Lessons Learned from the Design of the Decision Support System Used in the Hurricane Katrina Evacuation Decision

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Abstract

Computer-based decision support systems are increasingly used to aid human decision makers in dynamic, uncertain, time-stressed and high-stakes contexts. The decision of whether, and if so, when to evacuate New Orleans as Hurricane Katrina approached landfall is a prime example. An evaluation of the "HURREVAC" decision support system (DSS) used during Katrina is presented. The evaluation is based on real-time screen-shots of the graphical and numerical information displayed to emergency response managers and other users. While the system is clearly an improvement over methods used prior to advances in information technology and real-time networking, design deficiencies were identified as well. The most crucial of these concern insufficient resources provided by the design to support users in reasoning effectively about uncertainty, and about the interactions among uncertainty and other aspects of the decision situation. The paper concludes by providing lessons learned and by identifying needs for cognitive engineering research to improve future DSS design in operational contexts.

INTRODUCTION

Hurricane Katrina made landfall in southeast Louisiana at 6:10 am local time on Monday, August 29, 2005 as a large category 3 hurricane with sustained winds of approximately 125 mph. With a central barometric pressure of 920 mb, Katrina was the third strongest hurricane ever to make landfall in the US. The damage and loss of life resulting from Katrina is catastrophic, with estimates of over 1,300 fatalities, over a quarter of a million homes damaged or destroyed, and estimated financial losses on the order of $100 billion. By these measures Katrina was the costliest hurricane in US history and one of the most deadly (Johnson, 2006).

Much discussion and even controversy still exists today about the effectiveness of the government's response to Katrina at the local, state and federal levels. Much if not most of this discussion centers on post-landfall events in the city of New Orleans. Importantly, it is crucial to stress that the analysis presented here does not touch on these issues. Instead, the focus is on drawing lessons learned from the design of the computer-based decision support system provided to emergency response managers and other users as Katrina approached landfall. As such, this paper is also not an evaluation of weather forecasts provided by the National Weather Service (NWS) and National Hurricane Center (NHC). The Department of Commerce has already provided such a retrospective assessment by a team of qualified meteorological, weather forecasting, and other relevant experts (Johnson, 2006). Relevant excerpts from that report are cited in the following.

Finally, it is also important to stress that this paper does not consist of an assessment of the quality of evacuation decision making in Katrina. In the United States, such decisions are made by elected politicians, based not only on information provided to them by emergency response teams monitoring storm progress and forecasts, but also a potentially very long list of additional concerns including political, social, emotional, financial and other factors. Additionally, this information must be considered in light of balancing the tradeoff between making Type I and II errors: Issuing either an overly severe evacuation order than was necessary (resulting in significant costs and risks to life associated with evacuations themselves, and engendering a potentially dangerous "cry wolf" attitude among the public), or, by issuing a less severe or delayed evacuation order than was appropriate (resulting in significant storm-related costs and risks to life).

So although hurricane evacuation decisions clearly have dimensions transcending the purview of cognitive engineering expertise, it remains the case that cognitive factors dealing with the effectiveness of acquisition, integration and presentation of information about the current and predicted state of the environment places an upper limit on the quality of these decisions. These latter issues constitute the focus of this paper.

NWS PERFORMANCE IN KATRINA

In June, 2006, the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), National Weather Service published a 50-page report consisting of an evaluation of the performance of the NWS during Hurricane Katrina. The report was authored by David L. Johnson, Assistant Administrator for Weather Services for the NWS, describing the results of a team chartered to assess NWS performance during the event. Overall:

> The team found that the NWS performed exceptionally well before, during, and after Katrina. This was confirmed by the overwhelmingly positive feedback from users of NWS products and services. Overall, the timeliness and accuracy of NWS forecast products were well above performance standards. Throughout the event, NWS field offices provided high quality forecast and warning information to the public, mass media, and emergency management officials. Feedback from all groups was very positive. (Johnson, 2006, p. 37).

The evaluation team also analyzed the accuracy of specific hurricane track forecasts, concluding:

> NHC's overall performance during Katrina was excellent. The NHC forecasts provided a consistent message regarding the forecast track and intensity of Katrina. NHC forecasts and discussions were timely, and they effectively conveyed the level of confidence in the forecast which enhanced the utility of NWS information during this event. . . . NHC's official track forecasts for Katrina issued within about two and a half days of landfall in Louisiana were exceptionally accurate and consistent. The forecast errors were considerably less than the average official Atlantic track errors for the 10-year period 1995-2004. Every official forecast that was issued beginning at 5 p.m. EDT on August 26 showed a track crossing the coast of Mississippi and/or southeastern Louisiana. The NHC does not explicitly issue forecasts for the precise location or timing of landfall. The official track forecasts issued 12, 24, 36, and 48 hours prior to 8 a.m. August 29 were in error by only 19, 24, 32, and 56 nautical miles, respectively, an improvement of 31 to 44 percent over the corresponding average track errors for 1995-2004. These errors are less than half the magnitude of the corresponding 10-year averages (1995-2004) among all Atlantic basin forecasts. Meanwhile, the track errors for the 72 to 120 hour periods were somewhat higher but still 10 to 25 percent below the average errors for the past five years. The relatively small errors at 12-48 hours greatly helped in the issuance of accurate and timely coastal watches and warnings. (Johnson, 2006, p. 12).

Apparently supporting these assessments, the report also contains a figure depicting the 72-hour forecast track for Katrina issued on the NHC website at 11pm EDT August 26th, 56 hours prior to the hurricane making landfall, as shown in Figure 1.

Figure 1 apparently buttresses the overall assessment that NHC forecast performance was, by all technical measures, excellent, as it apparently shows that the most likely track for Katrina, as it was forecast 3 days ahead of time, would pass extremely close to New Orleans. Figure 1 appeared at the time on not only the NHC website for public use, but also as one component of the decision support system used by emergency response managers and other users responsible for advising politicians on evacuation decision making in New Orleans, and in many other threatened areas as well.

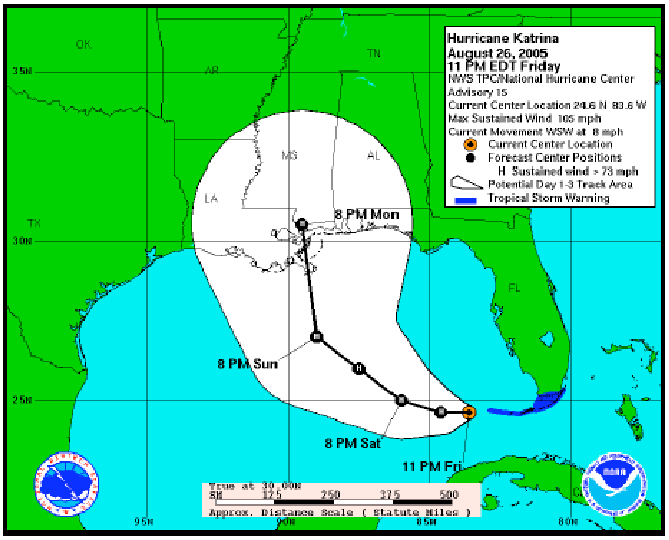


Figure 1. Graphical depiction of NHC 72-hr forecast track 56 hours prior to landfall. The white shading indicates the "cone of uncertainty." From Johnson (2006).

THE HURREVAC DECISION SUPPORT SYSTEM

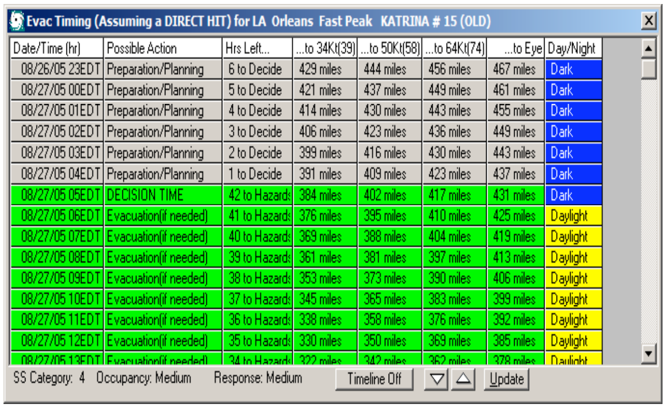
The support system used by emergency response managers and decision makers in the Gulf Coast area, including New Orleans, during Hurricane Katrina is called HURREVAC. From the Federal Emergency Management Agency (2006) website describing this computer-based system:

> HURREVAC stands for "HURRicane EVACuation" and is a restricted-use computer program funded by FEMA and USACE for government emergency managers to track hurricanes and assist in evacuation decision-making for their communities. This real-time data analysis tool allows state and local emergency management officials to make prudent and informed decisions based on information

> developed during the FEMA Hurricane Evacuation Studies process and real time forecast data distributed by the National Weather Service (NWS) and the Tropical Prediction Center/National Hurricane Center (NHC).

HURREVAC contains the same types of displays as shown in Figure 1, in addition to textual overlays that aid the user in determining necessary evacuation times, as shown in Figure 2. The logic behind the system is (from the same FEMA website) as follows:

> 1) The arrival of tropical storm winds (34 knots or 39mph) in your area is computed using the NHC projections with adjustment for a direct-hit or worst-case approach to your community.
>
> 2) Evacuation Clearance times (the time it takes to get residents out of storm surge vulnerable areas are computed using Saffir-Simpson Scale category of storm, response of the public, and occupancy readings for the area. The basic data for the clearance times is produced by a local Hurricane Evacuation Study, usually performed by the Corps of Engineers and FEMA.
>
> 3) The clearance time duration should be subtracted from the tropical storm winds arrival time to reach a suggested Evacuation Decision Time. Other factors, such as time of day, must be included in the evacuation decision in order to be effective. This approach is based on the need to have the at-risk population out of vulnerable areas before tropical storm winds reach the coast and weather and roadway conditions become unsafe.



Evac Timing (Assuming a DIRECT HIT) for LA Orleans Fast Peak KATRINA # 15 (OLD)

Date/Time (hr)	Possible Action	Hrs Left...	...to 34Kt(39)	...to 50Kt(58)	...to 64Kt(74)	...to Eye	Day/Night
08/26/05 23EDT	Preparation/Planning	6 to Decide	429 miles	444 miles	456 miles	467 miles	Dark
08/27/05 00EDT	Preparation/Planning	5 to Decide	421 miles	437 miles	449 miles	461 miles	Dark
08/27/05 01EDT	Preparation/Planning	4 to Decide	414 miles	430 miles	443 miles	455 miles	Dark
08/27/05 02EDT	Preparation/Planning	3 to Decide	406 miles	423 miles	436 miles	449 miles	Dark
08/27/05 03EDT	Preparation/Planning	2 to Decide	399 miles	416 miles	430 miles	443 miles	Dark
08/27/05 04EDT	Preparation/Planning	1 to Decide	391 miles	409 miles	423 miles	437 miles	Dark
08/27/05 05EDT	DECISION TIME	42 to Hazards	384 miles	402 miles	417 miles	431 miles	Dark
08/27/05 06EDT	Evacuation(if needed)	41 to Hazards	376 miles	395 miles	410 miles	425 miles	Daylight
08/27/05 07EDT	Evacuation(if needed)	40 to Hazards	369 miles	388 miles	404 miles	419 miles	Daylight
08/27/05 08EDT	Evacuation(if needed)	39 to Hazards	361 miles	381 miles	397 miles	413 miles	Daylight
08/27/05 09EDT	Evacuation(if needed)	38 to Hazards	353 miles	373 miles	390 miles	406 miles	Daylight
08/27/05 10EDT	Evacuation(if needed)	37 to Hazards	345 miles	365 miles	383 miles	399 miles	Daylight
08/27/05 11EDT	Evacuation(if needed)	36 to Hazards	338 miles	358 miles	376 miles	392 miles	Daylight
08/27/05 12EDT	Evacuation(if needed)	35 to Hazards	330 miles	350 miles	369 miles	385 miles	Daylight
08/27/05 13EDT	Evacuation(if needed)	34 to Hazards	322 miles	342 miles	362 miles	378 miles	Daylight

SS Category: 4 Occupancy: Medium Response: Medium

Figure 2. HURREVAC call-up window as it appeared at the same time as the screen shown in Figure 1 (11pm Friday evening Aug. 26), showing a recommended evacuation time of about daybreak, Saturday morning. Katrina made landfall about daybreak Monday morning, about 50 hours later.

The information contained in Figure 2 (see caption for details) indicates that, for New Orleans, an evacuation decision would need to be made at daybreak, Saturday morning Aug. 27th. Yet New Orleans Mayor Ray Nagin issued his first evacuation order at 5pm that day. While we can not know what factors prompted Mayor Nagin to act (and not act) when he did, we can at least consider the decision situation as it would have appeared to emergency response managers and decision makers via the HURREVAC DSS.

HURREVAC users were presented with forecast track information as it appears in Figure 1, and the evacuation time guidance presented in Figure 2. It is clear that Figure 2 provides support for deciding when a decision needs to be made, but little if any support for what that decision should be. This can be seen from reading the top (white on blue) text in the figure: "(Assuming a DIRECT HIT) for LA ORLEANS." That is, the DSS design provided users with evacuation timing guidance as shown in the table shown in Figure 2. This advice, however, assumes that the uncertain event that users were attempting to prepare for will occur with certainty.

On the FEMA HURREVAC website, one learns that this aspect of the system's design represents a "worst case scenario" to users (FEMA, 2006). The implication of this statement seems to be that providing guidance in this way reflects, in some sense, the most conservative or risk-averse approach to decision support in uncertain conditions. And considering, in retrospect, the devastating effects of Katrina on New Orleans, one may be tempted to agree with this view. However, it bears keeping in mind that HURREVAC users at locations across the entire gulf coast, from Florida to Texas, were also viewing evacuation advisories from the DSS "assuming direct hit" for their own locations as well. At the time depicted in Figure 1, should HURREVAC users as far west as the Texas/Louisiana border and as far east as the central Florida panhandle have been thinking identically about whether to advise evacuations?

Because the answer to this question is clearly no, presumably any warranted uncertainty users should consider about whether or not Katrina would strike their own locations would license them to influence their decision making, and possibly also their decision horizons. How they should do is a cognitive challenge that does not appear to have been explicitly supported in HURREVAC design. However, while no explicit support dedicated to this aspect of the decision task seems to have been provided, the DSS did at least make forecast uncertainty information available to users. This information about track uncertainty could then be used in conjunction with the advisory display shown in Figure 2, in order to make decisions and adjust time horizons in accordance with, not only the worst case scenario, but also with the chance of this scenario actually occurring.

Specifically, the uncertainty associated with an NHC track prediction is depicted in HURREVAC in two ways. The first is the white "cone of uncertainty" shown in Figure 1. The second is a different display page that can be called up to view the numerical strike probabilities provided at each forecast update by the NHC. Figure 3 presents a screen shot of this combined graphical-numerical display page as it appeared at the same time as the graphical track prediction shown in Figure 1.

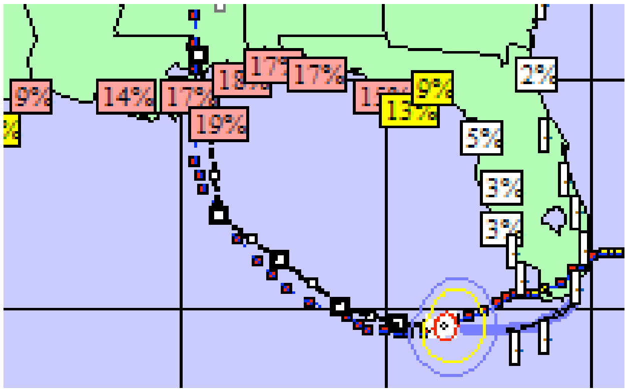


Figure 3. An expanded view of the forecast Katrina strike probabilities for various Gulf Coast locations at the same time depicted in Figure 1. The forecast strike probability for New Orleans is 17% at the same time the HURREVAC DSS was also displaying Figure 1 on a separate page.

At least two issues arise when considering Figures 1 and 3 in parallel. First, some reviewers of this paper and its earlier drafts mentioned that they were struck by how low the strike probability for New Orleans was actually estimated to be at the time depicted in Figure 1 (17%). Second, note in Figure 3 the relatively high entropy, or variance, of the displayed probability distribution over the broad range of locations shown. While the cone of uncertainty shown in Figure 1 communicates this high entropy to some extent, it does so in a relatively broad-brush fashion as compared to the numerical estimates shown in Figure 3. Apparently, a binary threshold was used to define which areas in Figure 1 should be displayed inside and outside the cone of uncertainty, with a resulting information loss.

SOME LESSONS LEARNED AND COGNITIVE ENGINEERING RESEARCH NEEDS

While the availability of HURREVAC is no doubt an improvement over hurricane evacuation decision support methods used prior to advances in information technology and real-time networking, some deficiencies of the design are also evident. The most crucial of these concern insufficient resources provided by the design to support users in reasoning effectively about uncertainty, and about the interactions among uncertainty and other aspects of the decision situation. More specifically:

1) In uncertain situations, it may be tempting to base decision support on a worst-case scenario in the name of caution or safety. However, any faith that this approach will result in the most effective support for human decision making may be misplaced. Adopting this posture is akin to designing event detection technologies (e.g., magnetometers, medical tests, collision alerts, smoke alarms) with highly conservative threshold (beta) values. In such cases the burden passes to the human to identify the true "hits" among a sea of false alarms. In the case of HURREVAC, an analogous burden passes to the user to determine how to benefit from advice assuming a worst case scenario, when the probability of that scenario may in fact be low. More research is needed on how to make use of distributional information rather than point (e.g., worst-case) predictions to design improved technology to support decision making under uncertainty. This is doubly true of decision support technologies in highly dynamic, high-stakes contexts.

2) A picture may well be worth a thousand words. But in reality, most are not. In particular, caution must be taken when a decision is made to present a graphical depiction of data (Figure 1) with significantly lower information content than might be communicated by other means (Figure 3). It may well be the case that a purely graphical, rather than graphical-numerical, presentation of information could be found that is superior to both of the displays shown in Figures 1 and 3. However, additional research on the effective presentation of uncertain information is clearly needed to address this and related questions.

3) Certain aspects of the HURREVAC DSS (some of those described in this paper and others not, such as the effective use of color, etc.) could have benefited by existing cognitive engineering and human factors techniques, principles or expertise. Future case studies of high-profile events, such as the one presented here, are needed. Such studies may serve a dual role in both advancing our discipline and in (hopefully) bringing the fruits of our labors to the attention of those who might benefit by them.

ACKNOWLEDGMENTS

Portions of this work were first presented at the NSF Workshop "Doing Something About the Weather" held at the Naval Postgraduate School (NPS) in Monterey, CA, January 2007. I would like to thank workshop organizer Prof. Eva Regnier for helpful discussions on hurricane evacuation decision making, and Prof. Patrick Harr of NPS for helpful discussions on tropical cyclones and their prediction.

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