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Understanding the Effect of Risk Aversion on Risk

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Abstract

As we progress, society must intelligently address the following question: How much risk is acceptable? How we answer this question could have important consequences for the future state of our nation and the dynamics of its social structure. In this work, we will elucidate and demonstrate, using a physically based model, that the attempt to eliminate all thinkable risks in our society may be setting us up for even larger risks. In order to illustrate this point the simplest example is something with which we are all familiar and have known from the time we were very young. When children burn their finger on a hot item they learn the consequences of touching fire. This small risk has taught the child to avoid larger risks. In trying to avoid these small risks as well as larger risks, one runs the dual danger of not learning from the small events and of having difficulty in differentiating between large and small risks.

We will illustrate this problem with a series of social dynamics examples from the operation of NASA to network operation and then make an analogy to a complex system model for this type of dynamics. From these results, recommendations will be made for the types of risk responses that improve the situation versus those that worsen the situation.

In order to progress, society has to recognize that accidents are unavoidable and therefore an intelligent risk management program must be implemented that is aimed toward avoiding or reducing major accidents. It is not possible to avoid all risk but it is more prudent to avoid the greater risk situations for society.

1. Introduction

Society must intelligently address the following question: How much risk is acceptable? How we answer this question could have important consequences for the future state of our nation. This world would not have progressed as far as it has if people were not willing to take risks. People took risks in the early days of global exploration, aviation, pioneering, and other facets of life. If previous generations were not willing to take risks then society would not have progressed to where it is today.

In this work we will elucidate and demonstrate using a physically based model that the desire to eliminate all thinkable risks in our society may be setting us up for even larger risks. Perhaps, the proper strategy in dealing with risk is to develop within society the ability to rationally differentiate acceptable from unacceptable risk [1]. A physical example of the inability to differentiate between risks is when snow piles up on a mountainside. If the stress is relieved through small avalanches (analogous to small accidents) then the probability of a large avalanche (catastrophic accident) is reduced. Conversely, if all the small avalanches (the inconsequential accidents) are suppressed then the probability of a large avalanche (major accident) is increased. Therefore, the ability to differentiate between what is a major and what is a minor accident is of critical importance for society. The reporting style of the news media, which often does not differentiate between major or minor incidents, only foments often irrational hysteria over all issues and in the end leads to excessive aversion to all risk. Taking risk and even failing is both useful and important, since it is the memory of the failure, or the memory of the lessons learned that helps protect us from future larger risks. However, it should be kept in mind that memory fades with time and must be constantly refreshed in order to both set the time scales for our system and to make it dynamically evolve.

All engineered systems have a variety of modes of failure. There are standard accidents [2] such as random failure of a piece of equipment or human error, however, these accidents can be compounded by operator/societal reactions to the accident. These responses are encompassed in the decision making process both on the short and long time scales. If the operators of the infrastructure or the society at large are particularly risk averse then the responses to the small incidents are likely to be overblown. This can then mask larger problems, which can in turn increase the probability of a larger "normal" accident [2], even system-size, failure. In order to conduct proper risk assessment, the human decision making component of infrastructure operation must be included as an intrinsic part of that complex system [3].

Why is this issue important? In order to progress, society has to recognize that accidents are unavoidable therefore an intelligent risk management program [4] must be implemented in which the risk of major accidents is reduced. It is not possible to avoid all risk but it is preferable to avoid the greater risk situations for society.

The remainder of the paper is organized as follows. In Section 2, we will present four examples of human systems in which risk-averse behavior can have counter productive effects. Section 3 will present a model and preliminary results from this model showing the effects of risk-averse behavior. We will conclude in Section 4 with a discussion of the implications for infrastructures and the general societal impact of risk, risk perception and risk response.

2. Examples of Risk Averse Operations

To illustrate the effects of behavior based on risk aversion we choose three very disparate systems. These systems are children's learning, corporate safety culture, NASA space safety culture, and the physical systems of river floods and wildfires. These four examples form a nice hierarchical set, in that we all go through the childhood learning process and on a large scale most of us exist in a corporate safety culture, on the largest scale, governmental programs like NASA permeate society, and finally humans interact with nature.

The example of how children's behavior in regard to safety develops is one that is familiar to all of us. Upon first introduction to a dangerous system such as fire, there are two ways that the child's development can be influenced. First a parent can see a child pick up a match, become frightened, display their fear to the child, and then remove the match from the child. This behavior of the parent inculcates into the child the feeling that the match, and by extension the fire, is an extremely dangerous thing to be feared. Alternatively, the parent could supervise and observe the child playing with the match and even go so far as to allow the child to feel the heat from the match. That latter method, combined with a discussion of fire and heat allows the child to develop a healthy respect and understanding of the real dangers of fire. This way the child can understand that the fire from a match is less intrinsically risky than a forest fire. In the first case the child who learned that fire from a match is something that is very dangerous and something to fear will not be able to differentiate between the risks of lighting a match and the risk of lighting a forest on fire. This is of course an extreme example but illustrates the point that a child must learn to differentiate between the levels of risky behavior. This is done by allowing them to experience some of the consequences of the risky, yet less dangerous behaviors [5], such as falling off of a jungle gym or a bicycle and getting a scraped knee. The public dialog about encouraging children to take small risks as a learning tool in order to be able to identify larger more dangerous risks, is quite active in the United Kingdom, Australia, and New Zealand, as seen in web discussions [6], newspaper editorials [7], and social care research [8]. "There is a growing concern that children and young people have greater difficulty than previous generations in 'bouncing back from adversities, that is, have become less resilient." [8] The Cheshire County Government in the United Kingdom [6] has gone as far as providing information on their web site on Support for Students and Teachers that outlines the dangers of removing all risk from the lives of children. They state that: "Minor accidents, which result in scratches, bumps and bruises, must be considered an inevitable part of growing up. If we persist in attempting to protect our children from all risks, we may find that future generations are risk illiterate. A nation of youngsters shielded from any challenges because of the risk of accident will be unable to cope with risk when they become adults. These young people are far more likely to underestimate real dangers and may well seek to gain their excitement by engaging in far more hazardous pursuits."

They conclude by saying that "If you take away all the risk from a child's life you prevent them from testing themselves, finding out what their own limits are, or what they are capable of." In the standard academic literature, Lewis et al. [9] report that fathers believe more strongly than mothers in the developmental benefit of injuries. While this has more of a focus on perceptions, this topic suggests that there is rising concern about not allowing children to explore the world on their own and to learn from their mistakes.

Turning to corporate culture, we have all seen the sign, '100 days of accident free operation'. That sign typifies the lack of differentiation between different levels of accidents. Many corporations in their desire to be able report 'X' days of accident free operation, with X getting larger and larger, do not differentiate between different types of accidents. Clearly, there is a difference between getting a paper cut and loosing a finger in industrial operations. And yet, in many industries if medical personnel are involved it is considered a reportable incident. Therefore, in the admirable but misguided desire to increase safety in the workplace, accident avoidance training is often mandatory. As is natural, this accident avoidance training is usually reactive so that the personnel undergo training in response to the most recent incidences that have occurred. Many of us, therefore have undergone training sessions on the importance of holding a banister when walking down stairs, or not taking the steps two at a time, or not walking with a pencil or scissors. One might ask what is wrong with reminding people to hold onto the banister in order to avoid a fall. The problem is not that the training attempts to prevent people from falling, but rather the problem is that the training does not differentiate between the real risks of different behaviors and different potential accidents. If the operational staff of an organization is trained with the same frequency and intensity about the dangers of paper cuts, tripping down stairs, or electrocution, then they will come to treat all three of those as having the same level of risk. In reality, we would like to prevent catastrophic accidents much more than we would like to avoid minor incidences. The zero-risk tolerance culture which does not differentiate between the severity of risks can actually increase the risk of the catastrophic incidents by overwhelming the personnel with small risk warnings, which mask the important ones. For example, one can imagine operating a table saw and on the table saw there are warnings that are all written red and are all the same size. "Warning, corner of table can poke you"; "Warning, table surface can be hot"; "Warning, splinters can jab you"; "Warning moving saw blade can cut you"; " Warning, will not operate if not plugged in"; "Warning, saw can eject wood"; and "Warning do not eat or drink on surface". Buried in the middle of these warnings, were one or two real, important messages, however, if all the warnings were present, then the user would view them as background noise and pay attention to none of them. This then could actually increase the risk of a serious accident. An additional institutional problem, also one of the unintended consequences of a good idea, is the issue of responsibility. When safety/risk avoidance become a focus of an organization, often safety offices are set up. Then, the "real" responsibility for safety and on the spot risk analysis is shifted from the people involved to a nebulous group, often resulting in ambiguities or worse in terms of responsibility.

At the largest scale, governmental organizations, in their desire to make the operations as safe as possible, often try to mitigate all risks by extensive planning and training [10, 11]. It is of course ridiculous to argue against planning and training, however, it is also clearly impossible to plan and train for all eventualities. The danger in over planning and overtraining for avoiding specific incidents is that then one is less prepared for the unexpected. It is interesting in this regard to contrast the culture of risk management in the NASA and former Soviet space programs. In the case of NASA, extensive contingency planning, design improvements and risk management for all foreseeable incidents is done [12]. The astronauts are trained and equipped to deal with all of these foreseeable incidents. For the Soviet program the cosmonauts were given basic training, some tools, and ”duct tape and bailing wire” and were told to deal with any problems that arose. Remarkably enough, they were usually able to do so. Some observers worry that systematic organizational procedures for managing risk can lead to too much risk aversion. As Bill Weber said about NASA “Many now worry that risk will become the single management metric du jour. It's the obvious reaction to a series of failures. However, risk reduction costs money. At what point do you draw the line? In the space business, no mission will ever be risk free, regardless of the amount of money spent. Thus, too much risk aversion and NASA is on another path to oblivion” [13].

In the broader US societal culture, when something unexpected occurs there can often be difficulty in dealing with it because it falls outside of the planned-for and trained-for sphere. Additionally, the planning of responses to all foreseen events has the same effect that we were discussing in regard to organizational culture and childhood learning, the lack of differentiation between different risk levels. This is not to say that the planners are not aware of the different risk levels, rather when the organizational culture overwhelms personnel with the planned responses, it becomes difficult for the organization to rationally differentiate risks.

In large complex infra-structures systems, decision making and operations planning are based on an evolving assessment of risk [11]. This assessment of risk, or aversion to risk, depends upon the size and frequency of failures in the recent past and on an overall cultural or societal acceptance of risk. Therefore, understanding how different levels of risk aversion influence decision-making and how failures affect the risk aversion are fundamentally important to properly model complex infrastructure systems.

Two final examples which the combine the human desire to minimize all risk with natural dynamical systems that intrinsically have incidents of all scales, are river flood/flood control and wild-fires/fire control. After the devastating 1927 Mississippi flood, the US Congress enacted the 1928 Flood Control Act, which prompted the the U.S. Army Corps of Engineers to construct in the 1930-40s by raised levees, diversionary channels, wing dams, revetments, and reservoirs to protect life and property [14]. Among these structures evident around the Mississippi are wing dams and revetments, which are rock and earthen structures placed along river banks to stabilize channels, keep water levels adequately high for barge traffic, and to prevent floods. It was thought that flooding had been contained until the summer of 1993 floods, when there was anomalously large amounts of rainfall throughout the Midwest on top of already saturated soils. Analysis by Criss and Shock [15] of hydrological data gathered since the 1860s, suggests that rivers with wing dams (e.g. Mississippi and Missouri) display rising flow levels whereas those without wing dams (Ohio River and Merrimac) display flat flow levels over the record. They have concluded that the placement of wing dams has led to much higher water levels for the same flow volume in St. Louis, which is very vulnerable to flooding. The wing dams constrict the flow of water on the river, which in turn raises the height of floods. Before World War II, floods that reached 38 feet or higher in St. Louis occurred rarely (every 50 years), however at present, flood stages of this strength occur with much greater frequency. This provides an example of how controlling small floods can enhance the intensity and frequency of large floods.

Finally, in an example that we will return to; it is now widely recognized that suppressing all wild fires can increase the probability of large wild fires. Both the 1988 Yellowstone fire and the 1991 Oakland/Berkeley Hills fire are in part attributed to the policy of suppression of all fires [16]. This policy leads to a dense cover of brush, deadwood and old trees, which in turn provides an ideal setup for a major fire. Consequently, because there are no natural open spaces from previous fires which would provide natural fire breaks and limit the fires size, any fire that starts can grow without bound. Since even the best fire suppression organizations will not achieve aone hundred percent success rate, particularly since multiple fires can (and often do) start simultaneously, an eventual trigger that is not caught is inevitable. In this over grown situation the fires grow out of control to nearly the natural system size.

3. A dynamical model of risk averse systems

In order to quantify this type of behavior, and guided by the physical systems, we have developed a simple deterministic dynamical model for the response to incidents. Weknow that the real systems behavior is deterministic, which is important, since the reaction today depends, at least to some degree, on what happened yesterday. At the same time, the model is random forcing which is consistent with the notion that events, perhaps unforeseen, outside the system, are forcing the system. It should be pointed out up front that this model is very simple at its lowest level and is not meant to capture the details of behavior at all. Rather it is meant to illustrate and investigate some of the dynamical aspects of response to risk discussed above.

We employ a cellular automaton based model set on a regular grid with fixed interaction rules. The systems we will discuss here are a subset of that general class of models in which the rules are local and the grid is regular. Both of these restrictions are straightforward to generalize, and for some real decision making processes other choices might make more sense, but we use them as a reasonable starting point.

The rules for this simple dynamical system are:

1) A node has a certain (usually small) probability of failure (p_f)
2) A node neighboring a failed node has another (higher) probability of failing (p_s)
3) A failed node has a certain (usually higher) probability of being repaired (p_r)

The steps taken in the evolution are equally simple:

At step t

1) The nodes are evaluated for random failure based on their state at the end of the t-1 step.
2) The nodes are evaluated for repair based on their state at the end of the t-1 step.
3) The nodes are evaluated for failure due to the state of their neighbors at step t-1.

4) All nodes are advanced to their new state

For risk response, the nodes can be thought of as elements in an "incident" space. The responses to the incident are in the short term a suppression of a repeat of the same incident, followed, after a recovery period, by a return to the former risk level (as memory fades). Incidents (failures) in these systems can grow and evolve in non-uniform clusters and display a remarkably rich variety of spatial and temporal complexity. They can grow to all sizes from individual node failures to system size events. The recovery rate for nodes is usually slower than the time scale of a cascading failure, making recovery during an evolving cascade unlikely. An important feature of this model is the "memory" of previous incidents in the structure of failed and recovered nodes within the system. The characteristic time scales of the system are also captured in the repair time and random failure probability. This type of model gives long time correlations between the failures, a feature that comes from the dynamical memory of the system. It should be kept in mind that this model is not intended to simulate a particular decision making system. Rather the simple nature of the system allows one to investigate the effect of suppression of small events (as a result of risk aversion) on the incidence of larger events. The mechanism by which this is done is simple. If an incident below a certain size starts to occur it has a high probability of being fixed. This is then evidenced by lack of "memory" of the event in the system, since it did not occur. Therefore, when a few simultaneous events occur, or the suppression of a given small event is not effective, the event can grow beyond the suppression limit only now, because of the lack of memory, there is no natural limit on the size of the event. Put another way, because we did not allow experiences of smaller incidents to create this protective memory, the large incident is able to occur. Operationally, in the model we allow the incident to start (i.e. the random external triggering event can occur) and then we start suppression after that. This means that we are not suppressing the very smallest, size one, incidents but only those between 1 and our suppression size. Also, it should be noted that the suppression is not, in general, made one hundred percent effective. This means that there is a chance that a small incident could become a large one, as well as, the possibility that a number of simultaneous triggers occur, making the incident larger than the suppression size right at the outset.

Figure 1 shows the time history of incidents for 2 systems. The normal system is shown by the solid line and has a variety of incident sizes.

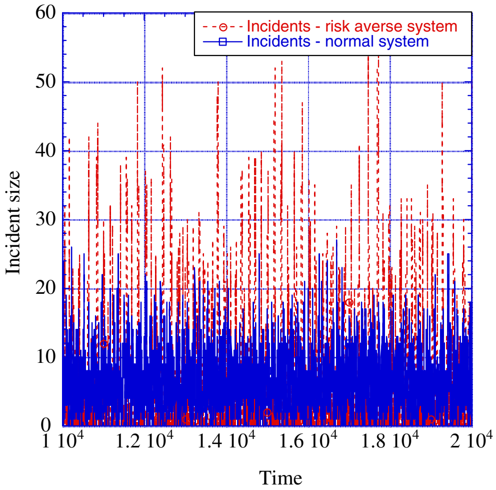

Figure 1: Time evolution of incidents for a risk averse system (dashed) and a normal system (solid), showing increased large events when small events are suppressed.

The dashed line is for a system with the same parameters but with incidents under a size of ten suppressed with a probability of 50%. In this case one can see more large incidents. This is quantified in Figure 2 in which the PDF of the incident sizes is shown for the two systems. At smaller scales there is a reduction in incidents (though it should be noted not at the smallest scale). At the larger scales, there are more and larger incidents.

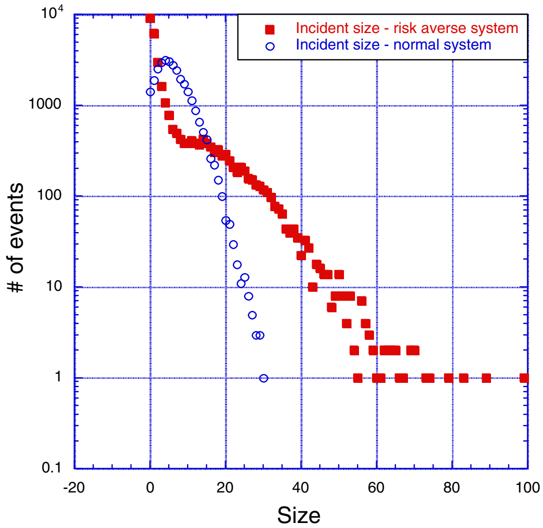

Figure 2: PDF of incident size for a risk averse system (solid squares) and a normal system (open circles), showing more large events when small events are suppressed.

Figure 3 shows the maximum size of the incidents as the suppression size or probability is increased. The relevant parameter for the "strength of the suppression" seems to be the product of the maximum size suppressed and the suppression probability α.

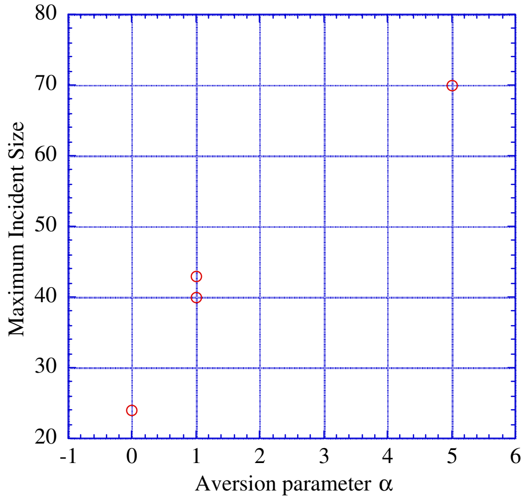

Figure 3: The maximum incident size as the suppression/risk aversion parameter α is increased.

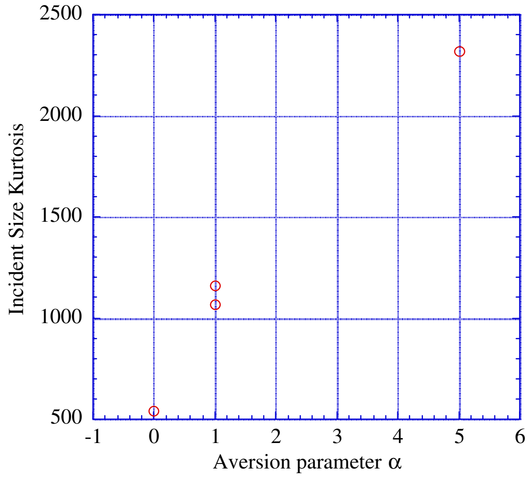

Figure 5: The kurtosis of the incident size distribution as the suppression/risk aversion parameter α is increased.

Figure 4 shows four PDFs for 3 values of α with the middle values coming in one case from a maximum suppression size of 10 and a suppression probability of 0.1 while the other case comes from a maximum size of 2 and a suppression probability of 0.5. It can be seen that the PDFs of these two largely overlay each other supporting the idea that α is the parameter of importance.

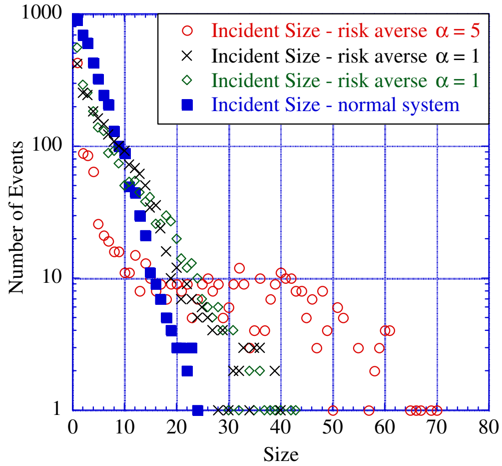

Figure 4: PDFs for 4 systems with varying values of risk aversion.

As α is increased the maximum size increases as does the kurtosis (Fig. 5) as a measure of how heavily weighted the tail of the distribution is. From the arguments given earlier, this type of result makes some sense since by focusing on the smaller risks (incidents) the system modeled has no memory and therefore no natural resistance to the larger events, consequently increasing the probability of such an incident. This type of model can be coupled to an infrastructure model and driven by the events in that model so that the repair responses in the infrastructure model are modified by the state of the risk/decision making model.

The converse effect is also true. Namely, if small incidents are stimulated, the probability of larger ones is actually reduced. We can use the same model to investigate this by perturbing the system with increased triggering or increased probability of propagation. Figure 6 displays the PDF of event size for a system with no perturbation (circles) and a system with an applied perturbation (squares). This is of course not to say that society ought to actually cause accidents to stimulate this effect but rather that encouraging some risk taking, and learning how to differentiate between different levels of risk, might actually reduce the probability of large incidents.

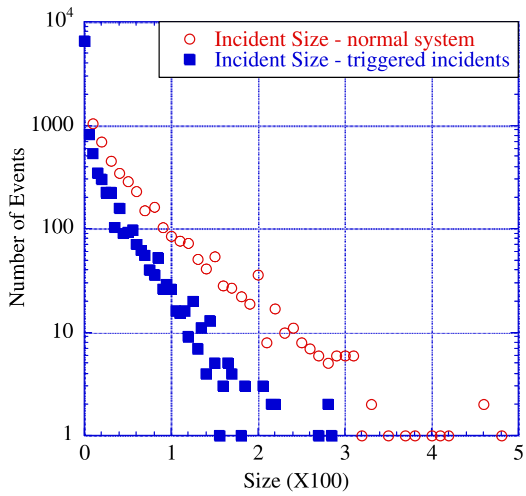

Figure 6: PDFs for 2 systems. One with triggering and one without.

As an aside, an organic analogy to this is the body's immune system. It is becoming well accepted that some exposure to viruses, bacteria and allergens is good for the immune system, particularly for children [17, 18, 19]. This exposure seems, among other things, to increase the immune response thereby boosting resistance to infection, a result very much like the memory effect in the model we are investigating. One could think of the small accidents as providing a kind of safety immunity even to the point that the psychology of risk and safety might be like an immune system; familiarity with pathogens/risks both increases resistance and allows the body/system to recognize what is really bad versus what is only slightly bad.

A much more readily understood and familiar physical example of this type of phenomena is the dynamics of the forest or brush fire system [20] briefly described in the previous section. In an area with a very efficient fire fighting system, small fires are effectively suppressed. This means that any fire below a certain size (usually resource limited) has a high probability of being extinguished. This clearly reduces the probability of small fires. However, over time it also increases the density of the foliage. With the increased foliage, when a few random fires are started (lightning strikes, careless people, etc), or an attempted suppression fails, the fire can spread and get beyond the controllable stage quickly and can lead to larger fires. Therefore, if you suppress the small-scale events you are more likely to experience large events. The wild fire control community has come to understand this, so instead of fighting all small fires, those not threatening structures or protected areas are allowed to burn, others are intentionally lit and clearing (a fire surrogate) is performed. These are the very actions discussed earlier, with Figures 1-5 effectively showing the impact of fire suppression and Figure 6 showing the effect of controlled burns or clearing. The forest systems with fire suppression show increased frequency and size of large fires. [21] While conversely, the systems with small fires set (control burns) has a reduction in the frequency and size of large fires. The model can be used to investigate both the effects of risk aversion as well as other types of decision-making paradigms and their effect on overall risk. Consequently, this model could be used to investigate the development of more intelligent risk management techniques.

4. Discussion and Conclusions

In the management of complex infrastructure systems the planners and operators of the system [22, 23] both explicitly and implicitly take into account the acceptable level of risk of failures at various levels. While we often make the statement that a system or system component must be made failure free, most planners and operators realize that it is impossible to eliminate all risk and the best we can do is to minimize the most serious risks. However the level of acceptable risk is highly dependent on the time history of incidents in the system (and to some degree outside the system in society as a whole). Therefore in modeling the infrastructure systems [24, 25, 26, 27] the level of risk acceptance or aversion must be taken into account in describing the short andlong term response of the system (operators/planners) to incidents.

In response to a major incident, risk aversion increases, this leads to operators and planners trying to reduce risk as much as possible. Since this is most easily done in the simplest areas, it can end up reducing the risk of small events which actually increases the risk of the larger events. To improve the accuracy of the modeling of such complex infrastructure systems, the infrastructure models should be coupled to risk based desision making models in order to capture this important response feedback.

In a society such as ours, in which major risks have been removed from our lives, it is natural to start focusing on the smaller risks. That combined with the natural human desire to assess blame when something goes wrong, leads to a universal attempt to remove all risks, large and small. Perception of risk is an important component of this desire to remove all risk [28]. Yet, since clearly it is impossible to remove all risks the very act of attempting to do this could have the counter productive effects described earlier. Therefore using models and planning, this instinctive behavior must be kept in check.

These dynamic complex systems range from:

- Congress with legislation
- Employee accidents (OSHA)
- Industrial safety
- Mississippi Floods

In all of these systems it is critical to differentiate between what is important and what is less important. More and more society is moving towards avoiding all risks and this could be very dangerous for our survival.

In order to progress, society has to recognize that accidents are unavoidable therefore an intelligent risk management program must be implemented in which major accidents can be avoided. It is not possible to avoid all risk but it is better to avoid the greater risk situations for society.

The most important remediation to this problem is the ability to differentiate between large and small risks in planning and response.

Without this, "We may wake up one morning and find the human race is in decline, undone by something as simple as being unable to take a risk." [7]

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