Newport Biotech Consultants

Volume 2 Issue 8 – October 2009

What Happens When Systems Break Down: Preparing for Disasters

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What happens when one or more of the complex systems that keep our civilization running break down? As unpleasant as it is to contemplate this question, its consideration dominates the thinking of Dr. Wolfgang Kröger, Professor and Director of the Laboratory for Safety Analysis of ETH Zurich (Swiss Federal Institute of Technology). Kröger recently discussed the discipline of disaster analysis to a group of journalists focusing on Swiss emergency preparedness technology.

According to Kröger, "We seek to help avoid systems collapse through the application of high quality technical and organizational tools; the goal being to prevent minor incidents from expanding into catastrophic failures."

Modern industrial societies are ruled today by highly complex, interlocking technologies which, although man made, may be poorly understood in the aggregate. In order to preserve the integrity of such systems, it is necessary to map their interactions, which become increasingly fragile as their complexity expands. The mitigation of disaster consequences must be based on the deep understanding of system's behavior as a whole and a willingness to become aware and to be prepared. This requires a definition of targets and acceptability criteria.

Failure to follow such a program can exact a high price. Kröger cited the catastrophic failure of the wheel assembly at 250 km/hour on the ICE high speed German train on the 3rd of June 1998. This incident resulted in 101 fatalities, huge financial losses and the cancellation of train construction contracts throughout the world. The effects of this incident reverberated throughout German society. To prevent a reoccurrence of such events, it is necessary to design a risk and vulnerability analysis, including maintenance issues and to have available a scientific support structure capable of strategic decision making.

The study of complex systems has grown into a major discipline in the last decade, and encompasses both manmade and natural systems. Indeed, systems biology seeks to understand such complex phenomena as cancer, thought processes and aging, using the same tools as those applied to complex human constructs, including the power grid, transportation and communications networks.

Kröger emphasizes that today a broadened set of hazards and threats is arising throughout the world, exacerbated by a pervasive use of modern information and communication technology, a growing number of malicious attacks as well as changing weather patterns that accompany global warming.

All complex systems display features which put them at risk for catastrophic and unpredictable failure; these include inadequate information regarding their constitutive elements, non-linearities and feedback loops, each of which tends to create ugly surprises. Nowhere are these features more in evidence than in the control of the electric power grid. Kröger describes the UCTE, the Union for the Coordination of Transmission of Electricity, which controls the transboundary flow of electrical energy, serving 450 million people within the European Union and continental Europe. In recent years there have been major failures due to different causes that resulted in a domino effect and a collapse of a large part of the power grid. One of the most dramatic was an outage in 2003 that shut down most of Italy's electrical power.

Domino effects occur within electrical grids when they become overloaded, with resultant heating and sagging of the power lines, causing flashovers (too short distances to obstacles like trees) and line cut-offs. Mitigation of these events include technical devices, improved topology and, most importantly, adequate load shedding. Much of Kröger's work involves modeling of these events to better understand them.

Kröger and his associates have learned some important lessons from their analyses. Causes of systems malfunctions include operation of the structure beyond its original design parameters, unexpected response of critical equipment and protective devices, lack of emergency preparedness, poor cross border coordination, and failure to adequately implement security criteria. In order to understand these breakdowns and redesign the operational regimes responsible for them, the Kröger team has built an object-oriented modeling approach describing the behavior of the components and their interactions. This includes stochastic or "Monte Carlo" simulation in order to investigate the macrobehavior of the system, i.e. no longer as the sum of the micro behavior of its parts. This modeling allows the emergence of scenarios and states that are not predicted or pre-defined. A robust model will then allow the prediction of frequencies and moreover the consequences of these events.

One of the most important conclusions that Kröger draws from his investigations is that “until research efforts currently under way to develop much more secure internets are successful, the Internet should NOT be used for any function which is vital to the supervision, operation or control of any critical infrastructure.”

Taking into account the constant reports of security breaches in both the public and private sectors, this may be the most important and difficult recommendation for large organizations to adopt.

Kröger drew a sobering conclusion, a sort of Murphy’s Law, that given the complexity of the systems that run our society, “Even in the best of circumstances, preventive measures may fail, and severe problems occur.”

Anatomy of a catastrophe

On June 5, 1998, a high speed passenger train, the ICE 884, was roaring across the German countryside at 250 kilometers per hour on the Munich-Hamburg route. It carried two locomotives and 12 passenger cars. Near the village of Eschede in Lower Saxony, a fatigue crack, which had developed in one of the wheels, caused its steel tire to separate from the wheel and was dragged along until it jammed in the tongue of a switch. This caused the switch to toggle and the rear of the train to be directed to a neighboring track. The rear of the train derailed and slammed into a pylon of a road bridge over the track, causing the bridge to collapse and bury a portion of the train. The accident resulted in 120 fatalities and was a terrible blow to the German economy as well as a painful psychological shock to a country which has prided itself on its technological sophistication for the last 200 years.

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