A Dynamic Delphi Process Utilizing a Modified Thurstone Scaling Method: Collaborative Judgement in Emergency Response

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ABSTRACT

In an extreme event or major disaster, very often there are both alternative actions that might be considered and far more requests for actions than can be executed immediately. The relative desirability of each option for action could be a collaborative expression of a significant number of emergency managers and experts trying to manage the most desirable alternatives at any given time, in real time. Delphi characteristics can satisfy these needs given that anyone can vote or change their vote on any two options, and voting and scaling are used to promote a group understanding. Further utilized with Thurstone's Law of Comparative Judgment, a group decision or the range of acceptability a group is willing to consent to, can be calculated and utilized as a means of producing the best decision. A ubiquitous system for expeditious real-time decision making by large virtual teams in emergency response environments is described.

Keywords
Delphi, emergency response system, Thurstone's Law of Comparative Judgment, ubiquitous, group support system, paired comparisons, incomplete data, time series, judgment, collaboration, decision support.

INTRODUCTION

In an emergency environment, new requests are being made as the dynamics of a situation unfold. Re-prioritization of requests in increasing importance reflects the needs of the situation. In addition, a list of options is both increasing as new action requirements emerge, and decreasing as actions are being taken to satisfy these needs. An emergency response requires that a large group of individuals work collaboratively on these types of tasks together for the life of the emergency. Numerous challenges arise with decision support systems managing the needs of not only emergency response, but of any dynamic environment where uncertainty and changes in decisions over time need to be accurately reflected.

There will be situations in particular domains requiring expertise. This is where only subsets of the networked individuals can make high confidence judgments about the relative preference for any two given options. For example, out of the entire group collaborating during an emergency response, there may be only a handful of bioterrorist specialist knowledgeable about anthrax. These individuals would handle problems, as would other professionals, specific to their expertise creating a solution-centered structure. An advantage is that no particular geographic region would need to have expertise in all possible emergency situations. Groups could be experts who are situation specific. In the case of a hurricane, there could be a specialized hurricane emergency response group of experts who are educated, experienced and fully qualified to deal with the problems of the situation. This is different from our present state of affairs where, for example, if a hurricane destroys an area, the local governmental officials are required to act as coordinators and experts in the field and react accordingly.

History shows that this is not an effective assumption as local governmental officials cannot have expertise in all potential problem areas. Actually, it's unrealistic to believe that our public officials, who can change with every new election, have the necessary training, background, experience and expertise in which to respond to such calamity. It would be more advantageous for the local people, and for society, to have qualified people in these positions not required to live amongst them, but available to assist in any location by use of electronic media. It is likely this would be cost beneficial because disasters cost a lot of money and mistakes amplify the costs of recovery.

Our fundamental objective is to design a group collaborative system that allows a large group of professionals to arrive at decisions that are better than any one single individual in the group could do. And to allow that group to function as quickly as a single individual might function in a command and control system dealing with complex problems occurring in a major emergency or disaster. This system will account for changing events, opinions, judgments and decisions over the duration of the event.

The remainder of this paper is structured such that, in the Background we cover techniques chosen for our methodology and show why we believe this to be the best approach. Delphi is described along with Thurstone's Law of Comparative Judgment. Modification is through the implementation of the dynamic features for time and uncertainty. These are given by a partial least squares solution for the incomplete data set and a method for time series detecting changes based on merit.

Based upon concepts from the Delphi Method (Linstone and Turoff, 1975; Wish and Carroll, 1975), we propose an approach to dynamic voting (Turoff, et al., 2002) that turns Delphi into a continuous asynchronous process where large groups of participants can engage in a group decision process. This process has been characterized in the past as a Social Decision Support System (Turoff, Hiltz, Cho, 2002). Conclusive statements are made outlining the broader impacts of the system. We end with further discussions considering high reliability organizations and virtual organizations taking other viewpoints from what has been presented.

BACKGROUND

Scaling Technique and Voting

We have chosen the paired comparison approach to solicit judgments, not only because it reflects greater accuracy in human judgment than traditional methods (Miranda, 2001, Torgerson, 1958), but also because it allows users to focus on which items they wish to vote on or to focus on incremental changes. Our objective is to utilize voting and scaling to promote the understanding of groups and teams to collectively comprehend the implications of their subjective judgments of a list of items about which they are deliberating for the purpose of arriving iteratively at a result exhibiting collective intelligence (Hiltz and Turoff, 1978). We are not treating scaling as a measure of a fixed human judgment about a set of preferences but one that can dynamically change as a result of discussion and feedback on a joint qualitative and quantitative structure. According to Thurstone (1927b), " …qualitative judgments of a rather intangible sort, loaded usually with personal opinion, bias, and even strong feeling, and regarded generally as the direct antithesis of quantitative measurement, are nevertheless amenable to the type of quantitative analysis which is associated historically with psychophysics."

In our case we do not require that everyone participating votes on all of the items. We consider the appropriate voting mechanism to be a relative comparison of two objects in the list because at any moment not every participant may feel able to compare all the alternatives. We are addressing a situation where information pertinent to the decision may occur at any time simultaneously with the problem solving process, and where people may change their preferences at any moment due to either external inputs or internal discussion inputs. To allow this to be accomplished, we have evolved a dynamic voting version of the Thrustone's Law of Comparative Judgment (Thurstone, L.L., 1927a) which allows changes to the items in the list and to the voting, at any point in time.

Delphi

Studies have been conducted demonstrating that the Delphi approach is an effective system for group decision support (Linstone and Turoff, 1975, Hiltz and Turoff, Li, et all, 2002). Delphi systems are used by large groups of people to solve complex problems (Linstone and Turoff, 1975). Computers and the Internet have enhanced the original concept by allowing for computer mediated asynchronous communication that's now accessible globally by any group member. Add this flexibility to the user being able to participate in any phase of the decision process at any time, and the Delphi concept is being revolutionized. There are many group decision support systems, but what differentiates a Delphi system from any other is a unique set of characteristics (Linstone and Turoff, 1975, Turoff and Hiltz, 1996, Li, et al, 2001):

- Improve idea generation and resulting group problem solving
- Self organize the contributed content
- Anonymous user ability
- Facilitate equal participation of all users
- Reduce information overload
- Facilitate collaborative problem solving
- Utilizing voting to focus discussion on areas of disagreement and uncertainty
- Facilitate understanding by enhanced visualization through the use of scaling methods
- Facilitate comprehensive idea evaluation
- Allow exchange of tacit knowledge among professionals
- Allow changes in judgments at any time due to internal or external feedback
- Allow simultaneous modification of alternatives being considered

Prior work in this area (Li, et al. 2003) focused on a system where the list was first derived and fixed before the dynamic voting process was introduced which in essence resulted in a two-–phased Delphi process that had a dynamic voting process with respect to the fixed list and with a fixed number of voters.

METHODOLOGY

Thurstone's Law of Comparative Judgment

Thurstone's Law of Comparative Judgment takes two items and compares them based on some stimulus (Thurstone, 1927a). Paired comparison judgments give a more accurate reflection of a rank order when taking numerous items into consideration (Miranda, 2001, Torgerson, 1958). This measurement of one item against another based on a stimulus is defined as the discriminal process which is measured on the psychological continuum. Thus there is no pre-existing scale in which to measure, but items are scaled one against the other. So, not only can additional information be inferred from a group, but also, the range of values acceptable to a group, the 'heterogeneity' can be determined (Thurstone, 1928).

A frequency matrix is created based on decision input and from this a table of percentages is calculated. Unit normal values replace the respective percentages. The end result is not only a rank order of the items, but a degree of preference that can be measured amongst the items in the list. For example, in a given set X = {a, b, c, d} of rank order (*a* > *b*> *c*> *d*), one can conclude that *a* is selected over *b*. In a rank order, these intervals are assumed equal and no more information can be derived. On the other hand, Thurstone's method gives degrees of difference. This difference determines if further investigation is required on the voted upon course of action. For example, the selection process of items to be chosen for a course of action, *a* and *b,* may be very close in judgment amongst the group indicating an area of agreement or a need for further investigation. Also, *a* and *b* could be very far apart from one another informing us that the majority selection voted for *a* and no further discussion should be prompted. The results have meanings that are interpreted based on the particulars of a situation.

When emergency responders are faced with triage and the difficult task of prioritizing of who gets aid first, a normal a rank order would be given indicating no difference between the degrees of adjacent choices. Conversely, Thurstone's method allows strengths to be calculated by determining the difference of the items based on their location of the scale. Thurstone's method takes in individual's ordinal (rank) data and calculates a single group interval scale. This gives more precise information reflecting the group's opinion on which the decisions were calculated from or indicates where the group stands on a particular issue. So, not only it would be possible to determine that babies in ICU should be rescued and evacuated first, but when compared to healthy people stranded at the Super Dome Coliseum, you would also know that there was a much greater desire for the babies to be evacuated over the healthy stranded civilians. This tells you that more resources should be dedicated or given higher priority for this in the event that other situations should arise where resources are requested.

Incomplete Data Sets and Uncertainty

Thurstone's Law of Comparative Judgment has primarily been used with complete data sets and in a fixed setting. Only a small percentage of a large population may be participating on one aspect of an emergency situation, while other small groups are working on other aspects of the same emergency situation. Professionals and experts are divided into many subsets of groups that interact together as a whole with one common goal: managing the emergency at hand effectively and efficiently. For example, only 10% of a population may form a group and vote completely on a course of action, but others may selectively vote on items of interest to them. An individual's expertise may cross over many groups qualifying them for some groups, but may eliminate them from additional groups. Professionals working within the zone of the emergency could lose communication leaving certain decisions to be made without them. Other experts globally located in safe zones could be fully utilized under these conditions. So, we are posed with the question of how to make the best inference given a small percentage of the population input (vote) on a course of action.
The procedure to be utilized was first presented by Gulliksen (1956) where he observed, "The general usability of paired comparisons, especially in fields such as sensation and value judgments, will be greatly enhanced by a precise method for utilizing all of the available data when dealing with an incomplete matrix." Decisions will be made given enough of the population in an area has voted and considered the alternatives.

As a disaster approaches, it is actually a complex decision process to try and determine who should be evacuated from what location and when. Additionally, the inputs to the decision should be from many different sources dealing with all the above factors that need to be considered. Uncertainty of when the disaster will hit presents the biggest problem. Estimates may change rapidly and frequently.

We can minimize this uncertainty by maximizing resources from many different professionals representing different organizations of organizational units, as well as different expertise, dynamically contributing their judgments which might change significantly as the hours go by. This is one example of a situation where it would seem to be desirable to have a large number of emergency responders able to contribute and change their views in a dynamic manner based upon their exchange of new information and reductions of uncertainty and ambiguity.

Dynamic Time Series Measurements

It is our intent to propose a Delphi system that is dynamic with respect to time series and that will reflect changes in decisions due to influential information that is presented along this time frame of irregular intervals. This is a direct reflection of the life of a decision process and human prerogatives. This system will have the ability (Fahrmeir, 1994) to produce the most recent and influential vote with time dependence. As time passes, judgment of items can change abruptly in response to incoming information. Most models don't allow a 'sudden change of events' to affect the process in an abrupt manner. Glickman (1999) derived a stochastic variance paired comparison model to overcome these challenges. In this model, comparisons of items in a list are made at time *t*. Time intervals are assumed equal and take on integer values. The calculations are such that if, at a point in time, $(i > j)$ then it is given a value of 1, and if $(j > i)$ then it gets a value of 0. These sudden shifts are detected as the variance of items grows large. This shows that through the difference, a preference probability is a function of the merit.

Methods such as these can to be brought together for a synergistic effect that can be applied to a real time decision making environment.

An Example: Hurricane Katrina

Hurricane Katrina, 2005 serves as an example. The event is divided by the environmental changes that called for dynamic decision making under the most volatile of conditions that occurred in New Orleans, Louisiana. These are separated into the following 5 phases:

Phase I: *Normal Preparations for Hurricanes - Friday, 72 hours until landfall*: New Orleans is no stranger to hurricanes. If not every year, every few years the area is confronted with an approaching hurricane. Normally, a neighboring area gets hit or the hurricane is categorized at such a low level that Louisiana, once again, gets away without suffering the much-feared consequences of 'living below sea level'. There are normal preparations that all Louisianans, tourist and public officials take prior to an oncoming hurricane. Usually, this early on during an approaching hurricane, its direction can change any number of ways and the projected path is narrowed down to about 1/3 the Gulf Coast region going anywhere from Texas, Louisiana, Mississippi, Alabama to Florida.

Phase II: Pre-Katrina - *Sunday, 24 hours until landfall*. New Orleans knew it was going to get hit hard. Katrina had elevated to a category 5 hurricane. Preparations for the worst went into effect.

Phase III: Post-Katrina - *Landfall Monday*. Late afternoon, the hurricane finally passed, New Orleans got hit hard, but the city made it through the storm unlike their most unfortunate neighbors in Mississippi, who were caught in the eye and devastated.

Phase IV: *The Levees Break - Monday Evening*. New Orleans residents and officials assess**ed** the damage from the storm. Unbeknownst to most, that evening, the levees broke and water was entering the city at an alarming rate, flooding 80% of the city.

Phase V: *After the Flood - Water Recedes*. Pumps removed most of the water in the city and officials formally assessed the damage. The city was virtually empty. There was no water, no electricity, and almost every survivor had been evacuated from the area.

This one event made for an unpredictable and ever-changing environment challenging decision makers with fluctuations calling for reprioritization constantly to meet the dynamic needs demanded of the current environment. Resource allocation, evacuation, and triage are just a few examples where this method described in this paper could have been utilized. On the local, state and national level during Hurricane Katrina, management of the situation was hindered by the lack of a way for government officials and experts to collaborate with dynamic decisions on an on-going real-time basis.

An example of use of the method presented in this paper using the problem of resource allocation and the distribution of generators supplied to government-established areas maintaining or running operations in the event of a power outage is presented. During phase I, the local officials would check and test their generators, and fill up on supplies like gas and oil. The overall count could change something like:

	Inventory: Working Generators	Inventory: Non-Working Generators	In Use Distributed	On Order	Lost Beyond Repair
Phase I Hurricane Alert	50	5	250	0	0
Phase II	40	15	250	100	0
Phase III	5	45	200	0	5
Phase IV	5	0	0	500	100
Phase V	0	0	5	1000	200

Table 1

Based on the information in Table 1, it is clear to see how the inventory could be drastically affected by the different phases of this catastrophic event. This would obviously be a factor in determining precedence of distribution. In the beginning, all 250 facilities are maintained with running generators ready, in place. With resources available inventory-wise, the overall 250 were still functioning after the hurricane hit the city with a few generators replaced.

New Orleans survived Hurricane Katrina: what they didn't survive was the failure of the levee system responsible for retaining the water from the city. Once the surge from the storm broke through the levees, water surged down the streets and eventually up over the roofs of some homes. All generators that weren't elevated were damaged beyond repair and obviously couldn't be used while others were incapacitated or unreachable. Some private businesses and government agencies, actually had their generators stored in their basements making them vulnerable to floodwaters. Worse yet, once the flood waters receded, the enormity of the damage was greater than anyone had anticipated and generators were now in demand more so than had been anticipated.

These types of decisions could be made quickly, efficiently and more effectively reflecting the needs to a greater extent given a scale, which could interpret degrees, which could then be translated into 'importance' indicators weighing on the priority. For example, the experts could find it much more important to have one of the 5 remaining generators during the last phases of the event, allocated to a hospital and another to a nursing home. Life threatening situations would be given priority where government facilities, although important, at the *present* moment, were not judged so.

Decision Making and Paired Comparisons

During the phases, given the following set of choices for the allocation of generators:

{hospital, police station headquarters, ambulance, nursing home, super dome, command and control}

Phase I: Highest importance is command and control. This would be because all other facilities were running properly. Although the threat was imminent, its potential to cause damage was still under undetermined. Coordination was most important during this time.

{command and control, hospital, police station headquarters, ambulance, nursing home, super dome}

Phase II: The onset of a category 5 hurricane will change the rank given the potential for destruction has increased. People in nursing homes and hospitals are trapped in the city at this point and now are given higher priority.

{command and control, hospital, nursing home, police station headquarters, ambulance, super dome}

Phase III: The aftermath of the hurricane is assessed. Only a few generators are distributed. However, people have been hurt, many tourists are still in the French Quarter sobering up from the past evening's Hurricane party, realizing they made it through a Category 4 hurricane unscathed.

{command and control, ambulance, hospital, nursing home, police station headquarters, super dome}

Phase IV: Floodwaters destroy all generators that aren't elevated to higher levels. Newborns, sick children, grandparents, and others are in the hospitals unable to leave. Refrigeration of medication and life support systems have to have electricity in order to preserve life. This changes the priority level. Although command and control is a must, it would run a close tie with the hospital at this point. Nursing home patients in need of dialysis, insulin and other sorts of medical treatments must be given priority. However, due to assessment of the likelihood of survivability, the hospital would have priority over the nursing home and give us a new sequence.

{command and control, hospital, nursing home, super dome, police station headquarters, ambulance}

Phase V: The floodwaters recede. Ambulances can now drive to rescue any remaining survivors. Everyone has been evacuated from the city. The Super Dome is filled with refugees. Violence is rampant in the city and the police must now try to reestablish order. The hospitals are closed, as are the nursing homes. Command and control has now reestablished itself in a working environment. The new list is as follows:

{super dome, police station headquarters, ambulance, hospital, nursing home, command and control}

Further observations show some of the items in the list didn't change much from their initial positions, such as command and control and the Super Dome. This is reflected in the interval measurement derived from the presented method. Also, the decisions concerning the items in the middle are given the proper amount of attention when detail is required. This adds the beneficial insight into the decisions that need to be made, thus gaining more information where needed and helping provide a better solution. Paired comparisons provides a precise reflection of the expert's judgment when concerning prioritizing of a set of items. So, with this system, an expert could be faced with a few comparisons like

(nursing home, hospital), (ambulance, police headquarters) (super dome, hospital)

thus lessening confusion and strengthening accuracy of the group of expert's collaborative estimation. Especially in times of high stress, the simplification of a situation makes for a clearer understanding of what is being decided when under pressure and amongst chaos. After a few comparisons, the overall list is reprioritized and *present* decisions and thus actions will be based on this reorganization making for greater effectiveness in end results.

CONCLUSION

Even when all experts in a group may not be able to participate at the *moment*, or some may be unqualified to vote on a particular matter, nonetheless, a decision must be made. This system is conducive for decision making given the worst of conditions, utilizing the information as well as the experts to their fullest capacity. In a disaster, it may appear that there are only poor selections after such a tragic event has occurred. However, a best decision must still be made, thus minimizing potential future damages and hence, maximizing the best obtainable outcome for the challenges that lay ahead.

A dynamic Delphi system will support real time decision making for virtual groups working in a changing environment. The Internet provides opportunity and lessens previous geographic boundaries to a great extent. The system is available online and is accessible anywhere there is Internet connectivity and a browser. In addition, the involvement of community members coming together as emergency response resident collaborators can expedite the dissemination of information and increase the coordination of local response utilizing tools such as the Internet, cell phones, text messaging and other forms of communication devices (Shneiderman and Preece, 2007). Crises are, by nature, filled with uncertainty and ambiguity as to the potential outcome, given the information on hand, in connection with the present and/or probable future states. Using the knowledgeable individuals during the entire process of problem solving and decision-making, gives the added benefit of collective intelligence.

The Internet promotes the collaboration of dispersed experts, some of whom due to their proximity would not otherwise be able to participate. This greatly increases the availability for experts to share their knowledge amongst numerous different groups since they can be at one location, but interact with many ongoing situations simultaneously. Therefore, people who are experts and specialize in a field, can now be an invaluable part of any decision that requires their unique expertise can fill positions that traditionally would have been filled by perhaps someone less qualified due to the supply and demand economics of geographic location.

Had a system as described here been employed during Hurricane Katrina, using experts from all over the world, not only would there have been a more organized and efficient response, but also, the political pressures for a national leader to 'save face', given the worldwide participation, would have influenced a more appropriate response. National leaders are held accountable and this cannot be overlooked in the face of an insurmountable amount of evidence, especially when the information is at the world's fingertips. For example, compare the response of Katrina to that of the Tsunami of 2004. Just days after the tsunami, which was a larger scale disaster than Katrina, there were organized efforts to fly in food and water and to provide aid. Compare this with Katrina where, days later, the president surveyed the damage from Air Force One, his private jet, flying back from vacation. Nothing had been organized or managed. People were still stranded and incapacitated as they initially had been and as they would be for days to come.

Although the responders to the Tsunami disaster obviously weren't using this system, they were using one of the primary concepts here and that is that more experts can work globally together as a virtual community. And when more knowledgeable individuals work together to solve a complex problem in good faith, there will be a better result due to collective intelligence (Hiltz and Turoff, 1993). It is probable that this will promote larger groups of people, dispersed geographically, to share their expertise and work on more complex issues together, thus improving decision-making and outcomes of those decisions in an increasingly ubiquitous manner.

FURTHER COMMENTARY

There are two other viewpoints one can take from what has been developed here. Both are relevant to the consideration of Emergency Preparedness and Response. In the context of "high reliability organizations" (HRO, Weick and Sutcliffe, 2001), this is a method of taking tightly coupled components of a complex decision and making it a looser coupled situation by the introduction of a human structured communication process. These allow the humans to act faster and much more efficiently to conduct a rapid decision analysis. This is useful to the persons that must trigger various alternatives

The second viewpoint is that this is an implementation method to carry out the actual evaluation mechanism implied by Abbe Mowshowitz (2002) in his book on Virtual Organizations. It is a model based upon the knowledgeable managers and professionals, maintaining two independent lists and establishing a rank order for those lists. This creation of a dynamic collaborative interval scale would seem more appropriate for that model and for virtual teams that could work the same way in dealing with complex problem solving. It is a mechanism that will enforce the consideration of detail and not be eliminated as one of the dangers of undermining HRO type operations

Both views are augmented by the need to remove uncertainty and ambiguity form the solution from a complex problem solving process by a larger group than cannot get together or function in a face to face setting. As in the original Delphi concept, we are trying to use voting and scaling to promote understanding of what is hoped to be an emerging best consensus on decisions that have no clear cut single criteria to resolve them.

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