (Quality Function Deployment). The latter is developed by the students to create an efficient evacuation plan. If an existing design is proven inefficient and should be improved on, *VSM (Value Stream Map)* are implemented. First, we develop a VSM for the *current state*, and assess the process. A second VSM is developed for the *future state*, and a comparison of process parameters (before/after changes) is performed.

An example of the Measurement Systems Analysis (MSA) mentioned above, is presented, using Gage R&R statistical procedures for attributes (pass/fail) and continuous (quantitative) measures.

We mentioned how support material (e.g. food) should be stored for use. But we need to assess their safety using *SPC (process control)* statistical procedures. It is not efficient to inspect every item (takes too much time), or impossible (destructive inspection) to do so. The alternative is to develop *Sampling Plans, and Control Charts*, which are explained in detail in the students' PPT.

Finally, the PPT discusses *Reliability* procedures, which are implemented to assess how methods or elements are able to fulfill their stated functions. Some procedures measure the probability of, say a Levee to withstand a given hurricane force (e.g. its Category) and require a data analysis. Others are qualitative (e.g. Failure Modes and Effects Analyses, FMEAs; Fault Tree Analyses, FTAs) and assess how system parts can fail, what are the consequences, what are preventive and corrective actions, what possible measures can be taken, given a failure, to prevent total collapse.

### 3.1 Other Hurricanes Quality Engineering Studies Presented

There are several other excellent student group final projects based on Hurricanes, that we share:

The PPT for the student group project based on hurricane Harvey, in Texas, is found in: https://web.cortland.edu/romeu/HurricaneHarveyPptS2018.pdf

This project analyses one of the most devastating and costly hurricanes of recent times. *Houston, Texas* is a heavily populated and industrial (*refineries*) urban area that becomes partially flooded when a *large reservoir gives in and floods* an improperly situated residential area. The PPT and project follows the same organization and parts as the ones above. In addition to shedding more light on how QE methods are implemented, it includes an example and analysis of Harvey's expensive economic impact, on the faulty elements that increased damages, and suggests some improvements. This is one of our most complete and detailed hurricane student projects received.

The PPT for the student group project based on the hurricane in the Carolinas, is found in: https://web.cortland.edu/romeu/StormSurgeManagement.pdf

This PPT and project discusses a particularly important problem: how to deal with, and endure, both surge and rain flooding produced by a hurricane. The Carolinas are two states that border the Atlantic Ocean. They have low areas adjacent to the sea, and irrigated by large, slow-moving rivers. Such characteristics exacerbate both, surges and flooding, as hurricane-induced water cannot run off. This student PPT develops excellent examples on how to develop quality assessments, including examples of questionnaires, assessment and improvements.

The PPT for the student group project based on the hurricane in Puerto Rico, is found in: https://web.cortland.edu/matresearch/PRHURRICAssessmentS2018.pdf

This project PPT illustrates a hurricane that lands *in a mid-size, isolated island*, eliminating its electrical system. It follows the same organization and parts, as the two hurricane projects above. In addition to shedding light on how QE methods are implemented, it includes examples and discussion about root-cause analysis and loss assessment, and suggests several improvements.

The PPT for the student group project based on the hurricane in the Florida Keys, is found in: https://web.cortland.edu/matresearch/DFSSQFDFlaHurr.pdf

This PPT and project presents the problems of hurricanes landing in *a strip of small islands*. It follows much the same organization presented in the projects above (Puerto Rico, Louisiana, Texas, and New York), shedding light on how QE methods are implemented and interpreted.

These projects were shared with FEMA and DHS (Homeland Security), federal departments dealing with hurricane and weather related disasters. Students were commended by their insight.

**5.0 Discussion**

*Our current research* deals with the *application of statistics-based engineering methods* such as: quality, reliability, logistics, industrial and systems engineering, and operations research, *to the design, development and improvement of* weather-related as well as public health *problems*.

This paper discusses *an important subject for nations in the Caribbean, South Pacific*, and Indian Ocean. In these latitudes, *hurricanes and typhoons* constitute yearly events that are vastly feared and highly destructive. With this paper we expect to contribute to mitigate their distress.

We have also shown how *graduate engineering students can study and solve real-life problems*. Such experience alerts them to *their societal engineering responsibility*, and provides them with additional fields (Professional Responsibility: The Role of Engineering in Society (utexas.edu)) where they can apply their engineering expertise and enhance their employment potential.

*Limited opportunities* currently exist for reliability, quality, logistics, industrial, systems and operations research, statistically-based engineers*, to work in weather disaster mitigation areas*. There, statistically-based engineers can apply many of the above mentioned methods to disaster mitigation and problem solving. We hope this report enhances such working opportunities.

**5.0 Conclusions**

Our *research objective* is *to alert* potential *disaster victims and their governments about* QE *techniques* that *exist,* and about *professionals* that can be *recruited*, to help them *improve* their *efficiency*. QE techniques can be helpful in designing and implementing mitigating solutions. Readers desiring further information about projects, or QE techniques, feel free to contact me.

We want to *encourage weather disaster professionals to use statistics-based QE* procedures and to *undertake joint work with quality, reliability, logistics, and industrial/operations research engineers*, and to use these methods not only *after weather disaster* systems have been designed and implemented, but also *during the time that these systems* are being *designed and prepared*.

We want to *encourage engineers,* especially retired, who have the experience, financial support (their pensions), and the free time to provide their assistance, *to contribute in helping with the planning, implementation and analysis* of *weather disaster* systems –or by writing about them.

We want to *provide illustrative examples* to subject matter researchers, government officers, and to the general public, to help them understand what quality engineers do, and how they can help improve *weather disaster mitigation* systems, thus *fostering greater collaboration*.

Finally, *this research on statistics-based weather disaster* systems *analysis* can *be used as part of a weather disaster course*, or as part of an *applied modeling and analysis graduate course in an industrial engineering, operations research, or applied statistics department*.

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Jorge Luis Romeu retired Emeritus from the State University of New York (SUNY). Romeu is currently a Senior Speaker Specialist for the Fulbright Speakers Roster Program, and an Adjunct (Part Time) Professor at Syracuse University (SU), where he has taught graduate Statistics and Quality Engineering courses for over 20 years. He was, for sixteen years, a Research Professor at SU. Romeu previously worked as a Senior Research Engineer with IIT Research Institute (IITRI), Alion, and Quanterion Solutions (QSI), which operated the Reliability Analysis Center (RAC), an Air Force Information and Analysis Center. Romeu has received seven Fulbright assignments: in Mexico (3), the Dominican Republic (2), Ecuador, and Colombia. He holds a *Licenciado en Matematicas y Estadistica* degree from the University of Havana, and a Ph.D. in Industrial Engineering and Operations Research, from SU. Romeu is a Chartered Statistician Fellow of the Royal Statistical Society (RSS), a Senior Member of the American Society for Quality (ASQ), and a Member of the American Statistical Association (ASA). He is a Past ASQ Regional Director and holds Reliability and Quality Certifications. Romeu created and directs the *Juarez Lincoln Marti (JLM,* https://web.cortland.edu/matresearch/) *International Education Pr*oject, which has supported higher education in Ibero-America for over 25 years, and maintains the *Quality*, *Reliability and Continuous Improvement Institute (*QR&CII), an applied statistics and O.R. web site (https://web.cortland.edu/romeu/QR&CII.htm).