

# Understanding the Role of Victims' Non-Discretionary Factors in Hurricane Evacuation Dynamics: a planning tool for disaster relief

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## Abstract

*Prompt and effective response requires the analysis of key information where the role of disaster relief organizations (DROs) is multiple. DROs approve the assistance requested by victims and coordinate supplies and personnel collected and transported to the disaster site. They provide mental health services and shelter while more long-term government aid is decided. The dynamic framework presented here was formulated to understand the complex multi-factor dynamic processes evolving over time during a hurricane emergency. It maps the process of interdependence between resource availability and satisfaction with human services and the influence of the media reacting to victims' complaints. Exogenous factors such as customer reactions to the category event; training level of response personnel; race, social stratum, home/pet ownership and education are all taken into account. The model was built with the analysis of data collected from victims of the 2005 Katrina Hurricane and paired with real operational data provided by the American Red Cross and then calibrated/validated by real data from the 2005 Rita Hurricane.*

## Keywords

Hurricane evacuation; environmental factors; system dynamics, data mining, disaster relief

*"Without understanding social stratification in the city of New Orleans – a city with one of the highest levels of income inequality in our country – it is difficult to understand the strategies people employed to survive the storm and that they are using to restart their lives in its aftermath. Inequality in education and income, residential segregation, and discrimination contribute not only to social stratification among individuals, but also to stratification between social networks – that is, the group of family, friends, and associates to which people can turn for help. Both factors shaped people's strategies to leave New Orleans or not, and how they are rebuilding their lives in the hurricane's aftermath."*

Elizabeth Fussell, in "Leaving New Orleans: Social Stratification, Networks, and Hurricane Evacuation" Published on: Jun 11, 2006, accessed online on March 16, 2009 at: <http://understandingkatrina.ssrc.org/Fussell/>

## **1 Background**

Globally, it is estimated that more than 535 thousand people were killed by natural disasters during the past decade representing more than 684 billion dollars in losses from direct damages to infrastructure and crops (International Federation of Red Cross and Red Crescent Societies, 2002). In the past two decades every state in the union --with the exception of Alaska-- has experienced weather disasters ranging at least one billion dollars in recovery expenses (National Climatic Data Center, 2003). The long-term economic impact of these disasters, both domestically and internationally, continues to affect economies at all scales locally and globally.

In the event of a disaster, the government of the affected region must conduct a needs assessment to determine what emergency supplies and personnel are required. Government in coordination with Disaster Relief Organizations (DROs). DROs become thus an important part of this process because they review and approve the assistance requested and coordinate supplies and personnel collected and transported to the disaster site. Effective management of relief assistance depends on anticipating and identifying problems, and on delivering specific supplies and personnel at the times and places they are needed. Prompt and effective emergency service response to both --natural or man-made emergencies and disasters-- require information prior to, during, and after these potentially catastrophic events. This information is most needed for mitigating the societal impacts of such events. In addition, whether these immediate needs are satisfied or not is what influence victims' perceptions of the aftermath and their prompt recovery to normal life.

Hence, a successful emergency-management system must be capable of demonstrating efforts to supply the necessary resources and equipment to support response operations and must accurately forecast what would be stored in advance in preparation for a potential emergency. Prior research has shown that the effectiveness of response efforts and the disaster's victims perceptions about such effectiveness depends largely on a series of factors that include the quality and quantity of the training that response personnel have received, pre-outage communications and communications in the immediate aftermath with victims, the existence of a quick-response protocol and the availability of resources and equipment needed for emergency functions (Hall, 2005). Due to the wide variety of factors that influence victims' service quality perceptions, once these events occur, the validity of any attempt to measure satisfaction of each one of the victims by means of traditional mechanisms becomes problematic. Nonetheless, estimating the perceptions that evacuated victims have about the quality of the service received before, during and after an outage has become both a practical and research priority due the impact that such vocal perceptions might have in the national media and in the DROs reputation, particularly after the last disasters that have hit the world in general, and the United States and its territories in particular. We know for example that victims' perceptions have a tendency to change depending on evacuation patterns, work required from relief agencies, resources available to meet those requirements, and the location of resources needed.

Currently, the relationship between service providers' (DROs) and service recipients' (evacuated disaster victims) perceptions have been greatly ignored. Thus, identifying service characteristics that make a victim feel satisfied with the aid received becomes just an indicator that such system is working properly. However, it is not enough to determine if a disaster victim was positively impacted by the treatment given before, during and after the emergency event but being able to foresee and act upon victim's unfulfilled needs is what is required. For this to happen in a situation in which a lot of the resources available to DROs are limited, we

need to understand the structure and behavior of the evolving system that is created by this interaction between the affected community and relief operation.

This research is important for social service organizations engaged in relief operations since it is essential for these organizations to ascertain the right formula of resources and protocols needed for satisfying victims' immediate needs. The satisfaction of the victims and the immediate outcomes of the intervention could in turn be used to decide how to adequately allocate necessary resources at their disposal and correct any mistakes. Actual service quality evaluation for emergency-management systems vis-à-vis the resources needed to take care of disasters' evacuated victims is not usually investigated as part of customer perceptions. For this reason, the issue of what kind of resource-allocation decisions these organizations can make or how can they improve the behavior of disaster response operations is a relevant research problem. The model developed as part of this research could become a tool for the analysis of disaster relief operations, where service quality perception is incorporated as an evaluation process of the emergency response cycle. Here a system dynamics model is described which shows how victims' characteristics, including demographic characteristics affect evacuation patterns and these in turn affect service delivery vis-à-vis the availability of resources.

### **1.1 Disaster Preparedness and Relief Systems**

Disaster relief operations are very different from other type of emergencies such as traditional war operations. During disaster relief operations everything has to go very fast, the relief workers have to leave on very short notice and cooperation with other organizations is needed in order to save as many human lives as possible. The information system of those operations has to be small, flexible, rapidly deployable and mobile (Mertens and Mees, 2006). Collaboration between various agencies and organizations is absolutely essential when discussing disaster planning, preparedness, and reconstruction. As most recent disasters have shown, it is critical that governments and civil society develop effective ways to prevent, relief and optimize supply distribution systems (United Nations, 2006a). Thus, emergency response is a product of *preparedness*. During preparedness, participating organizations ensure to respond to an emergency in a coordinated, timely and effective manner.

There is a prescribed system of how societies respond to disasters, which often is referred to as the *emergency response cycle*. This cycle includes immediate actions following an event such as rescue and relief, as well as longer-term stages in the recovery process (Cutter, 2003). Once the event occurs, relief organizations can have an effective and immediate response doing rescue (hours to days) and disaster relief operations (days to weeks). Preparedness and relief both depend on having the right information at the right time (Webster, 1994). Having preparedness activities help to maximize the positive effects of disaster relief operations and minimize its negative side effects. However, an evaluation of disasters' victim's feelings or perceptions has not been published as it relates to the emergency response cycle.

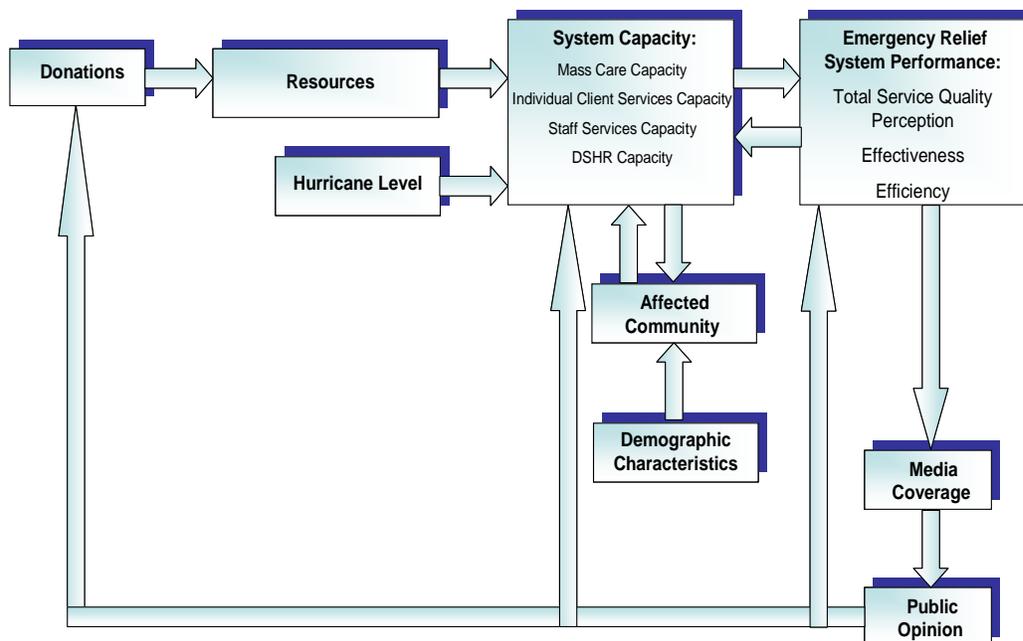
### **1.2 The role of service quality perceptions**

Considering that resource-allocation and quality service factors influence human perceptions and reactions before, during and after an emergency one can say that the dimensions that define quality represent influential factors on the overall performance of the relief system. Perceived quality is taken to be a subjective measure of how disaster victims see the service

level they receive. The inconsistency between resources delivered and client's requirements and their relative levels will determine the rate at which the level of perceived quality will change. As the dynamics of the model are played out over time, the levels of resources and perceived quality may rise and fall, in turn influencing other model variables. Further, factors such as customer reactions to the kind and category of the event; training of the personnel involved in the emergency response cycle; victims' claims depending on the race, social stratum, education, affected area, etc. are usually not contemplated in the evaluation of patterns and behaviors. Evaluating all of the above with a systems perspective and translating all to a simulation with the help of the System Dynamics methodology (Forrester, 1961) can take all these into consideration. This new model proposed here considers three aspects always present in the dynamicity of a disaster relief system: the *affected community subsystem*, the *system capacity*, and the *emergency relief system structure and performance*. This research work focuses on the emergency relief system performance features (see Figure 1). The American Red Cross (ARC) provided helpful customer and operational data of the Katrina and Rita relief operations. Finally, this model is capable of testing how a variation in resource-allocation policies affect quality service factors presented in the emergency relief system performance that influence perceptions and reactions of the evacuated victims, before, during and after a disaster.

## 2 System Definition

A conceptual representation of a disaster relief operation was made for the purpose of defining and understanding all the variables and the interactions occurring between them. This conceptual model was developed focusing on the relevant problem of the system. Figure 1 illustrates a general structure for this disaster relief operation conceptual model and the factors that influence system capacity such as donations and public opinion, as well as uncontrollable variables such as hurricane level and the characteristics of the affected community.



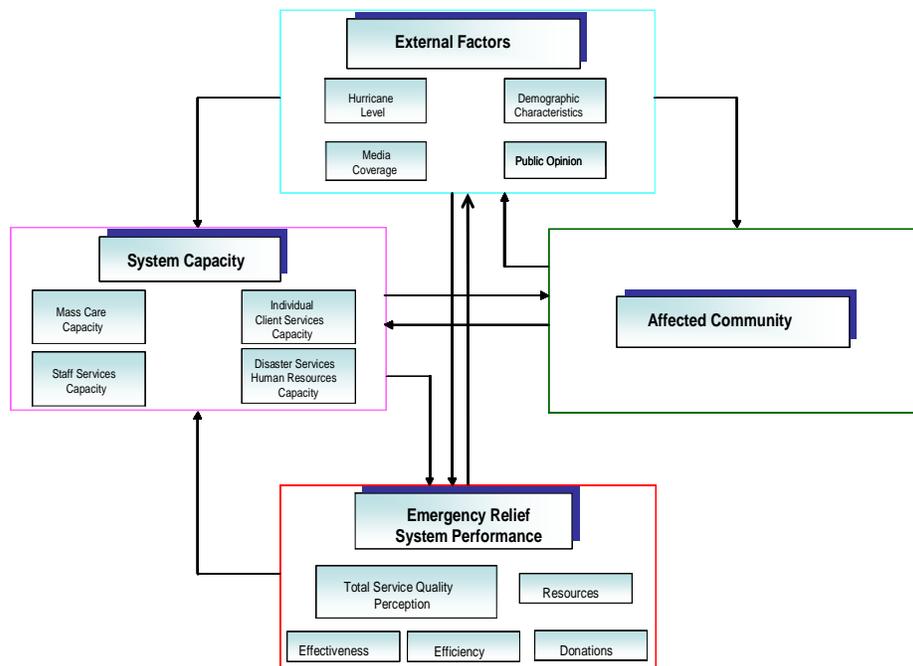
**Figure 1.** The conceptual model: Service Quality Response Cycle (SQRC). Author's Elaboration, 2007.

The main idea of this conceptual model is to provide a framework of knowledge of how the principal variables of the model's subsystems fit and work in relation to the outlined research problem, which is described as follows:

The **total service quality perception** that clients have prior to, during, and after an event occurs is affected by the **capacity of the system to fulfill clients' requirements** and by the **public opinion**. The capacity of the system is affected by the **quantity of material resources needed** to carry out the American Red Cross activities, the public opinion, **the hurricane level and the amount of clients requiring help**. The attainment of these resources depends greatly on the **donations (system performance)** made by non-affected communities. Hence, the affected community is influenced by the **amount of resources that the relief organizations have to allocate** in order to meet their needs. Therefore, the **service quality perception that victims/clients demonstrate**, end up influencing the media coverage, and the **media coverage** affects the public opinion concerning the organizations involved in the relief support and assistance to the affected community.

### 2.1 Subsystems Definition

Based on the above, various subsystems are contained within the structure of the model and represent several functions. Mapping these subsystems and illustrating their relationship using a diagram can facilitate the comprehension of the model. Figure 2 shows the graphical representation of these subsystems. The combination of the variables in the conceptual model and the representation of the reciprocal influences have allowed the identification of three interconnected subsystems which represent its core functions: System Capacity, Emergency Relief System Performance and Affected Community.



**Figure 2. The conceptual model: Service Quality Response Cycle (SQRC) and its Subsystems. Author's Elaboration, 2007.**

The assumed relationships are described as follows:

*The amount of resources needed for mass care to carry out relief operation activities is determined by the quantity of clients affected by the disaster. System Capacity also influences the affected community subsystem. System's performance embraces constructs, such as, service quality, effectiveness and efficiency that influence the perceptions of the community affected by a disaster event. Likewise system performance influences the quantity of resources required in the activities of the American Red Cross group/activity function. Therefore, system capacity, emergency relief system performance and affected community, are also influenced by external factors. Finally External Factors are influenced by the affected community subsystem, and the emergency relief system performance.*

A description of each one of these subsystems is provided as follows:

- A. Affected Community Subsystem:** This subsystem explains important factors of current and future residents that would influence their status in case of an emergency. Demographic characteristics constitute an important factor for the establishment of the victim's profile for evacuation decision before, after or during a disaster hits. Therefore, "*External Factors*" influences "**Affected Community Subsystem**" and vice versa (see Figure 2). As a matter of fact, expanding a comprehension of community concerns is an important first step in conducting a service quality impact assessment. Hence, "**Affected Community Subsystem**" influences "*External Factors*".
- B. System Capacity:** This subsystem represents the elements that contribute to system capabilities including the number of disaster trained human resources and material resources employed during the entire disaster relief operation. At the American Red Cross it is composed of three group/activity functions: "*Mass Care Capacity*", "*Individual Client Services Capacity*" and "*Staff Services Capacity*". It also includes any Red Cross unit employee or volunteer ("*DSHR Capacity*") who has acquired the competencies to assume the responsibility to carry out an identified activity in support of a disaster response., "*System Capacity*" influences "*Affected Community Subsystem*". People affected by the disaster receive help in the form of shelter and feeding which is called mass care function, and financial assistance which is called individual client services function. Then, "*Affected Community Subsystem*" affects "*System Capacity*". The cases opened through the casework process and the amount of financial assistance provided to the disaster victims, in form of client assistance cards, are the processes included in the Individual Client Service function. Mental Health Care Services are provided to the people and communities affected by the disaster and are a Staff Service function. Hard assistance and soft assistance change over time in every stage of the disaster relief operation. Therefore, "*System Capacity*" affects "*Emergency Relief System Performance*". Changes in the provision of resources over time depend on the kind and category of the event and the final impact on the community. Furthermore, they are decisive determinants for resource allocation and influence the perception of community concerning the treatment and satisfaction they received. Therefore, "*External Factors*", "*Affected Community Subsystem*" and "*Emergency Relief System Performance*" influence "*System Capacity*" (see Figure 2). The quantity of resources required by disaster relief organizations, with the aim of meeting the client's needs, is a critical part of the assessment and should contribute to any decision of future resource allocation of these organizations to improve its operations. Therefore,

“*System Capacity*” influences “*Affected Community Subsystem*” and vice versa. Resource allocation is what enables an organization to improve or maintain its performance. The correct operationalization of this construct is critical to the development of the system.

**C. Emergency Relief System Performance:** This subsystem describes performance parameters related to human and material resources as well as charitable contributions in the form of donations, and evacuated client’s perceptions. Voluntary contributions, identified as Donations, constitute an important factor for the improvement of the system, concerning the acquisition of resources needed, in terms of supplies. Then “*Emergency Relief System Performance*” affects “*System Capacity*”, since the availability of resources (equipment, personnel, etc) needed to support a disaster relief operation depends on the *effectiveness* and *efficiency* of how the system can respond when it is needed. Performance also depends on Service Quality provided to clients in the aftermath of the event since the correct distribution of resources at the time can be the difference between satisfaction and dissatisfaction for the victims. The quality of service provided to the community hit by a disaster causes changes in the citizens’ attitude and perceptions, since they evaluate the quality of the actions taken by the relief organizations by means of comparing it to received resources and perceived treatment during the aftermath. Then “*System Capacity*” influences the “*Emergency Relief System Performance*”.

Outside the system are “*External Factors*” that are always influencing “*Emergency Relief System Performance*” and vice versa (see Figure 2). This research work focuses on the emergency relief system performance subsystem. This subsystem shows the overall architecture of the model and transmits information provided by the different agents represented.

### 3 Literature Review

#### 3.1 Service Quality in Emergency Management

As was cited by Medina-Borja in 2002, emergency service characteristics can turn the perception of emergency victims of how the service was delivered and the outcome of the service into a path-dependant error rate. Numerous authors (e.g. Furlong, Scott and Scheberle, 1998; Schneider, 1992) have documented that there is a gap between the way emergency victims perceive the availability, usability and effectiveness of the agency providing support and the way the agency itself identify their operations and ability to take action. This behavior pattern is caused by victims’ expectations of the agency functions and responsibilities and the help that they are entitled to receive. When this help is not immediately available, victims may consider that emergency management agencies were unsuccessful delivering their service. Research on customer satisfaction and customer’s perceptions of effectiveness in these kinds of cases must consider this gap. Besides, it is a fact that not all individuals respond to traumatic events with the same pattern of adjustment (Freedy et al., 1992). That is because individual differences with regard to mediating variables (e.g. social support, coping behavior, etc.) may be very important in determining the reasons for unrealistic expectations of service. Post-emergency factors, such as current experiences, have also been noticed as influential on clients’ perceptions of the emergency service (Medina-Borja, 2002).

This research is centered in developing a new model for evaluation of disaster relief operations, where service quality becomes an integral part of emergency resource allocation as

a new phase of the emergency response cycle. We have called this model the Service Quality Response Cycle (SQRC) Model. At present, to the best of our knowledge there is no dynamic model specifying a relationship between the service provider's (disaster relief organizations) and the service receiver's (disaster's victims) expectations and perceptions. Using and understanding diverse components of service quality models it is possible to create a link between disaster relief organizations and disaster's victims. These components of service quality are: service encounter, customer desires, and its effect on customer satisfaction perceptions of performance, customer decision process, perceptions of internal customers, internal suppliers that recognize the level of internal service quality perceived, the better use of resources to produce higher service quality levels, among others. It is necessary that the whole theory related to this topic ties up all these concepts in order to describe a system dynamics model that reflects the distribution of resources and the factors of service quality which in turn influence the perceptions and human reactions of the clients, before, during and after an emergency. SQRC maps the interdependence between resource allocation and human service satisfaction and hypothesize key mechanisms that govern this relationship. The analysis of several risk models presented in the literature also allowed us to understand several features always present in an evacuation process such as evacuation time, hurricane behavior, community characteristics, psychological variables and social factors (e.g. Fusell, 2006)

### **3.2 System Dynamics and Evacuation**

System Dynamics suggests an effective method for the understanding of complex dynamic processes, where multiple factors evolve over time. System dynamics (Forrester, 1961) is a method for studying the world around us. Unlike other scientists, who study the world by breaking it up into smaller and smaller pieces, system dynamicists look at things as a whole. The essential idea of system dynamics is to understand how all the objects in a system interact with one another. The objects and people in a system interact through "feedback" loops, where a change in one variable affects other variables over time, which in turn influences the original variable, and so on. What system dynamics tries to do is to understand the basic structure of a system, and understand the behavior that it can produce. (MIT, 2000). Many of the systems and problems investigated with SD can be built as models on a computer. A computer model can be of much greater complexity and carry out more simultaneous calculations than can the mental model of the human mind. In 1961 Forrester created the stock and flow diagramming conventions based on a hydraulic metaphor - the flow of water into and out of pools. The stocks are seen as bathtubs of water. The amount of water in the bathtub at any time is the accumulation of the water running in through the tap less the water pouring out through the drain (assume no splashing or evaporation). The amount of material in any stock is precisely the accumulation of the flows of material in less the flows of material out. Flows will be functions of the stock and other state variables and parameters. (Sterman, 2000). Successful intervention in complex dynamics systems needs more than technical tools and mathematical models. System dynamics is essentially interdisciplinary and in that its use is most appropriate for the problem at hand.

There has been very little work on dynamic modeling of evacuation dynamics. One of the most important works is that of Ahmad and Simonovic in 2001 who developed a computerized simulation model to describe human behavior during flood emergency evacuation, using a system dynamics approach. The model simulated the approval of evacuation orders by the residents of the area under risk; number of families in the process of evacuation; in addition, time needed for all evacuees to reach protection. The model is conceptualized around the flooding conditions (physical and management) and the main set of social and mental factors that determined human behavior before and during the flood evacuation. Human behavior

during evacuation, in response to a disaster warning, was captured within the model with the aim of allowing emergency managers to develop the best possible response strategy in order to reduce the negative impacts of a flood event. Model relationships and all other necessary data were achieved through interviews conducted in the Red River Basin after the flood of 1997. In that, Ahmad and Simonovic's system dynamics model was capable of simulating the effect of different flood evacuation policies. The major benefit of this work was that by understanding how a specific structure of feedback loops is capable of generating the observed behavior, it was possible to get insights into potential results. Among the principal variables embraced by this model were the number of families under the flood threat, population in the process of evacuation, inundation of refuge routes, flood conditions (precipitation, river elevation, etc.), and different flood warnings and evacuation orders related variables.

There are similarities and differences with the Service Quality Response Cycle (SQRC). SQRC allows for different resource allocation policy options available to hurricane emergency managers to be evaluated before an emergency situation occurs (such as required training time, number of meals, number of shelters and people per shelter, etc) considering the different populations and relating human behavior to non-controllable variables such as home ownership status, income, education, pet ownership, age, etc.

#### **4 Methodology to Develop the System Dynamics Model**

To build up the new model that incorporates the victim's characteristics, behaviors and intentions prior to the emergency and then their perceptions of service quality during and after the disaster relief operation and the interrelation of those outcomes with resource availability it is necessary to determine several chronological steps. The method used is described step-by-step here and followed the methodology suggested by Sterman (2000) explained in the following sections.

##### **4.1.1 Problem Articulation (Boundary Selection)**

This phase outlines the real problem of this research work keeping in mind what is enough to delimit the model. The model concentrates on a particular problem, and it is not attempting to model the whole complexity of the emergency-management system. For that reason, boundary selection was a priority task that set the limits for this complex system and a selection was made of all components. The scope of this research work is enclosed in the disaster relief operation system, more specifically, in the emergency relief system performance subsystem. Only three functions of the ARC group activity/structure: Mass Care, Individual Client Services and Staff Services are contemplated in the model. The model considers hurricane disaster events only. Therefore, the number of variables was limited to those relevant to the specific problem. In the research problem, the issue of resource-allocation decisions related to the organizational performance improvement during disaster relief operations was outlined as a service quality and resource availability dilemma. After examining reference modes, this research included in the research problem, the issue of the clients' disposition to evacuate, and the interconnected nature with the other affected community factors.

##### **4.1.2 Key Observed Variables**

With a clear and defined purpose, the important components of the system were defined. The Emergency Response Cycle presented in Figure 3 shows the general action cycle followed immediately by DROs (Disaster Relief Organizations) after an event occurs and is applicable

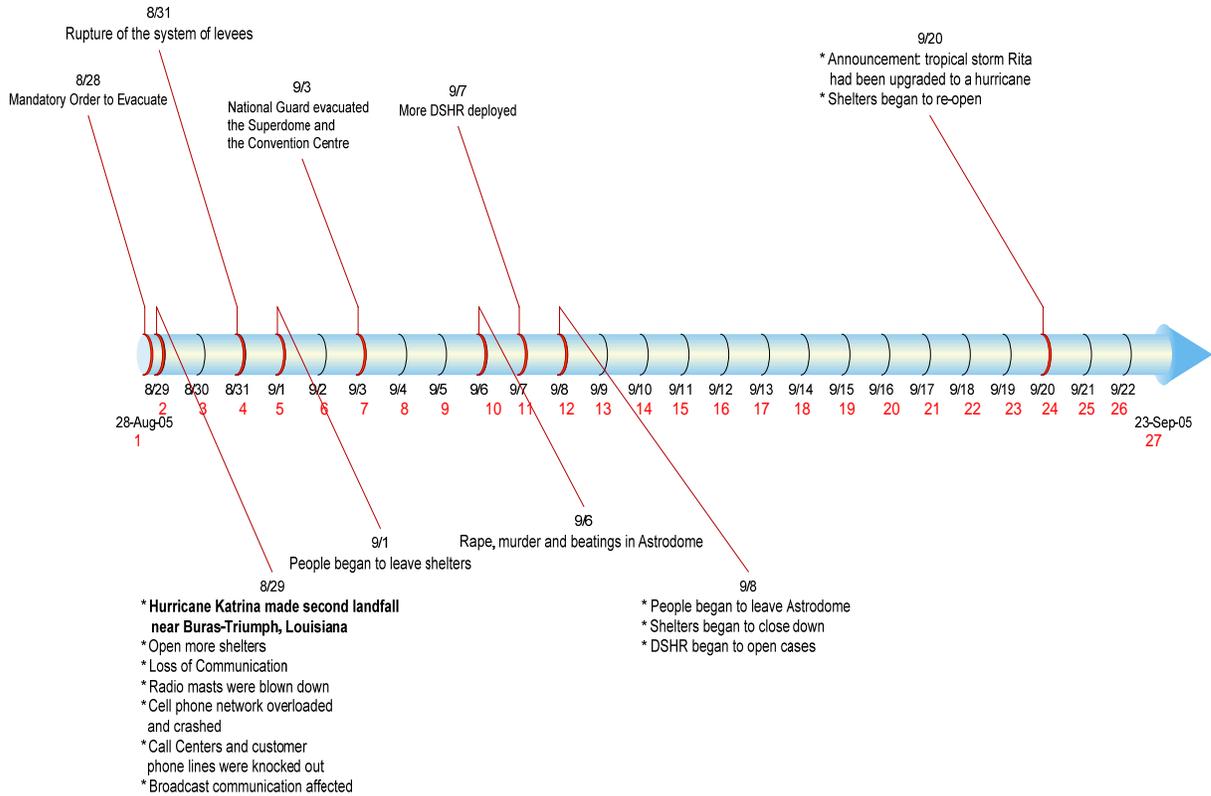
to any emergency response plan. The action phases of the Emergency Response Cycle (ERC) included in this research named as response (rescue and relief), recovery, reconstruction, mitigation and preparedness, are the general model actually applied to all the emergency-management systems. The causal loop diagram of the system (Figure 3) presents the observed variables of the Service Quality Response Cycle (SQRC). These variables were chosen because they represent the underlying service provision, and the data to support these variables were available in the databases provided by the American Red Cross.

#### 4.1.3 Time Horizon: Timeline of Hurricane Katrina

The time horizon of this research is explicitly stated. Katrina operation was 27 days long. It showed how the problem emerged and described its symptoms. The data source is detailed in the data cleaning section. Below, a brief description is provided for the chronological events that followed after Hurricane Katrina struck (see Figure 4).

- **Day 1, August 28:** It was only 24 hours before the hurricane struck that a mandatory order to evacuate the city was made (Cabinet Office Civil Contingencies Secretariat, 2006).
- **Day 2, August 29:** Hurricane Katrina hit the States of Alabama, Mississippi and Louisiana. The storm took all day to pass through the area. The ARC began to open more shelters to provide protection and temporary housing to the affected population. As a consequence of the hurricane pass, there was complete loss of communications, radio masts were blown down and the cell phone network overloaded and crashed. Call centers were knocked out disrupting local emergency services, and customer phone lines were knocked out in Louisiana, Alabama, and Mississippi. Broadcast communications were also affected (Cabinet Office Civil Contingencies Secretariat, 2006).
- **Day 4, August 31:** Eighty percent of New Orleans was flooded, with some parts under 15 feet of water. Most of the city's levees designed and built by the United States Army Corps of Engineers were breached (Wikipedia).
- **Day 5, September 01:** During this day people began to leave the shelters.
- **Day 7, September 03:** The National Guard evacuated the Superdome and the Convention Centre (Cabinet Office Civil Contingencies Secretariat, 2006).
- **Day 10, September 06:** Reports of rape, murder and beatings in Houston Astrodome were announced in the news (Boingboing A Directory of Wonderful Things).
- **Day 11, September 07:** More DSHR were deployed to the disaster site.
- **Day 12, September 08:** Many of those evacuated from the Superdome in Louisiana found refuge in the Reliant Park Centre in Houston (Cabinet Office Civil Contingencies Secretariat, 2006).  
During this day shelters began to close down and DSHR began to open cases.
- **Day 24, September 20:** Tropical storm Rita has been upgraded to a hurricane. During this day shelters began to reopen.

## Timeline of the Hurricane Katrina



Page 1

Figure 4. Timeline for Hurricane Katrina.

### 4.1.4 Dynamic Problem Definition (Reference Modes)

Reference modes were drawn related to the pattern of behavior for key variables over time. With these modes, it was possible to clarify, analyze past and future behavior in an explicit labeled time and limit the problem statement to the events described. The following graphs illustrate the chosen reference modes for this problem. They translate the behavior of the system into a graphical form. They were selected as the most relevant concepts for understanding the research problem and the design of the policies to solve it. Data for these reference modes was provided by the American Red Cross of pre and post Katrina Hurricane (Figure 10 and Figure 11).

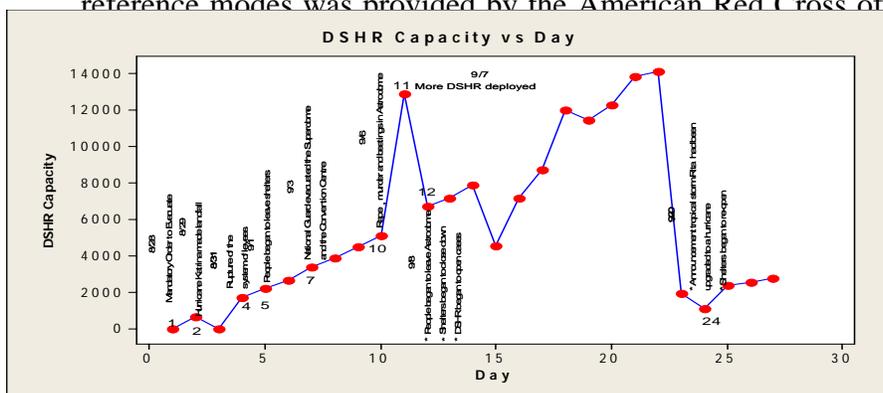
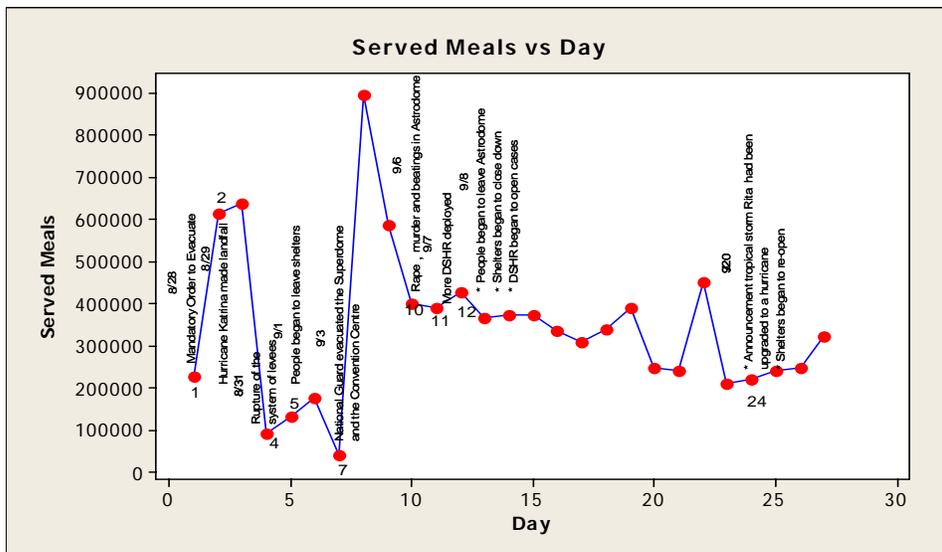
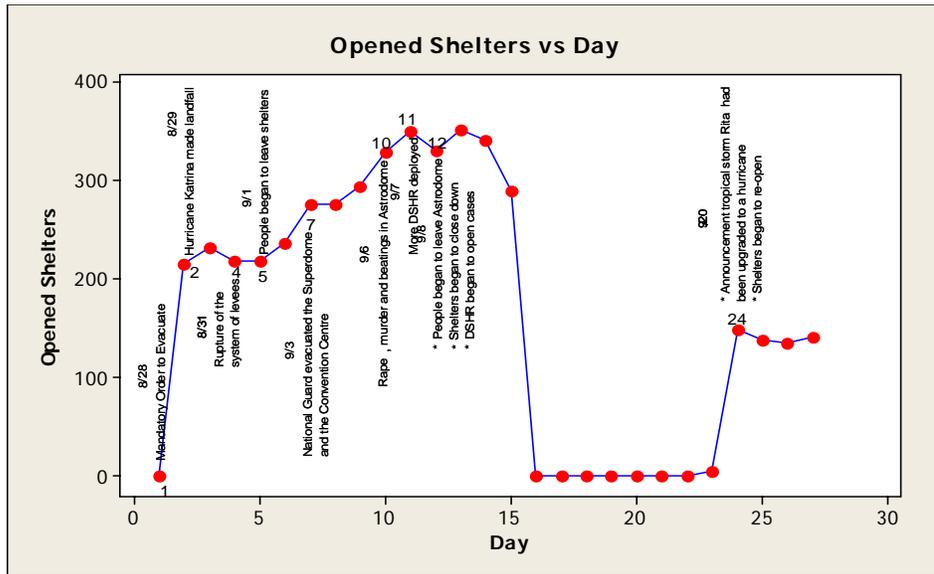


Figure 10. "Deployed DSHR" during Katrina Operation. Author's Elaboration, 2008.

DSHR reference mode provides information about the service provider human resources with which it can be possible to forecast what would be the human resources required in advance in preparation for a potential emergency.



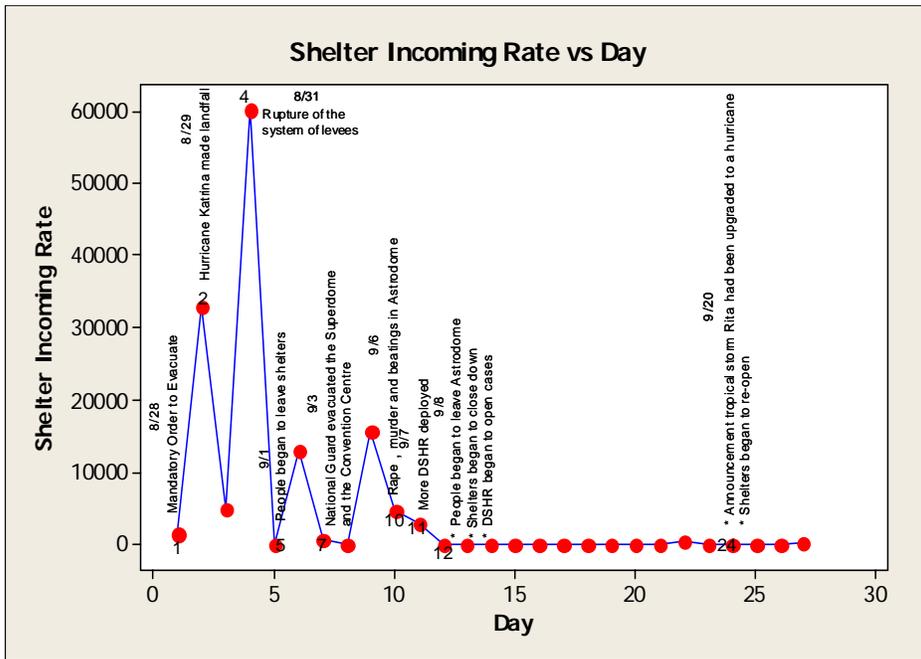
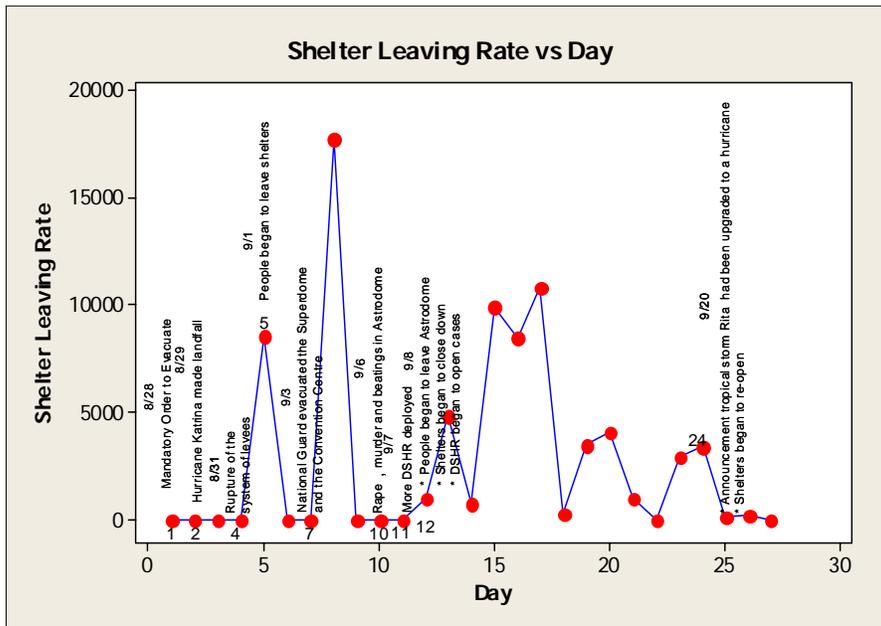
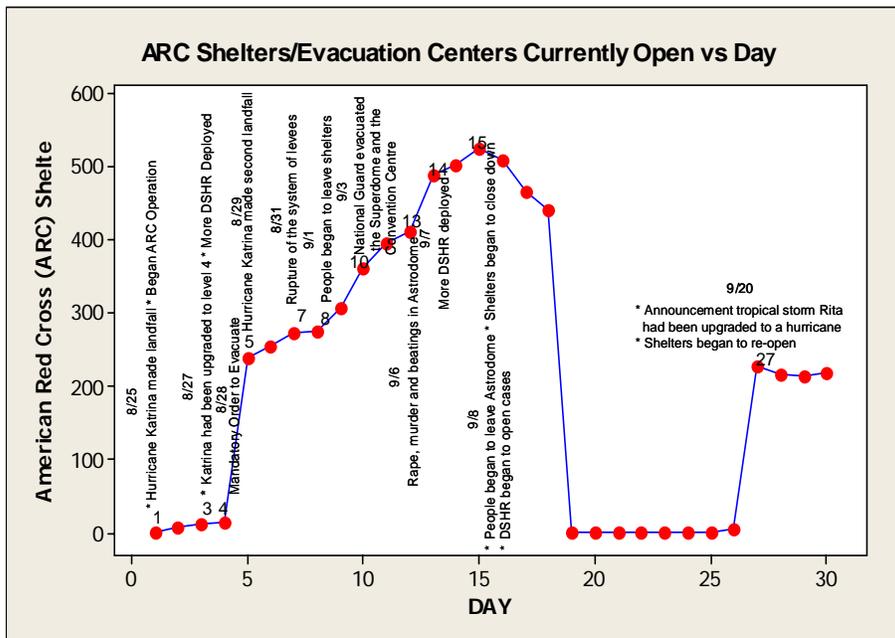
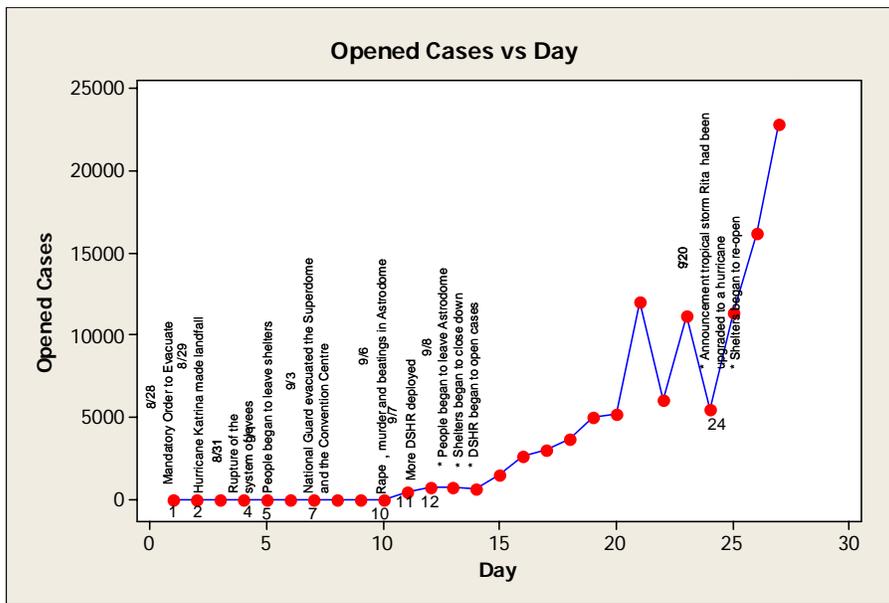


Figure 5. “Shelter Incoming Rate” during Katrina Operation. Author’s Elaboration, 2008.





The behavior of the clients satisfaction was totally assumed based on media accounts as no dynamic data was available to draw it based on anything else but assumptions. Data on victim's satisfaction was collected at one point in time only and there was no hard evaluation of the evolution of those perceptions over time. Although one of the databases available to us contained satisfaction data for each stage of the operation, it is impossible to link it with the number of days of response operation. The assumed behavior was determined after the analysis of the news and reports on the Internet about the assistance provided by the American Red Cross during the relief operation. This reference mode exhibits a pure negative exponential goal-seeking (also called exponential decay) behavior (Sterman 2000).

#### **4.1.4.1 The dynamic development of the Katrina Hurricane**

On the 1<sup>st</sup> day, a mandatory order to evacuate the city was made. The higher rate of people that went to the shelters, in the early phase of relief, occurred: in the 2<sup>nd</sup> day of operation, because that was the day Hurricane Katrina struck New Orleans; and in the 4<sup>th</sup> day when the system of levees broke. Therefore, more shelters began to open. People went to shelters during the first 11 days of the response operation. Some of them began to leave on the fifth day and the rest of them began to leave on the 12<sup>th</sup> day. It means that in general some of the population spent four days in the shelter and the rest of them 11 days. This statistic can be confirmed with the multiple response analysis made in SPSS (see appendix E).

On the 12<sup>th</sup> day, shelters began to close down, but they began to re-open on the 24<sup>th</sup> day. That behavior corresponds to the announcement made by the weather news on the 24<sup>th</sup> day, that tropical storm Rita had been upgraded to a hurricane.

Therefore, the number of "Served Meals" was tied to the number of people in the shelter at that time. From the 24<sup>th</sup> day, the number of meals began to increase, due to the announcement of Rita. In addition, the number of "Opened Cases" was a function of the number of people leaving the shelter and of the DSHR deployed. People began to leave the shelters on the 12<sup>th</sup> day, because they were waiting for the DSHR to open the cases to provide them with financial aid. Therefore, the rate at which people left the shelters depends on the rate that cases were opened. From the 25<sup>th</sup> day, the number of cases began to increase, due to the announcement of Rita.

DSHR deployed during the Katrina operation were a function of the number of people incoming and leaving the shelters. From the 25<sup>th</sup> day, the number of DSHR deployed began to increase, due to Rita approaching. There was an increment in the number of DSHR deployed on the 11<sup>th</sup> day. The reason could have been the reports of rape, murder, and beating in Astrodome, made by the evacuees to the news the day before. There was a delay in the deployment of the DSHR at the beginning of the relief operation. That was due to the training needed for the DSHR personal to be deployed to the relief operation.

#### **4.1.5 Formulation of Dynamic Hypothesis with Endogenous Focus**

With this step we established how the system works after understanding the structure of the system in the prior steps. System Dynamics seeks endogenous explanation for phenomena rather than exogenous ones. According to Sterman (2000), explanations based on exogenous variables are not of much interest because they explain the dynamics of interest variables in terms of other variables whose behavior is assumed. However, in the case of evacuation dynamics, victims' characteristics that affect behaviors during the evacuation become to certain extent, endogenous.

Three dynamic hypotheses were formulated to explain the behaviors of reference modes. These were formulated to be consistent with the model's purpose. The three dynamic hypotheses for this research are:

**DH1:** Given that the amount of resources necessary to meet the needs of the victims depends on the number of victims left by the natural disaster in need for help, then an increment in the capabilities of the system and resources available (served meals, delivered financial assistance

and DSHR capacity for the recovery of the victims) would increase the perception of the quality of service provided to the evacuated clients at each stage of the relief operation. This satisfaction then will be greatly affected by the timeliness of deployment of those resources.

**DH2:** Perceptions of poor service provided by disaster trained volunteers (DSHR) to the evacuated clients during the response operation, is defined by long waits to be served, resulting in a negative impact on the client's satisfaction. As the level of attention provided to the people in shelters, and the rate of reporting and opening of cases during and after the event depends on the amount of DSHR deployed for the response operation, then, the number of DSHR deployed is the key element in the development of this operation. Deploying fewer DSHR has the potential to diminish the system performance more than any other element.

**DH3:** The disposition for evacuation that clients had prior to the hurricane event, depend on their demographic characteristics and profile. In turn, the number of people that actually evacuated and required shelter is also a function of the fluctuations in the level of hurricane as well. Therefore, variations in the affected population mix would require different resource allocation to face sudden increments in the number of people that go to the shelters.

#### **4.2 Data Preparation and Identification of Probabilities, Relationships and Patterns**

Four databases containing survey data collected from Katrina victims were provided by the American Red Cross, and were used in a data mining exercise to find the patterns of client behavior during the Katrina operation. This in turn provided the likelihood (probabilities) of evacuation before, during or after the storm of an affected population given their demographic characteristics and other economic information (such as home ownership or not). This information was then joined with information from the census data and from FEMA databases and linked to data extracted from the media such as information extracted from newspapers and other public databases. This allowed the construction of a causal diagram that was later adjusted and refined to parameterize the stock-and-flow model with parameters derived from real victims of a hurricane.

This is probably one of the main contributions of this research, as this is one of the major undertakings ever to put together pieces of information of disaster relief that researchers have tackled as separate problems to construct a dynamic framework. Decision tree graphs were created as part of the data analysis. The extensive results are not part of this paper but it is worth to state the main predictor of evacuation before the hurricane hits as represented by the variable "Evacuate House or Apartment due to Hurricane Katrina" resulted to be the house ownership status represented by the variable "Own/Rent House or Apartment" .As expected, people owning a house were less likely to evacuate their property, followed by significant differences found if one factors race, pet ownership, age, disability status and others. This helped us create multiple profiles of evacuation given certain population characteristics and a number of evacuation rules that were coded into the dynamic model.

#### **4.3 Mapping System Structure**

**Causal Loop Diagram:** Shows the causal structure and is used to depict the feedback structure of system representation. It contains observed variables connected by arrows indicating the causal influences among the variables. It puts emphasis on the feedback structure of a system. (Sterman, 2000). It is based on initial hypotheses, key variables, reference modes, and other available data.

Basic “Demographic Characteristics” like household income information can be decisive to assess and determine the response of the “Population Affected” of a disaster area. It is a critical factor considering the reasons a client has to evacuate a potential disaster site. Depending on the reasons for evacuation, clients make the decision of abandoning, or not, this potential disaster site. Reasons for evacuation can vary, and embrace different aspects, and it depends on the lifestyle of each of them. Situations like ethnical background and be a realty owner or not, are some of the aspects that influence that kind of decision. Therefore, “Client’s Profile” influences the “Population Affected” and the “Client’s Disposition for Evacuation”. Then “*Client’s Disposition for Evacuation*” influences the amount of “*Evacuated Population*”. In addition, the “*Population Affected*” by the disaster influences the amount of “*Evacuated Population*”. The numbers of “*Evacuated Population*” establishes the amount of “*People in Shelter*”.

- The American Red Cross’ **Disaster Services Human Resources (DSHR)** system facilitates prompt and efficient disaster relief services to the American people, and it is composed by any Red Cross unit employee or volunteer who has the identified competencies to assume the responsibility to carry out an identified activity in support of a disaster response. The American Red Cross’ Staff carry out activities and services necessary to ensure the ability of Red Cross employees and volunteers, including spontaneous volunteers, to meet the needs of the people and communities affected by the disaster. Therefore, recruiting “*New Volunteers*” affects the number of “*Volunteers Trained*”. The number of “*Volunteers Trained*” influences the amount of “*DSHR Capacity*”. In the same way, “*Staff Availability*” affects “*Staff Capacity*”. On the other hand, the characterization of the destructive potential of hurricanes impacts the recruiting of volunteers. Therefore, “*Hurricane Level*” influences “*New Volunteers*”.
- **Mass Care** starts once a notification of an impending disaster or immediately following a disaster event arrives and must be initiated offering individual or congregate temporary shelters, fixed or mobile feeding to the affected people. Therefore, “*Opened Shelters*” and “*Served Meals*” influence “*Mass Care Capacity*”. Individual Client Services starts with the opening of cases through caseworkers. Then, direct financial assistance for replacement of essential items is provided. Therefore, “*Opened Cases*” and “*Financial Assistance*” influence “*Individual Client Services Capacity*”. To carry out Mass Care and Individual Client Services activities it is necessary to count on the availability of resources provided by the ARC. Then the “*Resources Available*” affects “*Mass Care Capacity*” and “*Individual Client Services Capacity*”.
- On the other hand, focusing resources available to accomplish service delivery efficiently for a specific disaster requires that there be in stock some of the necessary resources that need to be suitably balanced among the many inputs used to respond during the disaster relief operation. Large numbers of volunteers are useless without adequately built, equipped, and supplied facilities. Therefore, “*Resources Stored*” affects “*Resources Available*”. ARC resources are important to minimize impact on the affected community and could be, or not, adequate for the actions’ success.
- Another aspect is the emergency assistance provided to minimize immediate disaster-caused needs through the provision of material items depends on the quantity of resources deployed during mass care activities. This is called hard assistance and includes mass feeding and shelter. Therefore, “*People in Shelter*” determines the amount of resources

needed to be deployed in terms of “*DSHR Capacity*”, “*Opened Shelters*”, “*Served Meals*”, “*Opened Cases*”, “*Financial Assistance*” and “*Mental Health Care*”. The provision of mental health care to the population affected depends on the number of ARC personnel available for this activity.

- A case is a one-two page document that describes a disaster, crystallizes the disaster victims’ needs, describes the Red Cross response, asks for money, and informs donors and prospects how to donate. The case statement should be developed within the first 24-48 hours of the disaster and should be updated regularly to reflect current and relevant information. Direct financial assistance is provided through caseworkers to individual victims. Then, “*DSHR Capacity*” affects the “*Served Meals*”, “*Opened Cases*”, “*Financial Assistance*”, and “*Mental Health Care*”. The amount of personnel to be deployed in order to assist relief operations is also determined for the quantity of resources needs to be allocated. Therefore, “*Opened Cases*”, “*Served Meals*”, and “*Financial Assistance*”, influence “*DSHR Capacity*”.
- Material Support Services is a function of the Red Cross that supports activities and services necessary to conduct a disaster relief operation, including the securing of facilities. Therefore, the personnel involved in this function are in charge of identify sources for facilities and make the appropriate arrangements to open these facilities as shelters. This is the reason DSHR is not in function of “*Opened Shelters*”, because this function of the ARC is not included in this model. Finally, the amount of personnel and material resources deployed to the disaster site in order to assist victims immediate needs establish whether these needs were met or not. Therefore, “*Mass Care Capacity*”, “*Individual Client Services Capacity*” and “*Staff Services Capacity*” influence “*Needs Met*”.
- If needs are met or not changes clients’ perceptions of the service received. Then, “*Needs Met*” influences “*Client’s Perception ARC Service*”. Clients’ perceptions of the service are the beginning point of the evaluation of the service received overall. Then “*Client’s Perception ARC Service*” influences “*Total Service Quality Perception*”. Therefore, “*Total Service Quality Perception*” influences “*Client’s Satisfaction*”. When a service is not performed according to the standards, this creates a performance gap. This performance gap depends on satisfaction and perceptions of the total service quality provided. “*Goal for Satisfaction*” of this system consists in reducing the Performance Gap to zero. However, there is a delay in the reaction of the Red Cross organization to reports of client dissatisfaction. The correction is not immediate. Then, “*Goal for Satisfaction*” influences “*Client’s Satisfaction*”.
- People’s views about humanitarian services are only partly formed by their direct use of those services. The role of the Media is highly influenced by the people’s overall views of the performance of an organization, such as, the American Red Cross. This means that the “*Client’s Satisfaction*” of the service received affects the role of the “*Media*”. Therefore, “*Media*” and points of view of the “*People in Shelter*” are important factors in the process of “*Public Opinion*” formation, it can influence community opinions, and those controlling the media are capable of changing the nature of discourse in their desired direction. “*Public Opinion*” also affects the recruiting of “*New Volunteers*”. It is in this way, that “*Public Opinion*” becomes an imperative mobilizing weapon when an outage strike due to the right of people to be concern about the destination of “*Cash Donations*” that they

make to these kinds of events. As a result, the positive or negative influence of “*Public Opinion*” affects “*Donations*” cash flows made by community.

- These cash flows made by the non-affected communities determines the amount of resources the relief organization can obtain to assist people in the disaster site. Then, “*Cash Donations*” affects “*Resources Available*”.

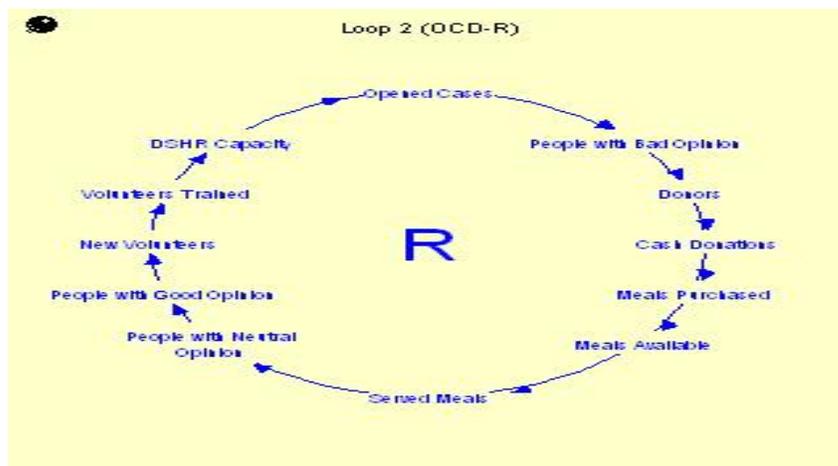
### Description of the Service Quality Response Cycle (SQRC) Causal Loop Diagram

The overall causal loop diagram of the system is shown in Figure 3. Now, taking reference to the polarities of this causal-loop diagram the above figure shows a possible set of causal relationships within this model. The arrows indicate the causal direction of influences. The signs beside the arrows indicate the polarity. For demonstration purposes we have selected only one of the various feedback loops manifested in the causal loop diagram which is described in detail as follows.

#### “Opened Cases” - DSHR Loop (OCD-R)

The arrow from “*Opened Cases*” to “*DSHR Capacity*” is cited as a positive influence: An *increase (decrease)* in the “*Opened Cases*” *increases (decreases)* “*DSHR Capacity*”. The arrow from “*DSHR Capacity*” to “*Opened Cases*” is given as a positive influence: An *increase (decrease)* in the “*DSHR Capacity*” *increases (decreases)* the “*Opened Cases*”.

Therefore, this feedback structure corresponds to an **Exponential Growth** behavior. The loop is a positive feedback loop which is expressed as a reinforcing behavior, and it is named as OCD-R (see Figure 12).



**Figure 12; OCD-R Loop**

#### **4.3.1 Formulation of a Simulation Model**

In this phase the system description is transformed into a model with equations, parameters and initial conditions that were represented as a stock and flow structure. Following are the steps embraced in the development of this model.

## Stock and Flow Diagram Notation

Three subsystems of the Service Quality Response Cycle stock and flow diagram are represented by Figures 13 to 16. The stock and flow structure has a one-to-one correspondence to the causal loop structure presented before, and was built using Stella™. The complete stock and flow structure is large and complex and therefore is not included entirely in the body of this paper. However, it is available.

### *External Factors Stock and Flow Structure*

In this sector frame of the model the converters that describe the demographic characteristics and profile of the population affected are specified. It also describes the structure for the spreading of news that will affect the reputation of the relief organization (in this case, the ARC)

- “**Hurricane Threaten**” is a switch that remains in ON mode to begin the simulation if there is any hurricane event.
- “**Hurricane Level**” is a switch that indicates using ON/OFF if the hurricane event is high or Low
- “**Birth Rate**” depends on “**Births**”. This flow controls the speed of population’s births daily in the United States. “**Total Census Population**” is defined as a stock that accumulates where the number of people flows into it, and the net number of people out of it. “**Death Rate**” depends on “**Deaths**”. This flow controls the speed of population’s deaths daily in the United States.
- “**Population Over 18 Years Old**” is defined as a stock accumulates where the number of people with 18 years old or more flows into it, and the net number of people with 18 years old or more out of it.
- “**House Ownership Status Census: Other**” depends on “**House Ownership Status Census: Own, House Ownership Status Census: Rent**” and “**House Ownership Status Census: Live with Parents**”.
- “**Household Income Census: More Than 10 K and Own**” depends on “**Household Income Census: Less than 10 K and Own**”.
- “**Race Non White Income More Than 10 K Less Than 40K Renter**” depends on “**Race Non Hispanic White Income More Than 10 K Less Than 40K Renter**”.
- “**Household Income Census: different categories of income and house ownership**”

Using classification trees analysis via CHAID, the likelihood of the client’s perception about the service provided by the ARC was estimated as described before. Perceptions about the service received were estimated as a result of the comparison between required and delivered resources. Then, “**Good Perceptions**” and “**Bad Perceptions**” of the service provided by ARC were evaluated for people affected by the natural disaster in terms of “**Financial Assistance**”, “**Mental Health Care**” and “**Meals**”. “**Good Perceptions**” is the principal factor for the establishment of the “**Service Quality**”.

### *Simulation Control Parameters*

The following are the simulation control parameters used:

- Length of Simulation: From 0 to 27 days. This time horizon corresponds to the duration of the Katrina Hurricane Operation and would correspond to a large disaster operation. For another disaster, a different time horizon would have been used.
- Interval of Time between calculations:  $DT = 1.0$  day.

## 5 Comparison to Reference Modes

This is probably one of the most important model behavior tests for any dynamic model since the objective is to mimic reality. It is essential to make a comparison with real life results to see if it closely resembles the behavior of the key variables. To achieve this contrast, the study of the actual behavior of the system was compared with the simulated behavior of the model. Therefore, every variable was proven for coherence to a significant concept in the real world. Figures 19-23 show the comparison between real and simulated data obtained during the model runs. The blue line represents the real behavior of each key variable during relief operation of Katrina hurricane (at least as reported by the ARC); and the red line represents the results of the model simulation. The X-axis has the time of the simulation in days. The Y-axis represents the value of the key variable both simulated and real at each time.

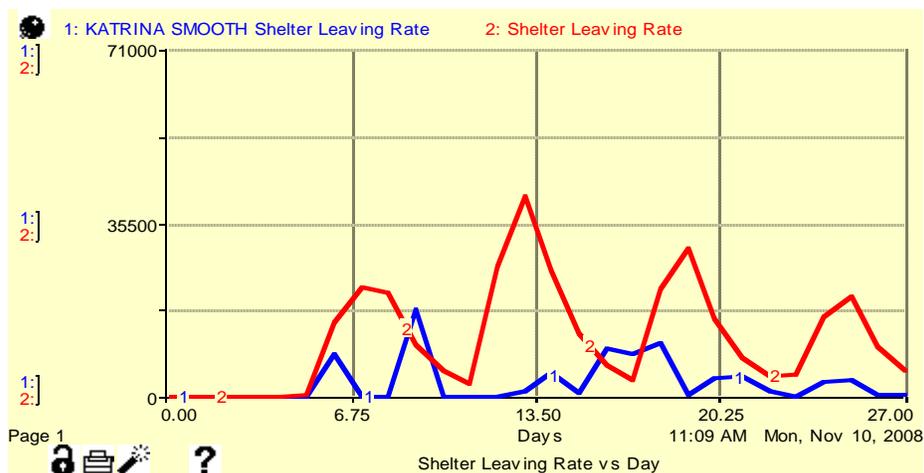
Graphs for key variables suggest an acceptable behavior between the simulation and real data. Both graphics follow a similar pattern of behavior. Data points of the simulation remain in a similar range in comparison to the real data. Because of the enormous fluctuations presented by the real data reported by the ARC, a smoothing method was applied with the objective of diminishing the noise of the data set. A smoothing procedure will change (soften) the fluctuations to represent a smooth curve instead that follow the trends of the behavior.

The dominant subsystem of this model is the System Capacity. This subsystem dominates the Emergency Relief System Performance and influences the Affected Community Subsystem.



**Figure 19. “Shelter Incoming Rate”: Reference Mode vs. Simulation. Author’s Elaboration, 2008.**

The real data for “Shelter Incoming Rate” ranged from 0 to nearly 60,098 people per day on the 4<sup>th</sup> day. The simulation shows data ranged from 0 to 29,100 people. For this key variable simulation runs decrease to zero on the 69<sup>th</sup> day.



**Figure 20. “Shelter Leaving Rate”: Reference Mode vs. Simulation. Author’s Elaboration, 2008.**

The real data for “Shelter Leaving Rate” ranged from 0 to nearly 17,784 people. The simulation shows data ranged from 0 to 41,292 people.



**Figure 21. “Opened Shelters”: Reference Mode vs. Simulation. Author’s Elaboration, 2008.**

In real data “Opened Shelters” ranged from 0 to nearly 352 units. Simulation shows data ranged from 0 to 246 units.



# SERVICE QUALITY RESPONSE CYCLE

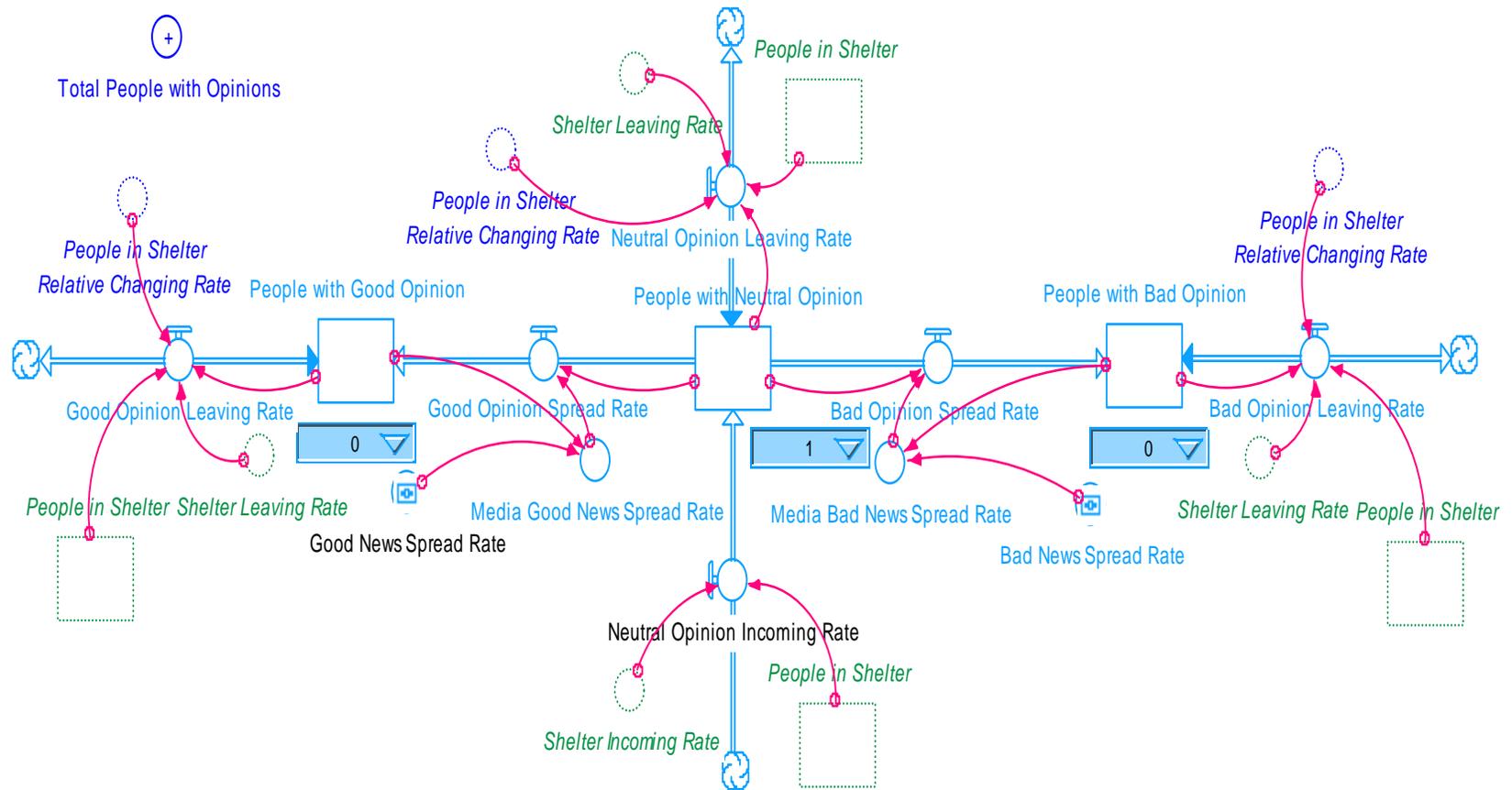


Figure 13. SQRC Stock and Flow Diagram Notation for the spread of opinions in the general population. Author's Elaboration, 2008 (Continued).

**Affected Community Subsystem**

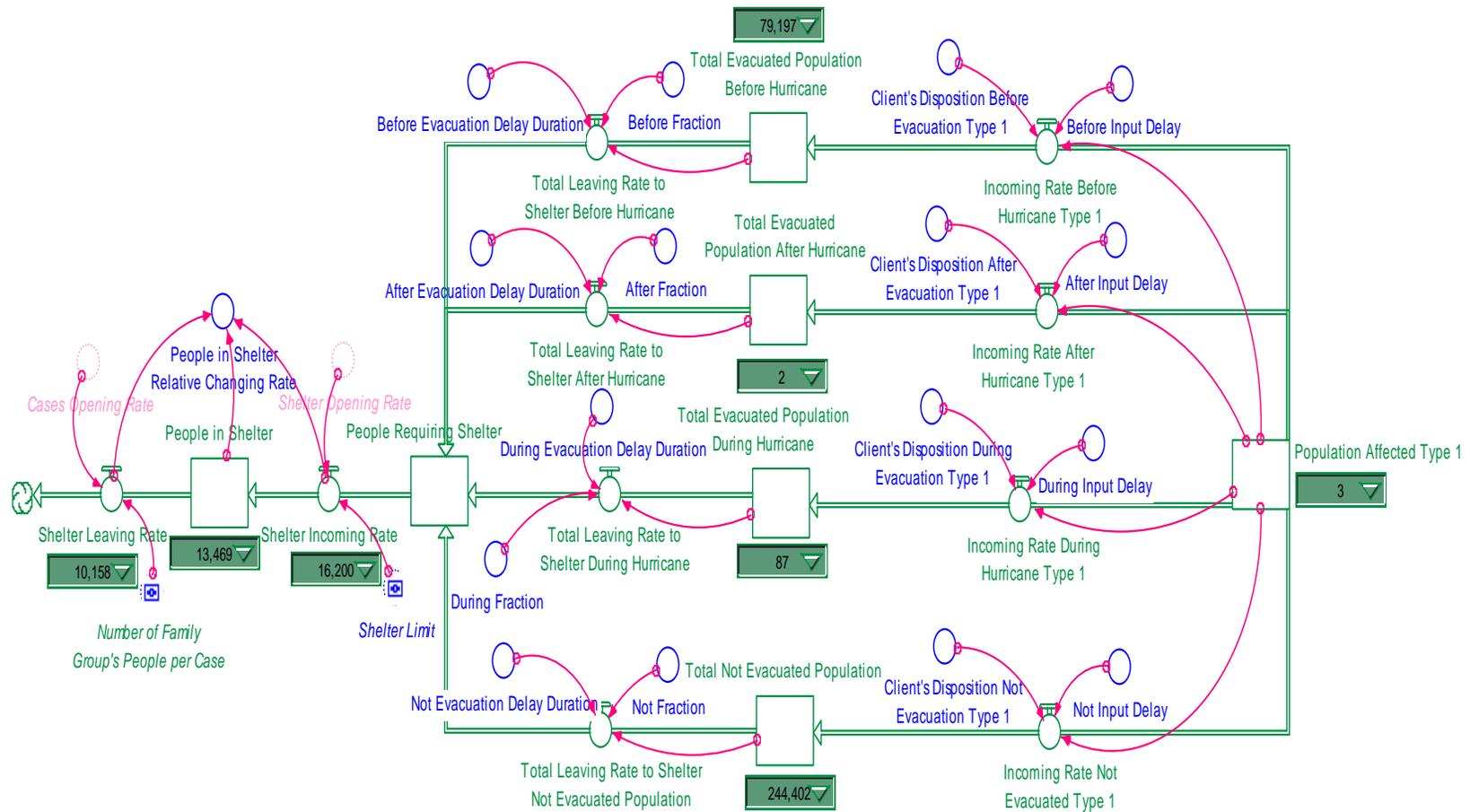


Figure 14. SQRC Stock and Flow Diagram Notation. Author's Elaboration, 2008 (Continued).

This is a schematic representation of one of the eight types of population impacted by the disaster that are included in the affected community subsystem. These types of population mixes were classified depending on demographics characteristics and profile obtained with CHAID analysis.

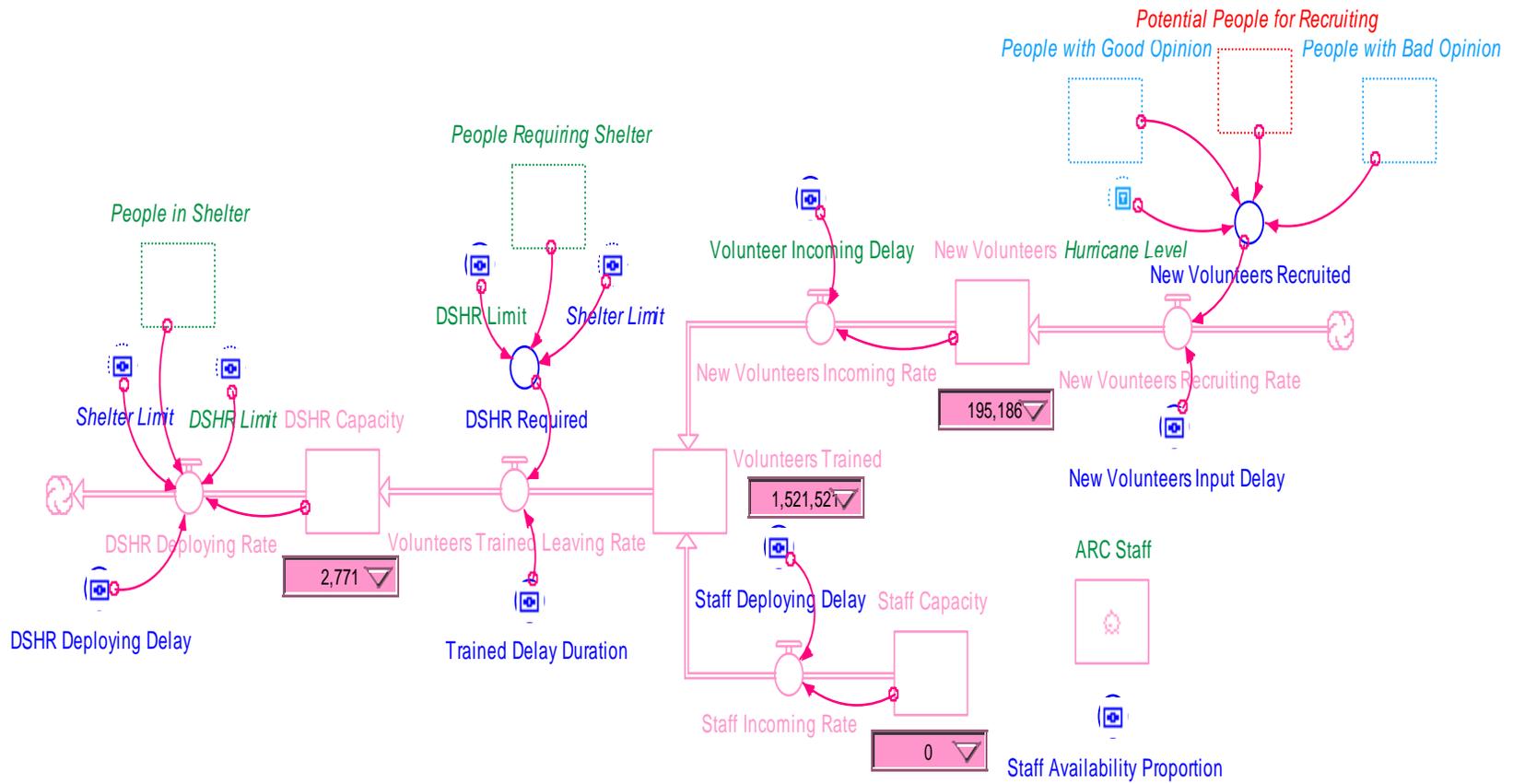


Figure 15. SQRC Stock and Flow Diagram Notation for DSHR capacity. Author's Elaboration, 2008 (Continued).

**Emergency Relief System Performance**

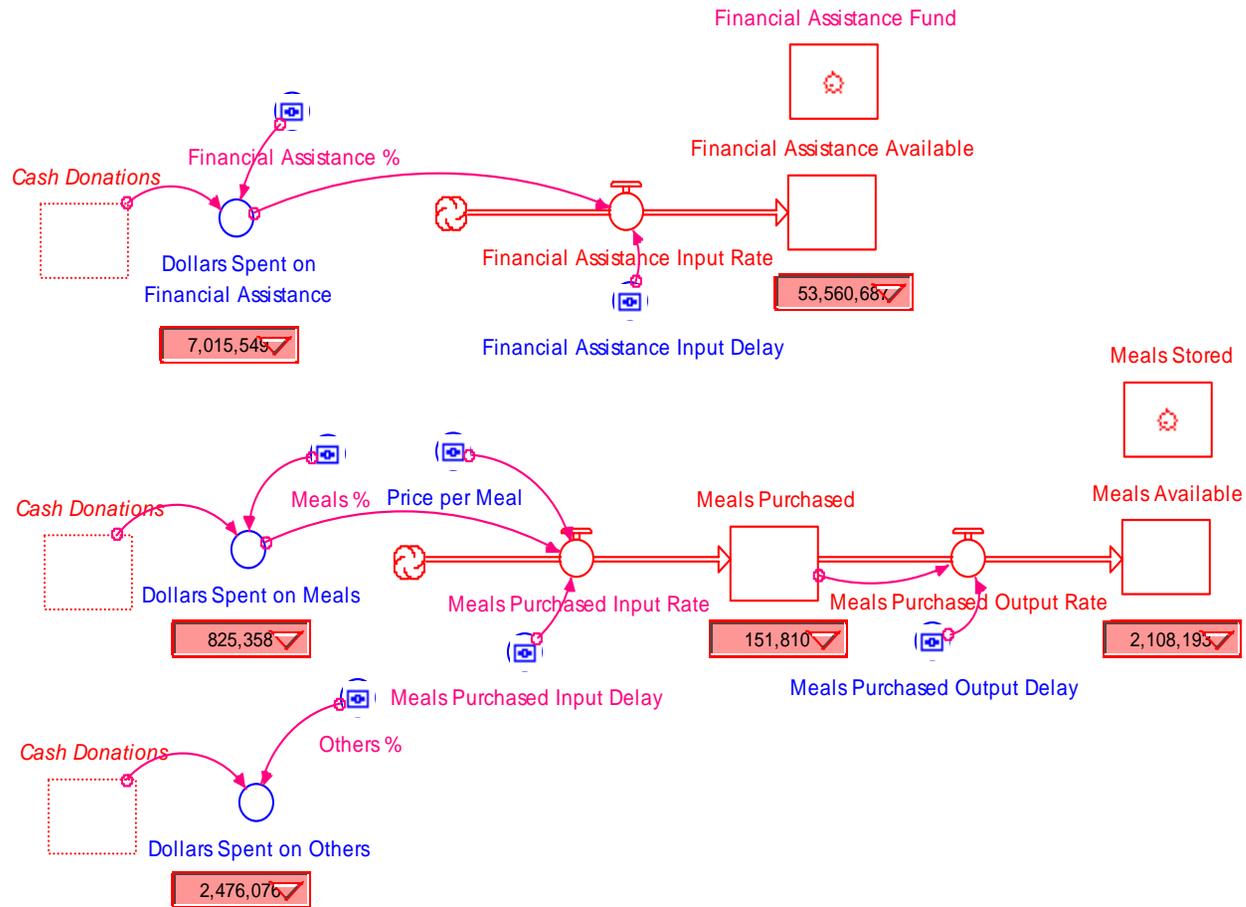
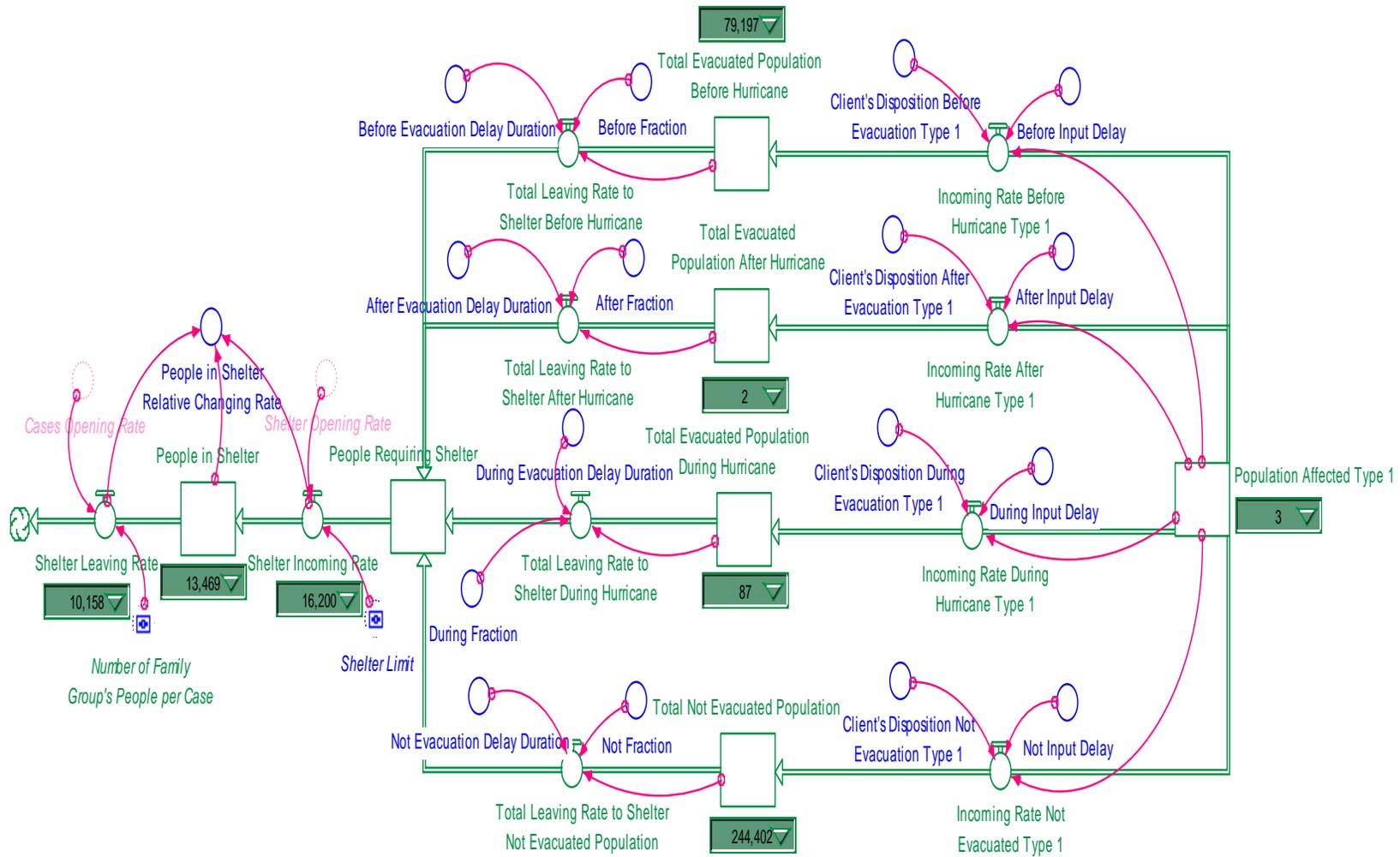


Figure 16 SQRC Stock and Flow Diagram Notation. Author's Elaboration, 2008 (Continued).



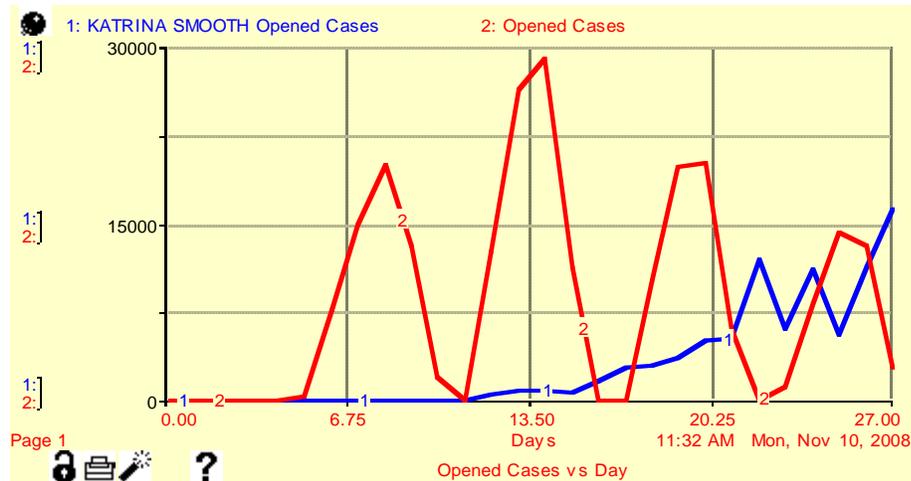
**Figure 17. Moment of the Evacuation Stock and Flow Structure. Author's Elaboration, 2008.**



**Figure 22 “Served Meals”: Reference Mode vs. Simulation. Author’s Elaboration, 2008.**

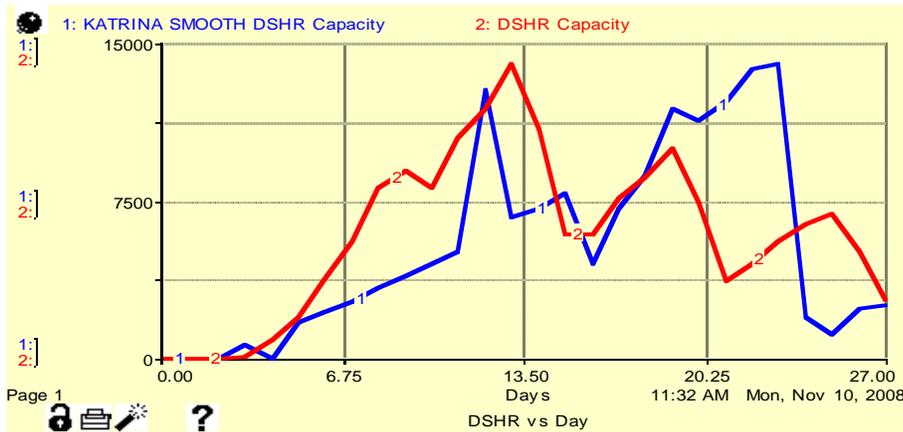
In real data “Served Meals” ranged from 0 to nearly 895,503 units. Simulation shows data ranged from 0 to 743,429 units.

Data obtained for served meals was from the beginning somewhat suspicious because it was obvious that meals provided to people outside the shelters was reported in the same column without distinction.



**Figure 23. “Opened Cases”: Reference Mode vs. Simulation. Author’s Elaboration, 2008.**

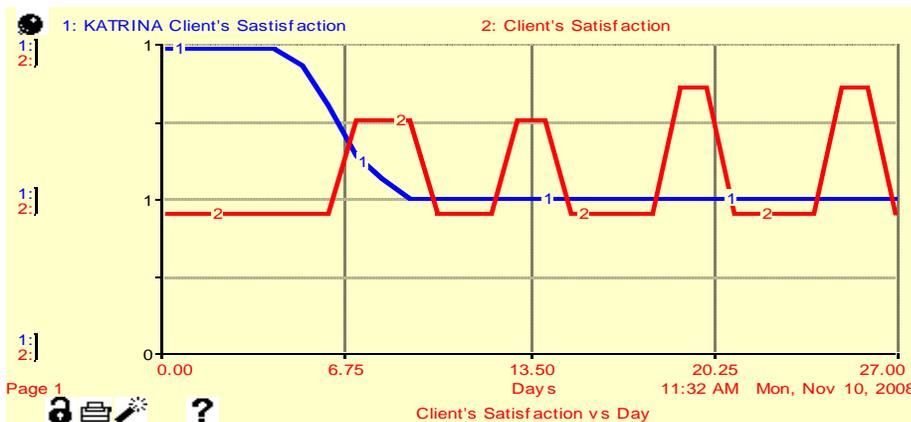
In real data “Opened Cases” ranged from 0 to nearly 16,200 cases. Simulation shows data ranged from 0 to 29,210 cases.



**Figure 24. “DSHR”: Reference Mode vs. Simulation. Author’s Elaboration, 2008.**

In real data reports, “DSHR Capacity” personnel ranged from 0 to nearly 14,067 people. Simulation results shows DSHRs ranged from 0 to 14,093 people.

For the key variable “Opened Cases” it can be seen that the behavior of the simulation doesn’t follow the same pattern as the reference mode. That is, because there are 11 days for which the report of data provided by the ARC for the relief operation is lacking this variable. The number of people that leave a shelter represented by the variable “Shelter Leaving Rate” depends directly on “Opened Cases”. “Shelter Leaving Rate” shows outflows of people beginning the 6<sup>th</sup> day. The number of staff in charge of processing the cases is represented by the variable “DSHR Capacity”. DSHR personnel were being deployed from the 3<sup>rd</sup> day of the relief operation. The simulated variable “Opened Cases” shows the processing of cases from the 5<sup>th</sup> day, which is consistent with the departure of people in shelters and the DSHR assigned to the relief operation.



**Figure 25. “Client's Satisfaction”: Reference Mode vs. Simulation. Author’s Elaboration, 2008.**

This behavior was assumed. In the Katrina reference mode it was presumed that the satisfaction of people diminishes each day during the relief operation, based in news reports of

abuse and violence inside the ARC shelters. It was corroborated by SPSS AnswerTree™ analysis that at its lowest, 79.6% of the people in shelters had a good perception of the service received by the ARC during the relief operation in terms of financial assistance, mental health care and food provided. The simulated model shows that “Client’s Satisfaction” presented several fluctuations over time. It means there were periods during relief operation were people experienced a high level of satisfaction: an 86.58% maximum percentage value of satisfaction was reached (see appendix G).

## 6 Using and Interpreting the Model

The model runs directly from a control panel designed for input of data by the decision-maker for ease scenario creation. Each subsystem of this model has its own control panel. The user can vary the input values of the model variables represented in the control panel as sliders, switches and knobs.

### 6.1 Key variables in the Katrina operation estimated by “other sources” vs. SQRC model results

Table 2 shows a comparison between other sources in the literature and the SQRC simulation’s results. The initial input value for “Total Population Affected” was set based in the value estimated by the CRS. Discrepancies were found between sources. Boyd et al. estimated that 1,000,000 evacuated before the hurricane hits. To match Boyd (2007), the SQRC model must be initialized at least in 2.5 million of Total Population Affected to generate the values they estimated for evacuated population. For that reason Boyd (2007), values don’t match the SQRC model values. However, FEMA and Boyd estimated numbers for the people that required shelter are remarkably similar to those projected by SQRC.

**Table 1. Comparison Evacuated Population: “Other Sources” vs. SQRC Model. Cruz (2008).**

<b>Population</b>	<b>Boyd, E. (2007)</b>	<b>FEMA (2007)</b>	<b>CRS (Congressional Research Services) (2005)</b>	<b>SQRC Model projection</b>
<b>Total Affected Population (LA, MS, AL)</b>	NA	NA	711,698	<b>711,698</b>
<b>Total Evacuated Population Before</b>	1,000,000	NA	NA	<b>393,590</b>
<b>Total Evacuated Population During</b>	100,000	NA	NA	<b>3,512</b>
<b>Not Evacuated Population</b>	130,000	NA	NA	<b>257,000</b>
<b>People in Shelter</b>	67,800	62,000	NA	<b>67,585</b>
<b>Evacuated Population after</b>	780,353	1,040,000	NA	<b>667,567</b>

## 6.2 MODEL VERIFICATION

The model was verified to be accepted and used to support decision making. With verification, it was ensured that the model program was correct and did not contain logical errors; the specification was completed and mistakes were not made in implementing the model (Macal, 2005).

## 6.3 MODEL VALIDATION WITH A DIFFERENT HURRICANE EVENT

This step involved the testing of the model as to whether it replicates the behavior of the real-world system. This model was validated by comparing the simulated results with the data provided by the American Red Cross for the **Rita Hurricane** disaster. Demographic data from the population living in the region affected by Rita was input into this model to validate the structure and the relationships. If the model is reasonable and valid, the known reference modes for Rita would be close enough to be able to be useful for decision making. Upon entering the demographic data for the Rita affected region, the simulation results mimic very closely the behavior of Rita.

The time horizon of this relief operation was 17 days long. Rita struck on 24 September, 2005 between Sabine Pass, Texas and Johnsons Bayou, Louisiana, as a Category 3 hurricane on the Saffir-Simpson Hurricane Scale. The affected areas were: Arkansas, South Florida, Florida Panhandle, Louisiana, Mississippi and Texas (Wikipedia).

### Simulation Control Parameters

1. Length of Simulation: From 0 to 17 days. This time horizon corresponds to the duration of the Rita Hurricane Operation and would correspond to a large disaster operation.
2. Interval of Time between calculations:  $DT = 1.0$  day.

Figure 26, Figure 27, Figure 28, Figure 29, Figure 30, Figure 31 and Figure 32 show the comparison between real data and simulated data for the model runs. Again, the blue line represents the behavior of each key variable during relief operation of Rita hurricane and the red line represents the results of the model simulation.

The X-axis has the time of the simulation in days. The Y-axis represents the value of the key variable both simulated and real at each time. Graphs for key variables suggest an acceptable behavior between the simulation and real data. Both graphics follow a similar pattern of behavior. Data points of the simulation remain in a similar range in comparison to the real data. Because of the enormous fluctuations presented by the real data reported by the ARC, a smoothing method was applied with the objective of diminishing the noise of the data set. A smoothing procedure will change (soften) the fluctuations to represent a smooth curve instead that follow the trends of the behavior (see appendix J).



**Figure 26. "Shelter Incoming Rate": Rita Reference Mode vs. Simulation. Author's Elaboration, 2008.**

The real data for "Shelter Incoming Rate" ranged from 0 to nearly 45,931 people. The simulation shows data ranged from 0 to 29,100 people.



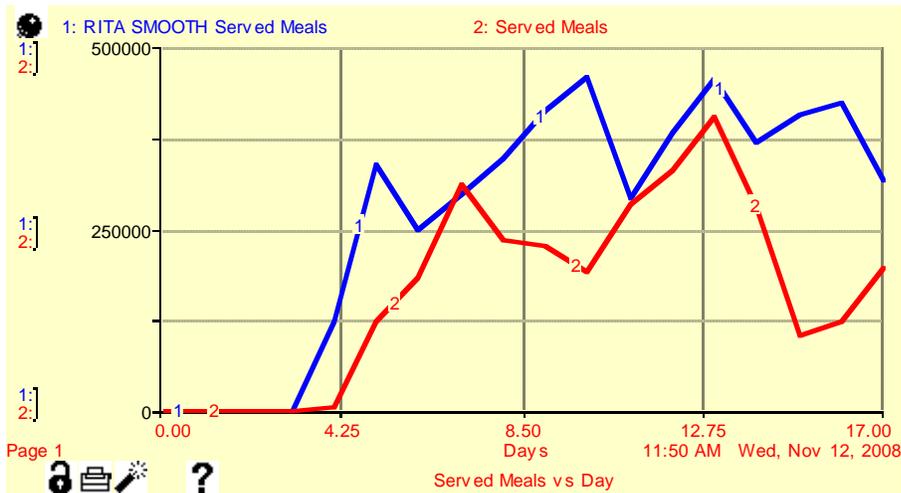
**Figure 27. "Shelter Leaving Rate": Rita Reference Mode vs. Simulation. Author's Elaboration, 2008.**

The real data for "Shelter Leaving Rate" ranged from 0 to nearly 41,292 people. The simulation shows data ranged from 0 to 33,100 people.



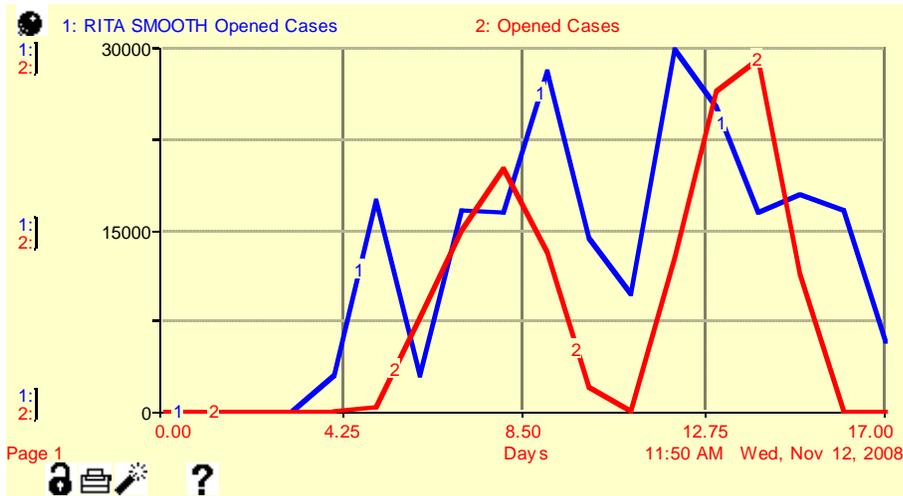
**Figure 28. "Opened Shelters": Rita Reference Mode vs. Simulation. Author's Elaboration, 2008.**

In real data "Opened Shelters" ranged from 0 to nearly 301 units. Simulation shows data ranged from 0 to 246 units.



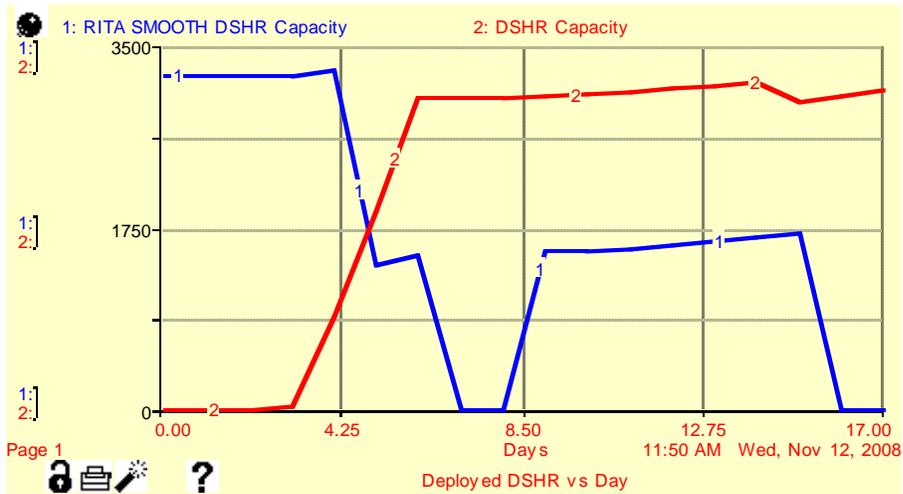
**Figure 29 "Served Meals": Rita Reference Mode vs. Simulation. Author's Elaboration, 2008.**

In real data "Served Meals" ranged from 0 to nearly 461,599 units. Simulation shows data ranged from 0 to 405,507 units.



**Figure 30 "Opened Cases": Rita Reference Mode vs. Simulation. Author's Elaboration, 2008.**

In real data "Opened Cases" ranged from 0 to nearly 29,994 cases. Simulation shows data ranged from 0 to 29,210 cases.



**Figure 31. "DSHR Capacity": Rita Reference Mode vs. Simulation. Author's Elaboration, 2008.**

In real data "DSHR Capacity" ranged from 0 to nearly 3351 people. Simulation shows data ranged from 0 to 3,179 people. Here it is necessary to remember that the Rita operation was unusual in many aspects. Hundreds of the DSHR were already deployed in the field due to the Katrina operation. Of course, for the simulated model all events are separate, and begin from zero staff in the field.

The model presented here is capable of simulating a situation and serve as a planning tool for decision makers based on demographic characteristics of the population in the affected zone.

## **7 Conclusions regarding dynamic hypothesis**

This section summarizes the conclusions the authors arrived regarding the dynamic hypothesis set up at the beginning of this study.

### **Hypothesis 1**

- **Increments in Meals, Financial Assistance and Mental Health Care Scenarios**

Several scenarios were run using several increments for each resource involved in the measurement of the client's satisfaction (served meals, delivered financial assistance and DSHR Capacity) tested separately. Scenarios show that no change is produced in this key variable

- **Reductions in Meals, Financial Assistance and Mental Health Care Scenarios**

The scenarios were run using several reductions for the resource variables related with the provision of financial assistance or mental health care specified before shows that no change is produced in client's satisfaction. A reduction in the provision of meals began to be critical above 50%

.This shows that in order to maintain an acceptable level of satisfaction between the evacuated clients, the ARC could reduce the provision of financial assistance and mental health care in any proportion and then the level of satisfaction would remain in the rank of the original values. However, reducing the provision of meals (which is in a way something that could be foreseeing as food is a basic need of the human being) to the affected people causes a reduction in the level of satisfaction when this decrease is executed above the 50% of the original values. Therefore, this scenario shows how important the provision of meals during a relief operation is as it leads to a drastic reduction in the client's satisfaction levels which in turn reduces the public reputation and eventually public donations of time and money.

- **Increments in Combined Resources Scenarios**

The scenarios were run using several increments for the combined variables involved in the measurement of client's satisfaction which resulted in increments in the perception of the quality of service provided to the evacuated clients. This shows that the ARC would need to increase the provision of meals, financial assistance and mental health care in a 75% and reduce, in the same proportion, the training time of its personnel to reach a level of satisfaction of 90.81% for the evacuated people. However, this would be a too high increment to achieve his goal. Therefore, this scenario shows that the level of satisfaction that the ARC would need in order to increase the client's satisfaction levels is not cost-effective for the organization.

- **Reductions in Combined Resources Scenarios**

In order to maintain an acceptable level of satisfaction for the evacuated clients, the ARC could reduce the provision of meals, financial assistance and mental health care below a 20%. However, reducing the provision of these resources above this value cause a consider reduction in the level of satisfaction.

### **Hypothesis 2**

- **No DSHR Scenario**

The simulation was run without DSHR, which shows how the provision of meals, financial assistance, the processing of cases and the client's satisfaction is severely affected. Running the model without DSHR shows that the number of served meals, opened cases and delivered financial assistance turn to 0. The client's satisfaction reaches the lowest value possible, 45.45% which happens when no meals, no financial assistance and no mental health care is provided as a result of No DSHR availability. Therefore, 45.45% is the client's satisfaction level achieved when no financial assistance and food are provided. Therefore, the results validate the hypothesis that the amount of DSHR deployed impact the level of satisfaction due to the effectiveness of services provided to the people in shelters and the rate of reporting and opening of cases.

- **Relationship with DSHR Training Efficacy**

Other scenarios were tested making increments and reductions in the "Trained Delay Duration" in order to illustrate the impact that a delayed and overdue deployment would have on the client's satisfaction. The scenarios were run using several increments in the "Trained Delay Duration"

### **Reductions in "Trained Delay Duration"**

Reduction in the training time began to be critical above 20%. In this table "Client's Satisfaction" in the Status Quo Scenario (Baseline) is compared to the SQRC simulation results obtained from the reductions in "Trained Delay Duration" Scenario. This shows that in order to maintain an acceptable level of satisfaction for the evacuated clients, the ARC could reduce the training time above a 20%. Therefore, the results demonstrate that the hypothesis that the amount of DSHR deployed impact the level of attention provided to the people in shelters and the rate of reporting and opening of cases for a relief operation, is shown for the actual structure of the model.

### **Hypothesis 3**

The simulation was run changing race and income proportions (for example of non Hispanic white people with income above \$10,000 and less than \$40,000). The hypothesis that race and income have an important effect was validated. A change in the proportion of non Hispanic white people whose income was more than \$10,000 and less than \$40,000 and who rent a property results in an increase in the of people that evacuated and require shelter. It means that if a person is a property renter, the higher the income the more likely it is that person will evacuate on time. Therefore, the results demonstrate that the hypothesis holds. An increase in the proportion of people with certain demographics characteristics and profile has a significant effect in the number of people that are requiring shelters and in turn increase the numbers of trained staff and volunteers that need to be ready for deployment in anticipation.

The main contribution of this work is that of investigating the structure of the system and building the model with real parameters observed in real victims found in diverse databases and then putting together this enormous system simulation, validate the structure with a different event real reference modes and being able to mimic the behavior. Therefore, one could assume

that for any given hurricane given census data disaster managers could come to the controls and simulate the patterns of evacuation and requirements for shelter, as well as the needs for volunteers and other supplies.

Further research introducing formal experimental designs to test additional factors and the magnitude of the effects is needed to understand the dynamics of this very large and complex system.

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