LOCKHEED MARTIN
MISSILES AND FIRE CONTROL
DALLAS, TX

-EMP CASE STUDY SENIOR DESIGN PROJECT-

MAY 10TH, 2010

Project Summary:

As is typical for students of the Southern Methodist University School of Engineering, we were required to participate in a Senior Design project. Our project was far from typical, and involved a large amount innovation on our part.

After weeks of searching for an interesting project for the team to work on, we came in contact with two Lockheed employees; Dr. Bill Nanry and Chris Askew. These men presented us with a project more exciting than we could ever imagine, aiding the research process of Electromagnetic Pulse. This effect, also called EMP, is extremely devastating and can be caused by both natural and manmade events. EMP primarily affects electronic devices, rendering them useless or destroyed. Since the United States is heavily dependent on electronic interfaces, we are extremely vulnerable to this effect. In addition to this vulnerability to the EMP effect, the United States has a very complex system of integrated infrastructures that are extremely hard to map properly. This presents a major problem, how can one forecast the possible failures of such a massive complex system?

The first step was to learn all we could about the effects of Electromagnetic Pulse. Lockheed had provided us with hundreds of pages of literature to read about countless studies into the effect, and these proved very helpful. The Internet contained many videos and simulations regarding the effects of EMP, which helped us get a visual sense of its devastating capabilities. After looking at this data we were able to construct a map of the possible interdependencies of the US infrastructure. Linking nodes such as Electrical Power to Telecommunications or Transportation to Petroleum Production gave us an insight to the scale of the problem.

With just this data about the possible effects and a simple map of the interdependencies of the US infrastructure we were invited to present to the EMIS Distinguished Advisory Board. This presentation focused primarily on the issues to be tackled, as well as a few possible scenarios where EMP might be employed offensively. The presentation went very well, and the positive reception gave us a huge morale boost.

This was the problem we were presented with, to find out what method would be best for analyzing a system as complex as the entire US infrastructure. We have looked at traditional Fault Tree Analysis and Failure Mode Effects Analysis, as well as a newly developed method called Bouncing Failure. We concluded that Target Systems Analysis, which can be adapted into a three-dimensional map, can ideally display interdependencies for an entire system if the algorithm is reoriented. The application of all of these was nigh impossible until we found that a suitable sample of the U.S. infrastructures could be setup by obtaining schematics from a resort in Western Kentucky.

Problem Background and Analysis Description:

What is EMP?

EMP, or Electromagnetic Pulse, is a wave of electronic and magnetic energy that is transmitted wirelessly through the air. Once this pulse comes in contact with conductive surfaces, such as power lines, it is transformed into high voltage and high energy waves that surge through a system. These waves come in three forms; E1, E2, E3. The E1 pulse is a very fast (lasting only a few nanoseconds) wave of high voltage energy. This wave moves so fast that it bypasses normal surge protection systems, allowing vulnerable circuitry to be destroyed instantly. The E2 pulse is something much more familiar as it is very similar to a lightning strike. E2 waves are high energy, and can destroy unprotected systems. The most devastating wave is E3, which is a pulse of such high energy and long duration that it can destroy very robust systems, such as the massive transformers at power generation facilities across the U.S. This pulse is very similar to a natural Solar Flare, which causes a geomagnetic storm.

How is it used?

EMP can be employed several ways, with each manner having its own special set of effects. A small scale local attack would involve a type of non-nuclear EMP device which may be no larger than a 16 oz can. Such a device would deliver an E1 pulse into a single system (like the New York Stock Exchange or a power plant) and destroy all small circuitry in that system, thoroughly erasing all data. A regional attack would require a nuclear weapon capable of a 40kt fission (for comparison, Hiroshima was approximately 15kt) to be detonated at an altitude of 40km. This detonation would cause E1 and E2 waves to strike an area the size of Northeastern America, causing cascading power failures and devastating infrastructure damage. A large, national event would require a complex thermonuclear fusion device of nearly 300kt to be detonated at an altitude of 300km. This national event would cause complete devastation of the entire Continental United States and would cause all 3 waves to appear, including the catastrophic E3 pulse, which would wipe out major infrastructures across the United States. A natural event, which has a very high probability of occurrence in the near future, would consist entirely of an E3 pulse. This event would be caused by solar flares and other activity which cause a geomagnetic storm.

Why does it need to be studied?

EMP can have a devastating effect on our increasingly interconnected world; therefore, it is extremely important that it be studied. Currently, no method exists to thoroughly examine all of the interdependencies between all of the different types of infrastructure in the United States. The current methodologies available to analyze EMP Effects:

Fault Tree Analysis (FTA) - This is a top-down approach that follows the direct single point effects through an infrastructure system. The method is missing a component that will evaluate the multiple failure modes associated with other infrastructures.

Failure Mode Effects Analysis (FMEA) - This method works in the reverse of an FTA, and is another single point algorithm. The missing element of this approach is its inability to measure combined effects across all infrastructures in a system.

Bouncing Failure Analysis (BFA) - This is a multi-point failure and effects systematic approach that can account for interconnectivity with certain infrastructure components. There has yet to be a valid application of this method in regards to any type of system analysis, but it could provide multi-effect trends that more accurately forecast the results of an EMP attack.

Last Resort:

The sheer size of the data that needed to be analyzed meant that it would be near impossible to accomplish in the time allotted. Luckily, the family of one of the members of the group owns and operates the Big Bear Resort in Western Kentucky. Because of this, we were able to map out a complete system that we knew functioned properly and was constructed realistically. The resort's electrical system was categorized according to transformers (both ground and pole based), electrical disconnects, power stations, and both above and below ground power lines. To simulate a telecommunications system within the resort, a node designated as a telecom provider was placed in the system, with several service tower nodes added to simulate a network. This resort data allowed us to accurately apply all of methods available for system analysis and adequately complete our designated project scope.

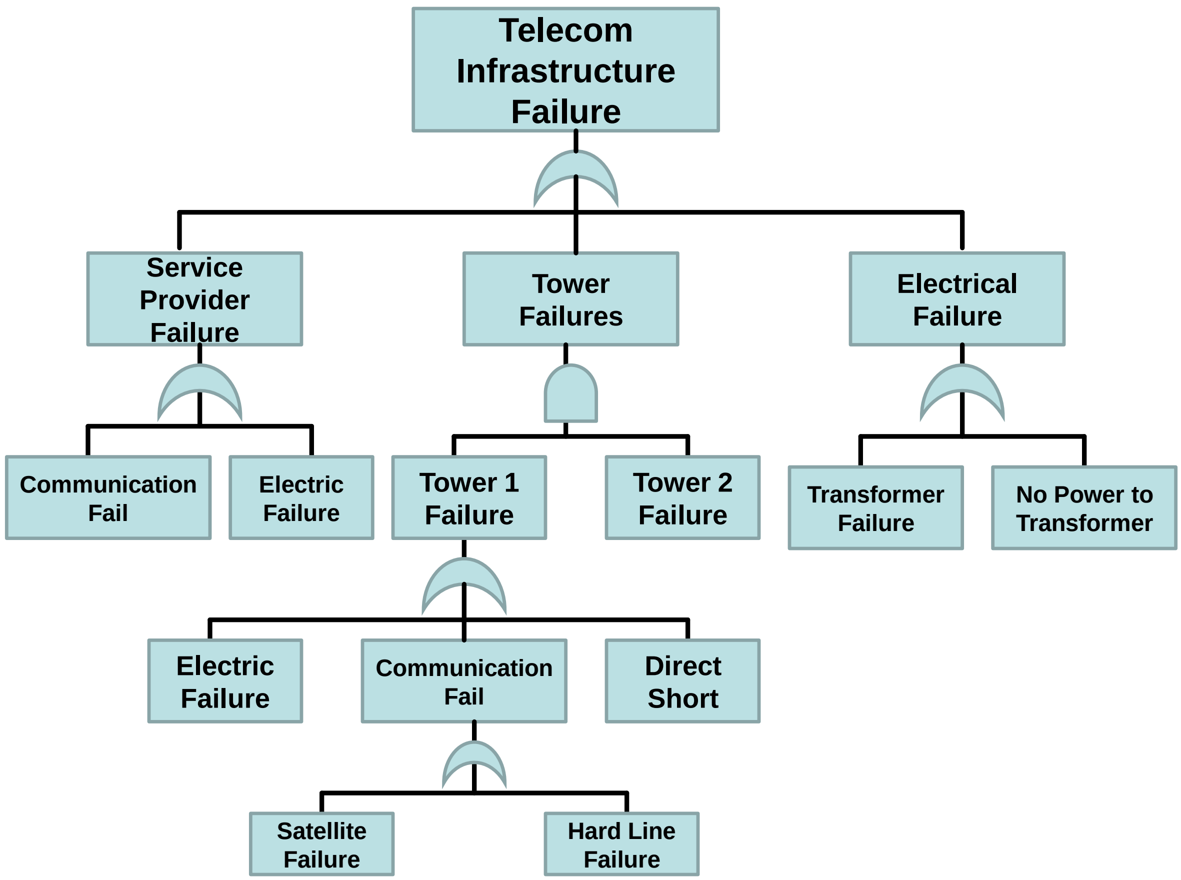
What we hope to accomplish:

As a team, we wanted to develop a horizontal systematic approach that will effectively explain the physics phenomenology, costs, and recovery time associated with an EMP event. Our focus will be on a comparative analysis of the FTA, FMEA, and BFA methodologies on a simplified representative system and the future development opportunities with a three dimensional impact network.

Methodology Comparative Analysis and Results:

FTA:

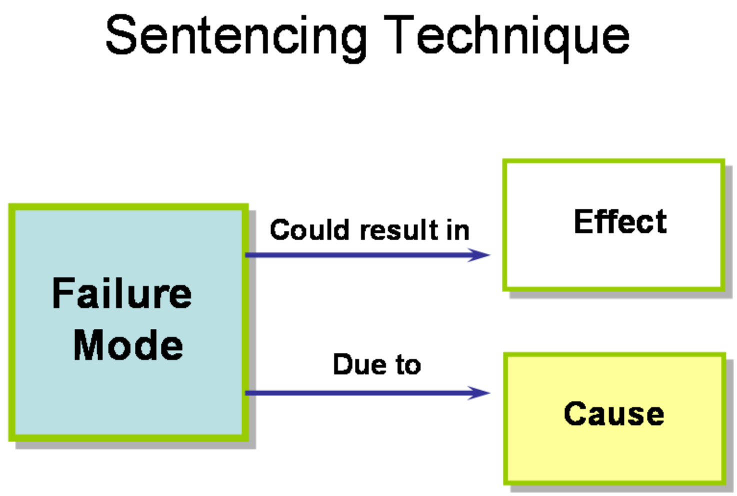
This approach is a basic vertical fishbone design that follows the critical path of a single component node down to the linear resulting effects. In the case of EMP events, this method can be used to describe the trends of a single infrastructure, such as the financial market, and trace the possible failure outcomes of the undesired event. In our analysis, we completed an FTA on our telecom infrastructure with the data given in the Big Bear Resort charts.



We found out that the approach will explain what system components are more vulnerable with regards to the infrastructure directly in line, but it does not have a horizontal interconnection present that will associate the vulnerabilities from other infrastructures. We concluded that this approach would not provide the desired results we wanted for explaining the percent effectiveness versus cost to harden infrastructures across the entire U.S. system.

FMEA:

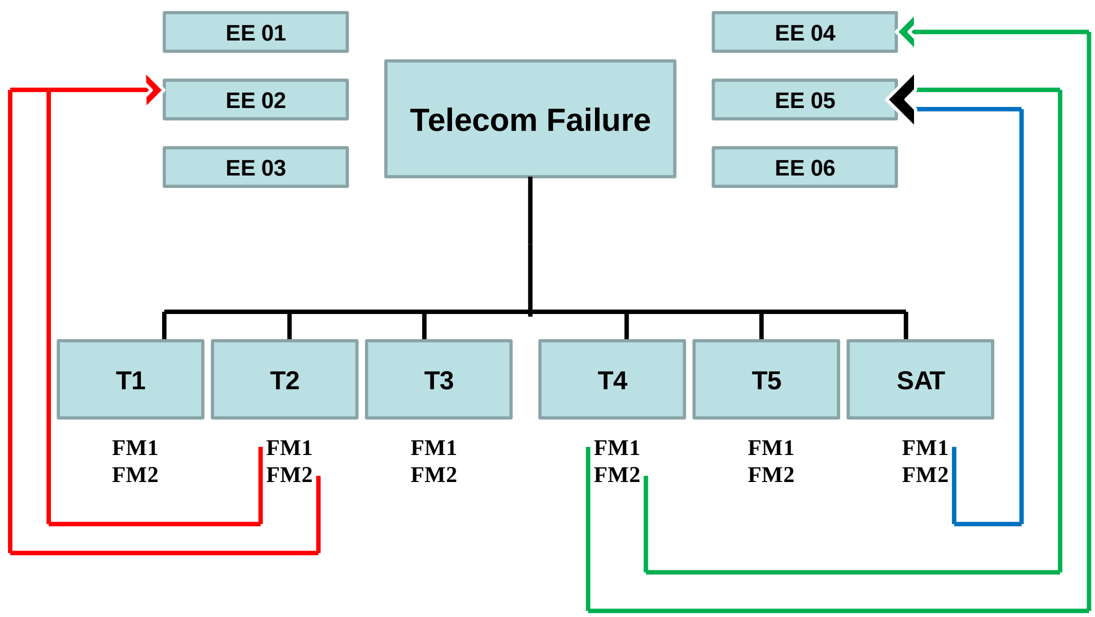
This single point methodology was primarily used by the U.S. EMP Commission hired to study the effects of an EMP event on critical U.S. infrastructures. The two reports resulting from their studies proved a critical path link between the failure modes of network ending devices such as a television or laptop plugged into a wall outlet, back to the cause and effects of the resulting infrastructure, in this case the electric grid system. An example of one component of the function tree in an FMEA/FMECA analysis is shown below:



Our further research of this approach to EMP case study proved that the overall risk management plan is valid for providing the most critical infrastructures in the Unites States, but the method only ranks the linear connections inside one infrastructure, with no allocation of resulting effects from neighboring infrastructures. For example, an FMEA analysis can provide an understanding of how failures in the electric infrastructure cause devices to lose power or malfunction, but any residual effects from the telecommunication infrastructure is not present in the analysis. This results in a need to further study other methodologies to describe the interconnections across infrastructures.

Bouncing Failure:

This multi-point methodology is a newly patented approach that can be linked with FTA and FMEA. The main beneficial component of the method is the series of n-squared matrices used to describe double and triple-point failures. This takes into account the critical path from multiple failure modes to the undesired end effects. The failure modes can be described from any applicable infrastructures and traced back to one undesired event. Since this method has never been applied to any system analysis before, we did several trials on different infrastructures of the resort data to test the method's validity. An example of the resort's telecom infrastructure is shown below:

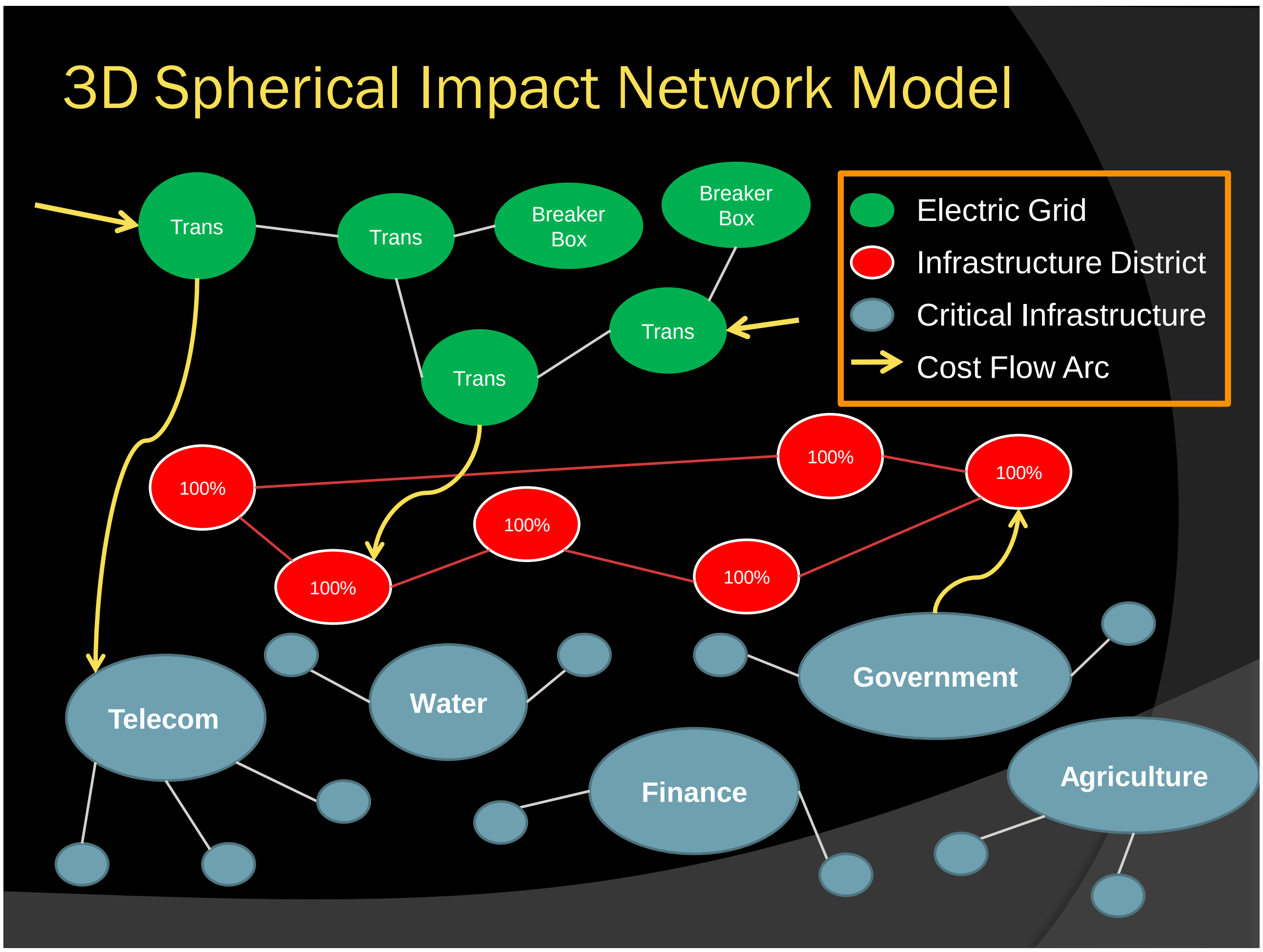


EE = End Effect
FM = Failure Mode
T(x) = Transformer #

After looking at the results from the multi-point failure matrices, the critical failure modes are described linearly and can be used to create a hybrid approach of FMEA and FTA. As mentioned before, FMEA focuses on the many end-effects that can be caused by one failure mode, while FTA focuses on the many failure modes that come from one undesired effect. The Bouncing Failure Analysis can be used to link more than one single failure mode at a time (FTA), while at the same time track the progression of the FMEA process. This analysis has one main drawback in that it does not provide quantifiable values for infrastructure damage or cost to harden devices. This meant that we had to look for a more optimal approach.

3D Impact Network:

This multi-point methodology is a revised target system approach used by Dr. Barr that we adapted in order to provide numerical results for system damages and costs involved with protecting against component failures. This method also shows the interconnectivity of all the critical infrastructures and how the damage to one affects the overall system. We were not able to create an algorithm for this method because it would take personnel from multiple professional backgrounds to properly develop the cost and functional value variables. The diagram below describes how this network would be setup to explain the interconnectivity.



The overall design will need to be a three-dimensional spherical representation of multiple impact networks that are interconnected through cost flow arcs. The top layer, (shown in green), will be the electric grid infrastructure of the system under analysis. The second tier will be separately allocated infrastructure districts previously designated to simplify the overall sample space. These districts need to be manageable surface areas that can be assigned a functional capacity percentage without overcomplicating the larger system. The bottom tier will contain the remaining critical infrastructures as separate networks that will be linked again by cost flow arcs to both the electric grid network and the appropriate infrastructure districts.

Conclusions and Recommendations:

The massive scope of the problem and the limited amount of time we had to do our analysis meant that the only way to rate the effectiveness of each algorithm was to use the aforementioned microcosm of the United States. This microcosm took the form of a small resort, owned and operated by the family of one of the team members. This proved to be a huge time saver, and helped us immensely. The resort data gave us access to a real-life working system that solved many of our issues.

With our issues resolved, we were able to analyze multiple scenarios and come up with several recommendations for further analysis of the EMP problem:

- First, one needs to use a small sample size and a closed system in order to avoid encountering too many variables. We accomplished this by using the resort data. This data had enough nodes to simulate a proper system without overwhelming us with data. The system was also closed, with no outside influences that could randomly affect our results. In our opinion, this is the most important recommendation because it makes the whole problem manageable.

- Second, use the three-dimensional impact network model to map out the data. This method allows the user to see the interconnectivities of a system and find real, quantifiable results.

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