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Scenarios for Crisis in European Critical Energy Infrastructure

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Abstract

A sudden crisis occurrence, such as a big electricity cut, might not be regarded as an isolated incident: In almost all cases, a power outage crisis might bring about multiple losses with e.g. legal, social and economic aspects: Owing to interdependencies, failures in grid nodes might propagate asynchronously, resulting in a compounded disruption by cascading effects[1], potentially leading to a societal catastrophe. So this is why crisis management has key importance in contemporary society. A proper scenario planning and its evaluation result should be regarded as an efficient and valuable approach to help Society prevent crisis occurrence and, if crisis strikes, mitigate the consequential losses.

This master project is a sub-task of EU (European Union) crisis management project. As a matter of fact this EU project is to identify some relevant scenarios of power cut crisis that might happen. By investigating them, provide a prototype model of virtual crisis scenario frame as well as simulation results. According to the research of crisis scenarios and simulation work, we make clear how to improve the crisis management so that it could mitigate cascading faults, and improve the system's resilience by reasonable resources allocation.

As the student researchers in this project, we propose an approach to quantify essential details of impacts, causalities and developmental sequences. Making use of general dynamic analysis software *Vensim* {Ventana Systems, Vensim Software - Linking system thinking to powerful dynamic models} to simulate whole process based on our analysis to relevant scenarios of power cut crisis. A virtual generic scenario regarding power outage which based on the research results was created in our project, and this virtual scenario prototype was evolved from the 2003 Denmark and Sweden power outage. The creation of virtual scenario is based on the research of the relevant scenario planning approaches, and the system dynamics knowledge was used as methodology to guide us achieving the conceptual modeling works. Actually our model is a simplified minimum conceptual model which focuses on the arguably central aspects of crisis management such as cascading faults, resources allocation etc. The results of simulation verified the importance of crisis management in terms of the lifecycle and presented dynamic behaviors in three distinct runs that are run "Equilibrium", run "Attack" and run "Resource deficiency".

[1] Cascading effects are unforeseen chains of events that propagate owing to system interdependencies.

Preface

This master thesis is submitted as part of the Master's degree in Information and Communication Technology at the University of Agder, Faculty of Engineering and Science. The work was done between January 2009 and June 2009.This project was carried out under the supervision of Professor Jose. J. Gonzalez at University of Agder.

Firstly, both of us sincerely wish to thank our supervisor Jose. J. Gonzalez. We thank him for his excellent tutoring, follow up and support with kind effort throughout the project period. We can't imagine how difficult it is to boost this project progress without his help. He encouraged us and helped us keep the spirit up and finish in time. We would also like to thank Research Assistant Finn Olav Sveen for his excellent presentation and valuable suggestions. With his help, we clarified our concept model and the stages of modeling. Finally we would like to thank our friend Xiong Yi, Suinan Li, Yu yu for their valuable advice in parts of our project.

Grimstad, May 2009

Jing Li &Pei Li

Introduction

It is well known that crisis management is an approach by which an organization copes with any potential threats and unpredictable events. As a relatively new field of management, crisis management requires organizations proactive to give a proper vision to the potential threats and provide a strategy planning to cope with them as well as acquire the prerequisite rapidly to prevent the crisis occurrence or mitigate the harm to organizations.

In this chapter we give an introduction of our understanding to crisis management. In particular, we shall concentrate on researching existed power outage crisis scenarios and make clear our task property and its function. In Section 1.1 we present the importance of topic of our master thesis and in Section 1.2 we present the contributions of SEMPOC to knowledge. Section 1.3 presents why we choose the system dynamic software Vensim by which it will be used to demonstrate our modeling thought and corresponding simulation results. Section 1.4 provides a proper hypothesis and questions so that we could sharpen our thoughts before we begin our in-depth research. Limitation and key assumption was presented in Section 1.5. The final Section 1.6 briefly describes the entire thesis structure.

Importance of topic

According to some prior study of scenarios, we found that crisis management is actually an essential approach by which organizations could be used to do future strategy planning. Organizations then use computer software to simulate the procedure of these strategies which use to treat with real crisis and thus validate that the treatment proposal conform to the practical situation or not. An obvious advantage of using computer simulation is it might help organizations to prevent the crisis occurrence in real-life thus avoid the costs of treatment to deal with the crisis or just only save the costs on handle crisis. So, finding out an absolutely typical scenario is helpful for both subsequent research and beneficiary party.

The theme of our master project requires us to research proposal named SEMPOC and MISSCRISIS which comes from Professor Jose J. Gonzalez, we need to find out typical scenarios based on our analysis and provide a system model as well as its simulation. Moreover the model should contain the summarized common characters which evolved from our scenarios analysis. In our opinion, three significant problems would be encountered, one is how to choose the quickest route to capture the root cause of crisis, and handle existed crisis in an organization rapidly and efficiently.

Additionally, how to help this organization prevent the same type of crisis occurred in the following period. Another important problem is how to cut off the crisis impacts that will spread to other same type organizations. Effectively and efficiently work through these issues might be the hard core in the crisis management. As two beginners in dynamic system modeling works, we will try to achieve a proper ideal model and its simulation to solve an invented crisis scenario so that we could validate our modeling work is success.

Contribution to research

This project is the beginning part of the EU project by SEMPOC which EU committee might refer our analysis results for the further research. We will provide the results of scenarios research and model simulation as the prior requirements to the ITE Development (The next phase of the EU project, but not involved in this project).

In a sense, this project is an innovative work which compared to the other sorts of projects.

- The first reason is often when a crisis occurred in certain place; the crisis itself would not be regard as a single issue. Various factors might lead social instability. To some extent, it required human beings gives greater consideration to human, organizational and cultural aspects in the lifecycle of an electricity power cut. So our project is not only focus on the crisis development from beginning to the end with a linear consideration, but also a deeply un-linear consideration in multiple social aspects.

- Secondly, if we thought a crisis as an involved process, this process would contain an origination and a termination, even as well as an uncertain incubation. It means that researchers have to consider the dynamic system model might possess a long term lifecycle or a short term lifecycle; it depends on the specific crisis property. Moreover, asynchronous consequences are also an innovative concept which will be considered in our project.

- The third innovation comes from the simulation approach. Though all the simulation works were achieved base on virtual generic scenarios, the bone of scenario was constructed based on the real world and parameter setting was strict followed with the current situation. To some extent, it will significantly increase the trust and commitment to the results from stakeholders and beneficiaries.

- As the old saying goes, “prepare something for a rainy day”. The essence of scenario planning determined that our prior research is different from some other system development project can explicitly know what should do. It requires human beings consider to the plausible future as much as possible before they know what should they do, and then start the project by proper make up.

Contributions of SEMPOC to knowledge

Innovation

The most important contribution of SEMPOC is its innovation. It's highly innovative project that *aims to prepare crisis managers, through modeling and simulation, to better react against potential CI (Critical Infrastructure) disruptions* {TECNUM, 2008, Collaborative Project (STREP) MISSCRISIS}. As a part of EU project, the project's another contribution is to do the prior research and provide some knowledge about scenario, to help the crisis managers to understand critical infrastructure interdependencies, cascading effects, cross border issues in order to effectively identify and manage the type, crisis lifecycle (duration of disruptions). The Project research results will provide proactive solution, lessons, policies analysis and recommendation of the resolution.

Potential outcomes of this project

The conceivable outcomes of this research would contain some components as below:

Models

A "minimal conceptual model" will describe generic aspects of crisis management. The model will be validated. Moreover this model should provide some relevant crisis management knowledge:

- Crisis Lifecycle: The model must conclude the crisis lifecycle: normal state (hidden faults), pre-crisis (manifest faults by attack without cascading effect), crisis (cascade faults by attack), and post-crisis (correction) phase.

- Attack: The trigger condition to cause pre-crisis and crisis.

- Faults Manifesting: The causal relation between hidden and manifest faults.

- Cascading Effects: As long as the manifest faults more than the threshold, a cascading effect would happen, and many cascade faults would be generated.

- Resource Allocation: Total resources are fixed, how to allocate them to ensure these manifest faults can be corrected in the shortest time without any unintended hidden faults introduction is a part of content need to be simulated.

Simulations

Run simulation of crisis problems in distinct circumstances, and give the simulation report. Illustrate specific behaviors by simulation figures and make relevant policy to improve these behaviors.

Documents

- “Scenarios for Crisis in European Critical Energy Infrastructure”: The thesis of whole project is a compulsory component.

- “Slides for presentation”: Make a brief conclusion for each part of our project and exhibit as slides for our final presentation, by using slides audiences would easily understand what we want to express.

- “Post”: An intuitionist way to exhibit our research findings and usually it’s a formal approach for showing master thesis

System Dynamics

According to the learning and analyzing scenarios that we searched, we knew that the scenario more like a complex dynamic system, not only it has the feature of Human Sciences but also used to study complex socio-technical systems. And System Dynamic is appropriate for study of any kind of complex, non-linear dynamic system, even pure social or technological systems (Forrester 1960, Sterman 2000).

System Dynamics is based on System Thinking which is an approach for studying and managing complex feedback systems such as one finds in corporations and other social system. But SD (System Dynamics) with its distinctive character compared with ST (System Thinking) is that the usage of computer-simulation tools.

As a model tool, sometimes Vensim will be compared with Unified Modeling Language (UML), which is a standard language for specifying, visualizing, constructing, and documenting the artifacts of software systems, as well as for business modeling and other non-software systems. In fact they are applied in different research domain. Vensim focuses on the SD domain, and UML concerns the Object Oriented Programming (OOP) domain.

Vensim, a system dynamics simulation software, would be used in our project absolutely more details in displaying not only linear relation between elements but also causalities between them. To a great extent, Vensim was accepted and widely used in this area for the reason that a complex system incident was triggered by multiple causes, and each dependent element in the model may influence the others. To show distinct cause-and-effect relations between elements as well as mathematical relations are both necessary. All of them are preconditions to make an useful model for management.

Indeed, our research area regarding power outage crisis in EU is a complicated and multi-disciplinary comprehensive problem which is concerned with social science, security and management aspects. By considering all sorts of potential inter-behaviors would be analyzed in our model, we choose Vensim as our system dynamics model software.

Reasonable hypothesis and Questions

To make several assumptions about possible difficulties we will face of during the project progress as well as ideal results we will have gotten after researching and simulations would be useful for us. Due to these original analysis, some hypothesis show as below:

Hypothesis	Question	Confirmation
Thorough comprehension of EU project's proposals which provided from our supervisor and of the concept of scenario can be comprehended. We can make a thorough comprehension to the concept of scenario so that we can achieve an excellent model contain mathematical formulae to validate our analysis.	Can we make a thorough comprehension to the concept of scenario? Or how much we can understand about this concept? How to ensure our understanding is correct?	**A criterion of how to search for scenarios can be achieved. Meeting with supervisor (Professor Jose), he will confirm whether our comprehension is correct or not.**
Search for and analyze many scenarios. According to our criterion, we need to search and find out many scenarios for analyzing work. As the time goes by, scenarios would be found out as much as possible, and generalize a	How the term “scenario” is understood and used by the research community in connection with simulations, in particular with system dynamics simulations? How is the term "scenario" understood and used by the research community in connection with simulations of crises?	**The answers of these questions will be delivered to our supervisor, And then we will discuss them together until all we think they are appropriate scenarios of power cut crisis in**

correct common character in progress.	Have authors' proposed scenarios for crisis management simulations? What scenarios have they proposed? Have authors' proposed scenarios for power cut crisis management simulations? What scenarios have they proposed? How many scenarios can be found? Whether if they are appropriate for our researching? What kind of features can be realized by our analyzing in these scenarios? What common characters can be summarized comparing with them?	**the project.**
Choose 1 or 2 scenarios for our researching work. We finally found out many scenarios, for instance found out 10 scenarios, but just only 1 or 2 typical scenarios are enough to be used to analyze and make solution point to these typical questions. **'A typical generic scenarios regarding power outage that based on the 2003 Denmark and Sweden outage'** scenario has been chosen to apply in the project.	Are these common characters been included in them? Are these scenarios typically and suit for our research? Can we implement measures to these scenarios after we detected? Does the chosen scenario represent the mainly feature of the crisis management of power cut?	**The chosen scenario can be checked by the criteria of crisis management features.** **We can indicate our research result, but finally professor will help us to determine which one is proper for us**
Qualitative analyzing to figure out interacted relation, and how to make measurements to treat with them. A rapid action of treatment during the crisis incubation stage requires us solutions should be provided in a certain period so that to make sure all the treatment are available, and we completed in time. Once the	Are these interacted relations correct? Are there any preventions, measures or notification to relevant nodes being included? How to guarantee that the crisis can be reported in time before treat the crisis in crisis incubation stage? How to guarantee that the crisis can be mitigated? And how to guarantee that relevant nodes know it in time and prevent it?	**Design and validate CLD models (Causal Loop Diagram).**

crisis or accident happened, it is obvious that many measurements have to be utilized to mitigate costs and impacts. At the same time, assured some relevant affected nodes know it and do some valid prevention to avoid it.		
Quantitative analyzing to formulate simplify and clarify, and provide data to verification them. We use correct mathematical formulas to quantify specifications of the common character what we summarized, and make absolutely correct models to conform our analysis.	How to choose correct mathematical formulas to quantify our summarized stuff? How to make a conformance between our summarized and models?	**Stock and Flow Models based on CLD (Causal Loop Diagram) models.**
Confirm models in distinct dynamic hypothesis circumstances and the real circumstance could be adopted respectively. Finally, we make use of distinct circumstances to validate our models conform to our analysis as well as summarization respectively, and availability existed, including the real circumstance, but it needs the organization's cooperation.	How to make the model credible? How to make appropriate dynamic hypothesis circumstances to validate our models accord with our analysis from scenarios? **How to guarantee our results of simulation are reasonable? How to test them in a valid method?**	**Comparing figures in different circumstances and testing report have to be included in our researching consequences. Evaluation report can confirm the researching effect if the organization can cooperate with us and adopt these researching consequences.**

Table 1 Hypothesis and Questions

Limitations and key assumptions

Limitations

Our research field is to search and analyse typical scenarios about power outage crisis in Europe Union with its legal, social and economic impacts. Untypical scenarios might be not chosen for the reason that we should keep typical scenarios tested by distinct circumstances.

According to our prior research of SEMPOC and MISSCRISIS as well as professor's requirements, the research work for this project that assigned to us is to help EU do some pilot research for this crisis management, it is possible that we pay more attention to do a general research on this problem, and try to summarize typical features from typical scenario which we will pick out. Based on these typical features, then do analysis, model and simulate it.

For our project we have to research various power outage crisis happened before in the world wide so that we could absorb enough essentials to create a high level generic scenario with its lifecycle. The scene of our scenario was set in Europe, and lifecycle was a short period (2 days) that we might be easier to finish our simulation, moreover we believed that more specific details in scenario would raise the difficulty level and not easy to highlight the key points in this crisis scenario. So we neglected secondary factors and kept the scenario frame more and more general.

Key Assumptions

Based on our project requirements, we finally chose a specific and existed scenario with its title that "Infrastructure failure interdependencies in extreme events: A typical generic scenarios regarding power outage based on the 2003 Denmark and Sweden outage" to do an intensive study. As regards the range of influence, we assumed that the crisis occurred in these two countries and just affected southern part of Sweden and Northern part of Denmark. People would be influenced in power outage crisis. So that the requirements of common sense are perfectly reasonable and the storyline was seemingly fruitful, however, the work to validate whether our approach is benefit for the future would not be included in our project for the reason that the test time is imponderable.

How to share knowledge

Since our project is a part of the EU project, our outcomes, include models, simulations and documents, will be displayed on the website (http://www.tecnun.es) to share with the other researchers. Besides that, knowledge could be supplied in the organized dissemination conference for open participation of interested bodies (decision-makers, experts, etc).

Thesis Structure

The rest of this thesis is organized as follows: Chapter 2 gives a specific introduction about the background and phylogeny of scenario, scenario planning and system dynamics, which closely relate to our research motivations, and moreover a specific introduction would help amateurs to understand what the scenario, scenario planning and system dynamics they are. Chapter 3 gives a detailed description of estimation theory why we prefer to choose this project and the specific reasons about our motivations in this project, so that we could to validate our project work whether it was satisfied our original motivations or not. Chapter 4 formally describes the problems in our project; here we discuss about the purpose of this project and its requirements, and give a specific description about our understanding to the power outage scenarios. In chapter 5 we give a specific record about self-chosen papers we read, and indicate what happened in each scenario respectively with black bold type to show all key points in them. In Chapter 6 we present our methodology which being used to finish this project as well as the relevant project process. Chapter 7 gives a deeply analysis about scenario and scenario planning by which we will use it for our scenario creation, besides a refined introduction and description about scenario and scenario planning might make amateur researchers to understand scenario planning as soon as possible. Afterwards, Chapter 8 is the main part of this master thesis—model approach. We discuss the very details about how to build this complex model, we illustrate our concept model based on our invented scenario first, and then expand it into a completely model steps by steps, besides that specific data setting are showed in this chapter. In Chapter 9 concludes this thesis. Chapter 10 we give a discussion about this scenario project and also outline some problems that arise and might be subject to further research.

Background

Background about scenario and our learning process

At the beginning of this project, we did not comprehend the exact meaning about ‘Scenario’ even though it’s a common word by which we might touch it in partial fields, for instance in the creation of a movie, various scenario formed one complete opus, and each scenario is a snapshot of an certain event, or series of psychological descriptions, actions and events. As a science fiction film, various splendid fictional scenarios raised people’s longings to the future technology by scenarists’ proper assumptions. As a documentary, the collection of scenarios might be regarded as a true presentation about historical events. Though different scenarios have diverse descriptions, a significant similarity is that scenarios are all being used to describe what happened in the past or the future.

In contract, the scenario which is a main focus aspect in our project is different from the mentioned above. These scenarios are stories that depict some future events, or rather an outline of a hypothesized chain of events.

In general, scenario development is used in strategy planning, for instance, if an organization prefer to test strategies against uncertain its future developments, a proper scenario should be created by strategy analyzers and tested it in diverse environments so that it might help this organization understand different ways that future events might unfold or possible potential threats.

Scenarios should not be used to forecast what will happen in the future. According to our prior research, we tried to give out an objective view to scenario –a scenario is a proper vision to a plausible future. A proper scenario might raise people's perceptions of the likelihood of the events so that help the organization prevent some negative future events occurrence or gain some profits by strategy modification, but an unreasonable scenario might distort people's perceptions or even cause massive failures in the organization.

For this reason, we found that the creation of a proper electricity power outage scenario is vital in our project, and how to create a proper scenario is a new challenge as two beginners. Based on these requirements and professor's guide, we designed a general learning process of scenario:

- Collect existed scenarios' descriptions from various kinds of mediums, such as academic dissertations, news or research reports, etc.

- Try to sift through collected existed scenarios carefully to separate the reference value ones from the rest of irrelevant ones.

- Carefully read these valuable scenarios and find out the similarities among them, although each picked scenario has the different causes and backgrounds.

- Sharpen our opinions by cutting no significant similarities and maintain vital relevant similarities.

- According to our reasonable hypothesis, create a generic power outage scenario which contained significant similarities.

Background about scenario planning

Traditional forecasting techniques often fail to do a prediction for significant changes in the firm’s external environment, especially when the change is rapid and complicated or even relevant information is limited. So vital opportunities and fatal threats might be neglected and the very survival of the firm might be in danger.

Compared to the traditional forecasting techniques, Scenario planning is a strategic planning method which used to sort out complicated and confusing incidents in the future. It requires the organization should start to design several conditions that might occur in the future, and then give a proper imagination what will happen unexpectedly. This analysis method allows us to carry out the full discussion of the objective, making strategies more flexible.

The smart player can always clearly imagine the next step and a variety of possible ‘scenarios’ when moves. Actually scenario planning provides a prevention mechanism for managers keep unflustered under the pressure. It much close to an immersive virtual game, imagines the possibilities that might appear in the future before the crisis occurred. By this way we will be able to be calm and well in response to the uncertain future.

Scenario planning was evolved from military strategy planning, predecessor Herman Kahn was an early founder of scenario-based planning in his work related to the possible scenarios associated with thermonuclear war (“Thinking the unthinkable”). As far as in the late 1960’s and early 1970’s, scenario planning had grown up into a business tool. Pierre Wack developed the scenario planning by using it to help Dutch /Shell to deal with the oil shock that occurred in late 1973. As a result, scenario planning gained much more focus from then on.

Because of the scenario planning achieved a great success in Shell. this management method became more popular in industry and academia than before. For instance, in 1994, the British Government established 15 independent think tank departments based on the industrial classification. By using application of scenario planning, British Government got a perspective plan for 2015.

Scenario planning is not a prediction to the future. Rather, it attempts what is possible. The result of a scenario analysis is a combination of distinct future incidents, all of which are plausible. The followed work then is how to work out each of the possible scenarios.

Some of the advantages of scenario planning as below:

- Managers are forced to break out of their standard world view, exposing blind spots that might otherwise be neglected in the generally accepted forecast.

- Strategy makers are better able to recognize a scenario in its beginning phase.
- Managers are better able to understand the source of disagreements that often occur when they are envisioning different scenarios without realizing it.

Background about dynamic system

System dynamics is an approach for learning things around us. Traditional method to learn things is to separate things into pieces, and then separate secondary pieces in to smaller pieces, repeated this action again and again until the thing pieces was smaller enough to analyze.

But system dynamics is different from traditional method to learn things. In system dynamics things could not be separated into small pieces, things have its integrity; all pieces could not be existed alone. The central concept to system dynamics is to understand how all the objects in a system interact with one another. Variables such as objects, people or incidents in a system interact through "feedback" loops, where a change in one variable might affect other variables as the time goes by, which in turn affects to the original variable, etc.

An example to show how variables affect between each other was shown below:

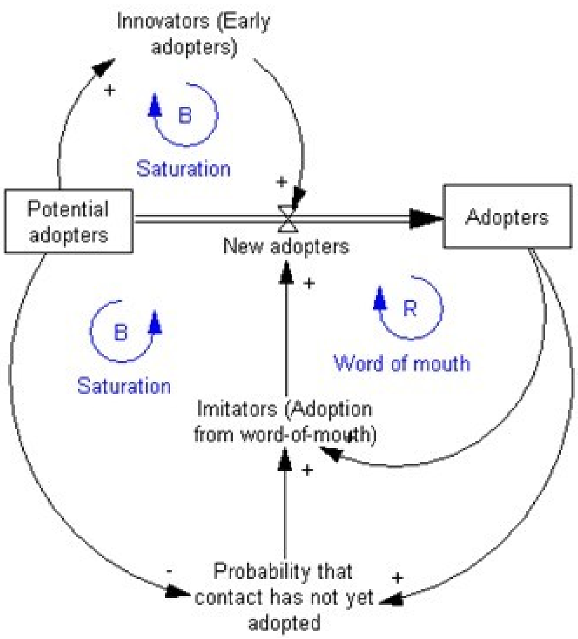

Figure 1 Systems dynamics modeling (John Sterman 2001)

System dynamics was invented at the beginning of the 1950s by a professor named Jay Forrester of the Massachusetts Institute of Technology. At the beginning, system dynamics was not an alone subject system until 1956, Professor Forrester got a professorship form newly-formed MIT School of Management. After that, the Forrester's works in engineering and management were more or less contributed to the creation of system dynamics. To some extent, system dynamics was evolved from Forrester's amazing insights to his research subjects that underlie the engineering and management (Robert A. Taylor 2008)

The originally developed was in the 1950s, Forrester helped GE to improve corporate managers' understanding to industrial processes, and from then on system dynamics was focused and accepted by business analysts. With the cycle of system dynamics techniques, currently system dynamics is being used in all kinds of application areas such as public relationship subjects, organization development, crisis management or stock analysis.

There are three kinds of elements in system dynamics diagrams:

- **Feedback**: Actions that cause changes in system to reinforce/ counteract further actions. (Jose. J. Gonzalez, 2008)

- **Accumulation of flow into stock**: Captures accumulated impact of decisions, allowing computer simulation over time. (Jose. J. Gonzalez, 2008)

- **Time delay**: A delayed period which caused by variables interaction (e.g. a variable change influences another), and get the result after the delay time.

Additionally, there are two distinct form of expression in diagrams:

- **Causal loop diagram**: a causal loop is a visual representation of the feedback loops in a system. An example of causal loop diagram with principle feedback loop in the HCP Management Model is shown below:

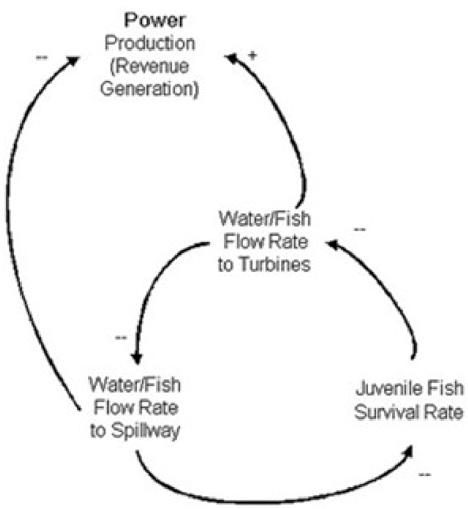

Figure 2 The principle feedback loop in the HCP Management Model

- **Stock and flow diagram**: In stock and flow diagram, a stock is the term for any entity that accumulates or depletes over time, and a flow is the rate of change in a stock.

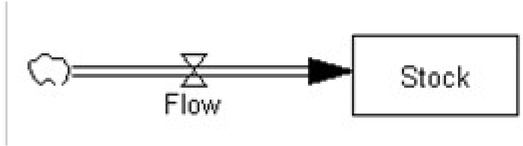

Figure 3 A flow changes the rate of accumulation of the stock

In our example, 'Population' and 'unborn' are stocks, two flows named 'Birth Rate' and 'Death Rate', the population number was affected by birth and death.

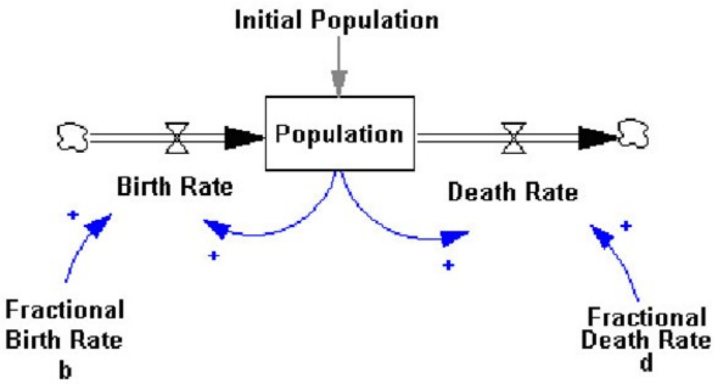

Figure 4 An example of dynamic population rate (Dr Peter Sloot, 2003)

Motivation

Actually during the early in thesis project selection, there are more than 15 distinct projects could be selected, But we thinking back on the purposes of why we chose this project, four main reasons could not be ignored by us:

- **What is the essence of crisis management?**

In our opinion, crisis management is not only a relatively new field of management, but also a branch of security subject. As we know, a system could be secured by technological means such as upgrade system controller software, patch or design new system software, besides system security also could be improved by the other efficient method such as management approach. How to use management tools to improve security environment is a problem we prefer to deal with. To verify whether management approach useful or not is our original driving force in this project.

- **How many aspects should be considered in this interdisciplinary project?**

Crisis is not a single unique incident existed alone, usually a crisis broke out in one node (a place, an area, etc) might bring disaster to the other nodes by cascading effects and impacted different aspects such as legal, social, human, and natural aspects. But according to our practical power outage analysis, how many aspects should we focus on is a problem we faced now. As two freshmen in system dynamics subject, we hold great interests to collect them.

- **How to use system dynamic software to model our generic scenario?**

Though we have learned some skills to use system dynamic modeling software, a creation of entire huge model has never operated before. According to our self-built generic scenario, we should use Vensim to demonstrate the causalities, key factors and relations by mathematical formulas, and then challenge to do a simulation whether it is conform to our analysis.

- **Improve our logical thinking and ability of get quantized data.**

Generally, crisis was generated from an extremely complex system; a timely treatment was determined by the fidelity of generic scenario which the strategy makers generated. They should set proper data for each variable and get the quantized data after the simulation. A strong logical thinking is also a significant ability strategy makers possessed.

- **Try to sniff out applied range of Vensim**

Vensim was known by us as a simulation tools for system dynamics, but the field of its application still puzzled us. Besides being used in energy crisis, are all other types of crisis such as financial crisis available? Both of us would like to come up with an answer of this question which hovered in our brain for a long period.

Problem Description

What's the purpose of our project?

For the energy crisis, disruptions from short energy infrastructure interruptions usually have a considerable duration, and even spread to other infrastructures as an infection with compound effects, for instance, legal, economic and social impacts. Owing to the complexity of energy infrastructure interdependencies and interoperability, effective mitigation will rely on rapid treatment in crisis incubation stage.

Based on our power outage crisis project is a sub-task of EU crisis management, a compulsory work of exhibit all causality between incidents and quantify all relations by mathematical formulas are our purposes in this project. Thus may EU would pay more attention to our research results.

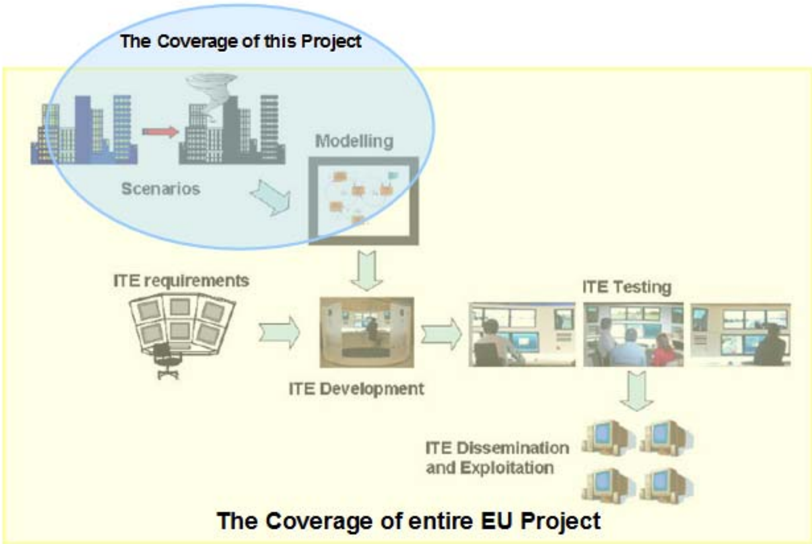

Figure 5 The relation between this project and EU project

The above diagram indicated that the stage of our master project belonged to the prophase research of EU project which included Scenarios (The abstract generic scenarios through analyzed a lot of power cut scenarios), Modeling, ITE [2] requirements, ITE Development, ITE Testing as well as ITE Dissemination and Exploitation. Obviously, this project is a pilot research project that is “Scenarios and Modeling”. For this project we need to search a lot of relevant scenarios and analyze them to find their common and general features so that we can model and simulate them by the dynamic system to provide the prior research of EU project.

The understanding of scenarios

A scenario is a synthetic description of an event or series of actions and events. There has the actual scenario and synthetic scenario. The synthetic scenario is all features’ combinations and permutations of actual scenario and related social changes, so that to research as more as possible useful events who are available to show up the investigative goal in one case.

Scenarios are being applied to do predicted research as typical incidents or full descriptions existed in research area. Scenarios development can be used in organizational development, policy planning, crisis management and so forth. A typical scenario could be supplied to test strategies against uncertain future developments when organizations choose to do. In this case, the scenario is used to

[2] The abbreviation of “Interactive Training Environment”

explore these problems in the life cycle of crisis management, and how to mitigate damage them as a template, so that when similar problems happen, they can be avoided in the stage of crisis incubation or damage can be mitigated in the stage of crisis eruption, or append experience in the stage of maturation.

Literature Review

Prior research on topic

Based on two distinct papers from our professor with their names Simulation Exercise to Manage Power Cut Crises "SEMPOC proposal" and "Collaborative Project (STREP) MISSCRISIS", both of us realized that to chase down typical scenarios are helpful, however, a practice to search scenarios is available in the previous time. Moreover, due to the crisis management relies on the system dynamics analysis, a serial of dynamic system theories and instances are considered as the relevant knowledge with meaningful effect to this project.

The Significance of SEMPOC

Prior research about other scenarios researchers' achievement is a significant approach to get a general theory about our project. Based on reading paper about EU project with title "SEMPOC Proposal", we comprehended the meaning of the scenario what we are not yet touched before. And realized the standard of the definition of scenario by reading documents, so that we get an appropriate way to help us choosing the scenario evolved from real cases. Besides that we can predict that what will happen in uncertain areas by cascading effects if one crisis happened in a certain place, and set up a general ideological system to finish our project research.

The Significance of literature besides, more than seven relevant publications from internet would be available for us to practice how to find out typical scenarios as soon as possible and get a correct common sense. It is possible that more than one scenario existed in each paper. And only the typical one would be chosen by us while ignore the other common scenarios. We don't need to dedicate our time to model and simulate the common scenarios just only for the typical scenario for the reason that typical one would be applied to as much as possible similar types of victims.

Significant literature

Twelve title related literatures from internet and library are available for us to practice how to find out typical scenarios as soon as possible and get a correct common sense.

It is possible that more than one scenario existed in each paper. And only the typical one would be chosen by us while ignore the other common scenarios. We don't need to dedicate our time to model and simulate the common scenarios just only for the typical scenario for the reason that typical one would be applied to as much as possible similar types of victims.

Some important relevant literature is shown below:

1) The Simulation Exercise to Manage Power Cut Crises (funded by the European Commission Directorate-General Justice, Freedom and Security in the 2008 Call Specific Programmed on Prevention, Preparedness and Consequence Management of Terrorism and other Security Related Risks).

2) A Model for a Water Potable Distribution System and its Impacts resulting from a Water Contamination Scenario.(Pasqualini, Donatella, Perry C. Klare, Paolo Patelli, Marc S. Witkowski, and Catherine A. Cleland. 2006. In the 24th International Conference of the System Dynamics Society.

3) Scenarios: The Art of Strategic Conversation. (Van der Hejden, K. 1996.Chichester Wiley.)

4) Scenarios: uncharted waters ahead. (Wack, P. 1985. Harvard Business Review (September-October):73-90.)

5) Infrastructure failure interdependencies in extreme events: power outage consequences in the 1998 Ice Storm. (Chang, Stephanie E., Timothy L. McDaniels, Joey Mikawoz, and Krista Peterson. 2007. Natural Disasters 41:337-358.)

6) Using Models to Analyze the Vulnerability of the Electric Power Network. (Holmgren, Åke J. 2006. Risk Analysis 26 (4).)

7) An Agent-Based Simulator for Critical Interdependent Infrastructure. (Panzieri, S., R. Setola, and G. Ulivi. 2004. In Securing Critical Infrastructures. Grenoble.)

8) The Organizational and Inter-organizational Development of Disasters. (Turner, B. 1976. Administrative Science Quarterly 21 (3):378-397.)

Among them, 2) 3) 4) 5) are used to learn how to make a further comprehension to concept of scenarios, 1) 6) 7) 8) are used to learn how to construct models and do simulations according to typical scenarios.

Additionally, five relevant power outage scenario literatures were chosen by us and did a key research in the following research with them shown below:

(1) Electrical Blackouts: A Systemic Problem (Jay Apt, Lester B. Lave, Sarosh Talukdar, M. Granger Morgan, Marija Ilic, 2004)

(2) The Public Perception of Power Blackouts (H Brayley, M A Redfern, Mermber IEEE, and Z Q BO, Senior Member IEEE, 2005 IEEE/PES Transmission and Distribution Conference& Exhibition: Asia and Pacific Dalian, China)

(3) The black-out in southern Sweden and eastern Denmark, September 23, 2003 (Sture Larsson and Erik EK, Svenska Kraftnat, the Swedish Transmission System Operator (TSO))

(4) General Blackout in Italy Sunday September 28, 2003, h.03:28:00 (S.Corsi, Meber, IEEE C. Sabelli)

(5) A Technical Review of the Power Outage on July 29, 1999 in Taiwan (Chien-Hsing Lee, Member, IEEE; Shih-Chieh Hsieh, Member, IEEE. Department of Electrical Engineering, I-Shou University, Kaohsiung, Taiwan, R.O.C.)

Scenarios Research

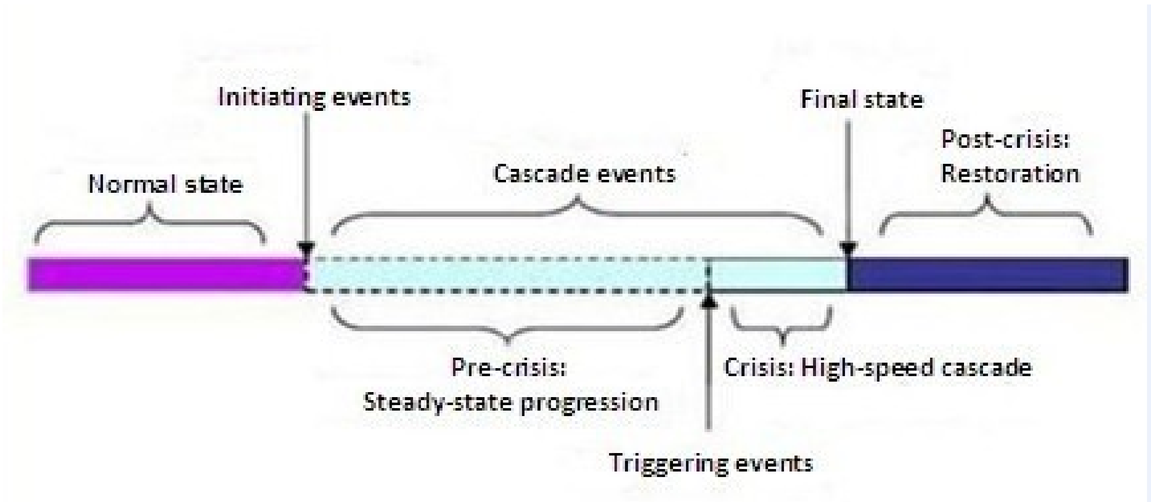

Figure 6 Phases of crisis

Normal state: In this phase, power generating systems operated stable and well. It means that systems work in a normal working condition.

Initiating events: To some extent, they could be regarded as 'seeds' and grow up into trigger events over time. Mostly trigger events might not the same as initiating events, but sometimes they are the same occasionally.

(Initiating events directly cause the crisis occurrences)

Cascading events: this phase contains two distinct sub-phases, '**Pre-crisis**' and '**Crisis**'.

Usually, **pre-crisis** phase is an uncertain incubation, and concrete crisis incidents might not jump out at the beginning of the stage, so a rapid action of treatment during this stage requires researchers provided solutions as soon as possible. Hopefully it can solve problems immediately, but if the problem could not be handled in a short time, more inspecting work are needed positively, so this inspection stage might be regard as a cycle process with an uncertain lifecycle.

If the problems could not be solved during the incubation stage, symbolic **triggering events** might appear unpredictably, at that time human beings will never block the crisis occurrences, and crisis will spread to the other place in a high-speed rate.

Final state: After the crisis fade out, there is a status we might call 'Final state' which obviously distinguish from Normal state.

Post-crisis: Restoration works will be followed with when the crisis faded out immediately.

Because of our project is concerned about power outage crisis, we choose five relevant power outage crisis scenarios as our research area with the advantages that they will make us clearly understand what happened during the power outage phases, and they are shown as below:

Scenario [USA/Canada Aug.14.2003 4:00 pm]

A generation was broken **[Initial Event]**.
Flashover by inadequate tree management as a **trigger event** caused a line broken, and high loads high temperature caused some key transmission lines sagged in Ohio. Meantime, SCADA/EMS **[Incident identify and response system]** is unavailable as the parallel event by neglect of analyst. This made the outage situation cannot be correct handle without enough information. This situation **[outage steady state]** lasted about 1 hour.

Afterwards power transferred to lower voltage levels resulting in voltage degradation **[correction actions]** and then made cascading events on the high voltage system by other lines overstressed and failed and 2 other lines were tripped due to tree contact also. Huge Damage made in this short duration **[cascading high-speed duration]** of 5 minutes.

As a result, the system cannot provide a correct assess without enough data because of they weren’t be saved. Finally, the power grid recovered its working state [**Restoration Duration]** in about 24 hours.

Scenario [Denmark/Sweden Sept.23.2003 12:30-19:00]

Maintenance period, an initial loss generated, a single 1250MW generation unit has been lose **[Initial Event: Loss of power plant]**, due to unit-3 in Oskarshamn Nuclear Power Plant started to pull back by manual control by internal valve problems. The reactor scrammed to a full shut-down and stopped after around 10 second.

The grid provided 15 minutes to active the stand-by reserves, but it cannot be worked by the maintenance, the only way to correct problem is cope with them **[correction actions].**

Meanwhile of repair, a double bus-bar fault **[Trigger Event]** occurred in 5 minutes on the western coast of Sweden and tripped another 2 nuclear power station totally 1750MW as a substation fault and relevant disconnector damage, four 400kV lines in south, as a combination has been triggered also **[outage steady state]**.

As a result, the voltage collapsed in Southern Sweden and Eastern Denmark during some 90 seconds **[cascading high-speed duration]** after the busbar fault. In total, the initial loss of supply was approximately 4500MW in Sweden and 1850MW in Denmark **[Total Initial Loss]**.

[Restoration] The national Grid Control Center managed to energize the 400kV grid down to the southernmost substations within **less than 1 hour**. Then the restoration suffered from faults and energized from Sweden accomplished some **70 minutes** after the grid separation. In **around 6.5 hours** all supplies in Sweden and Denmark were resumed. And the total non-supplied demand due to the disturbance was around 10GWh in Sweden and 8GWh in Denmark **[Total non-supplied demand]**.

Scenario [Italy Sept.28.2003 3:00-21:00]

The thermal losses, due to line current **[Initial Event]**, increase the temperature of the conductors and subsequently the line sag is increased. The neighboring line had to take the risk one’s work **[correction action]**, so the neighbor has a high risk to overload due to the loaded higher. That lasts around **24 minutes** from 03:01 h up to 03:25:30 h before the cascading outage **[outage steady state]**.

Unfortunately this neighbor line also tripped due to a flashover with a tree **[Trigger Event]**, interrupting 1783 MW to ground fault. During the last few seconds, insufficient relief of the overloads causes another 6 lines of the remaining interconnectors towards Italy tripped. The voltage instability phenomena would naturally have led to the loss of synchronism of the Italian generators. This result, unavoidable remaining unchanged the load, was anticipated by further interconnecting line tripping.

As a result, Italy lost synchronism with UCTE and then collapse during **2 minutes and 39 seconds [cascading high-speed duration]**. And the outage affected an area with an estimated 60 million people **[Losses]** and load variation in the continental grid from about 24000 MW at the early hours of the day, up to 50000 MW during the central part of the day.

Power was restored after three hours in the North area and during the same day in the large part of Italy. The energy not delivered amounts to 180GWh. After around 20 hours, the power grid has been recovered **[Restoration]**.

Scenario [London, UK Aug.28.2003]

The 28th August London blackout was the result of a combination of events which led to a loss of supply at 6:20 pm. The blackout lasted for **less than 40 minutes** and supplies from the National Grid were restored at 6:57 pm.

Maintenance period, the first event **[Initial Event]** was sufficiently serious for the transformer to be taken out of service when a Buchholz alarm was raised from a power transformer or its associated shunt reactor. After discussions with operators of the local distribution company, the transformer was taken out of service for **9 minutes [outage steady state**].

These switching operations **[Correction actions]** led to the tripping of protection for a second transformer and the isolation of that transformer. The event **[Trigger Event]** was ‘an incorrect protection relay was installed when old equipment was replaced. New Cross, Hurst and part of Wimbledon were therefore disconnected from the transmission system causing the loss of supply. Approximately 20 percent of the supplies to London were lost **[Initial Losses]**. This affected roughly **476,000 customers**, including parts of London Underground and Network Rail. This period **[Cascading High-speed duration]** lasted for **around 6 minutes** [from 6:20pm to 6:26pm].

[Restoration] After **around half hour** [from 6:26 pm to 6:57 pm], the remaining supplies to Network Rail were reconnected. The circuits were fully restored by 11:00

pm that evening [around 3.5 hour].

Methodology and Project Process

Scenarios are the real cases of crisis or disaster. In our project, power outage scenario is what needs to be researched. However every scenario has its distinct characters, so we have to abstract theirs common sense and make some qualified assumption to create a virtual scenario for our research.

How to create a reasonable virtual scenario? According to many real cases experiences, we find that Scenario Planning is an efficient method.

Scenario planning, in our opinion, it is a valuable effective strategic planning tool for all forms of companies, groups or organizations to do a long-term planning (G Enderle, et al, 1998) under uncertain environments and conditions. It helps them to draw up correct future plans for unanticipated environment and keep a vision in the right direction. In our thesis, scenario planning has been used to guide our virtual scenario making work as a methodology.

Since the virtual scenario has dynamic features with many dynamic behaviors and is involved in the science and management fields. Therefore the System Dynamic is the best method to analyze and model problems that happened in the specific scenario and summarize lessons for the future avoiding of similar failures.

System Dynamic *is an approach to studying the world around us with its function that deals with understanding how complex systems change over time. Internal feedback loops within the structure of the system influence the entire system behavior {SDEP, MIT System Dynamics in Education Project}.* It is the primary theory to instruct our researching work.

System Dynamic project has much different with the other software projects. Analyze and Draw the impact coverage relation among these elements affected by the power cut is the better method rather than data collection and questionnaire in our case. And ‘Vensim’, the professional analysis tool of system dynamic, will be used in our project.

Methodology of Scenario Planning

In general, the methodology of scenario planning might be refined into 4 steps and demonstrated by the figure as below:

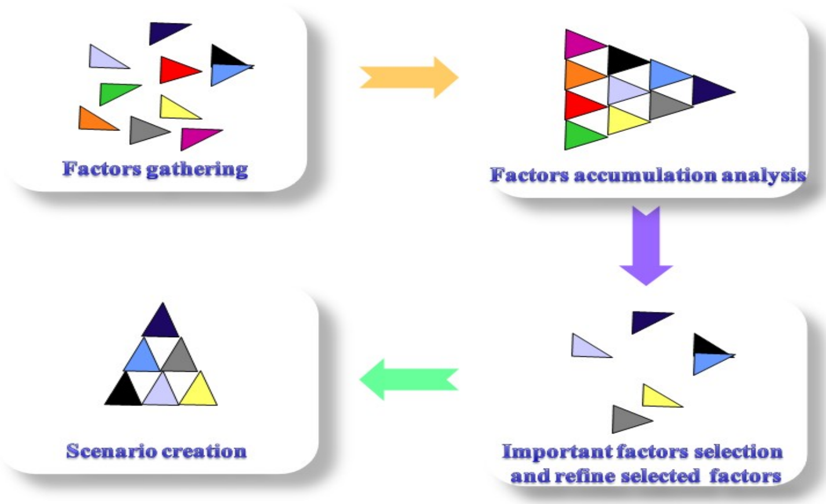

Figure 7 Methodology of Scenario Planning

When scenario planning applied in an organization, the original step by which the organization started was to gather factors from relevant scenarios as much as possible. But not all the factors worth be used in the scenario creation, so an extreme analysis to the accumulated factors seems necessary for the following stage, so that it could refine the accumulated factors into key factors. After all the preparation finished, a scenario creation would come.

The specific research approach of scenario and scenario planning refer to the Research of scenario and scenario planning of this thesis.

Methodology of System Dynamic

As we know, the project is based on System Dynamic. The researching methodology is shown as the following figure.

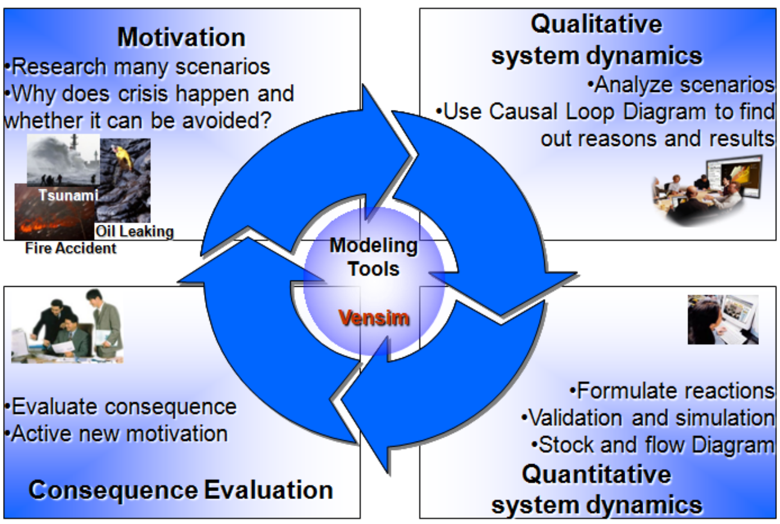

Figure 7 Methodology of System Dynamics

The general simulation software named Vensim will have been used in this project to help us to create models and simulate some consequences to demonstrate our research accord with practical situation.

Motivation

Our research is a part of the EU project which is be researched by our supervisor. It can be seen as our essential motivation to this project.

Generally, all sorts of serious consequences and a series relevant accidents were induced by even just only one crisis occurred. Why and whether it will be avoided or perspective or not? If not, how to control its influence or let the other’s organizations to avoid it? How to find these reasons and solve them are very complicated combination with system science and management science, and also is our research motivation about this project.

Qualitative system dynamics

According to analyze the specific scenario which has been used in this project, we can find many internal interactional relations or some other similar relevant crisis. Therefore the *Causal Loop Diagram* {Sterman, 2000, Business dynamics systems thinking and modeling for a complex world} can visualize these relations and help us to understand them better.

Quantitative system dynamics

After we figured out their interactional relations in stage of qualitative system dynamics, we need to quantify them. It can provide us real-data and formulas to explain how they interact with each other, and how to control them to raze these cascading effects or something like that. It can be solved by *Stock and Flow modelling* {Sterman, 2000, Business dynamics systems thinking and modeling for a complex world}.

Consequence evaluation

These consequences we got can be evaluated by organization to demonstrate whether these models could be validated or not. Furthermore, during the procedure of evaluation, new elements which be ignored or circumvents changed etc. make new motivation show up. Then, we can modify models to adapt new hypothesis and do a series works to improve these model's effect, and finally help organization to solve their security questions.

Project Process

Methodology can help us get a thorough comprehension to the whole project progress and work out easily to this project. Under direction of methodology, the research and practice process is showed as below in this diagram.

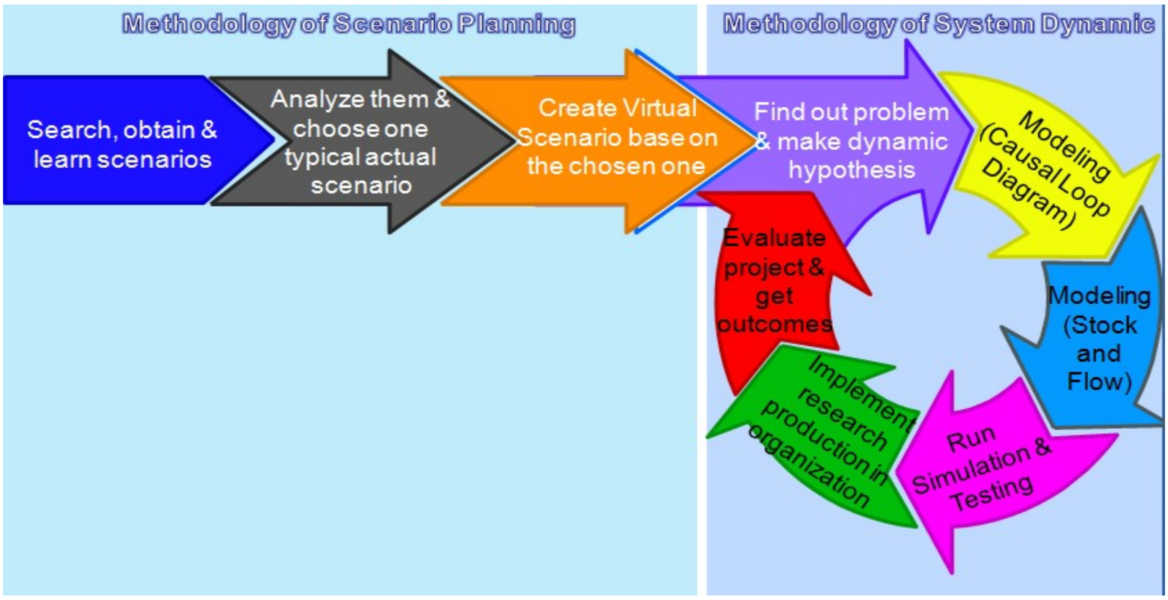

Figure 8 Project progress

There are a series of stages to be adopted by us to accomplish this project.

1. **Search, obtain and learn scenarios**
   Firstly, learn two proposals received from our professor which had been delivered to EU. Hopefully, a proper comprehension of Crises in European Critical Energy Infrastructure could be absorbed soon. And then a criterion about how to choose scenarios can be obtained through the study of these proposals. The summarized criterion of which how to determine a proper scenario should include these following features:
   - A large power outage in Energy Field.
   - An interdependent network; may be Distributed Structure.
   - Many Critical Infrastructures distributed in different location, that's better if they are multinational.
   - Cascading effects.

- Asynchronous crisis manifestation.

Large number of scenarios has been searched by us online; we finally confirmed several scenarios according with the criterion in the real world. They are been showed at the part of '<u>Significant literatures</u>'.

2. Analyze them and choose one typical actual scenario to use in this project

Through study and analyze these several scenarios respectively, some features can be got like: questions which arouse crisis happened, measures that organization made, and influence of the crisis etc. Finally, their commonness can be found. According to our learning and research, one scenario ('A typical generic scenarios regarding power outage based on the 2003 Denmark and Sweden outage') with clear common features must to be chosen to apply in this project.

In the typical generic scenarios regarding power outage based on the 2003 Denmark and Sweden outage, there were happened on December 15, 2003 the Swedish and Danish Power System experienced an electric power blackout. The blackout affected an area with approximately 180 thousand of people as well as their daily lives.

3. Create virtual scenario base on the chosen one

The virtual scenario might not as the same as the recorded scenarios such as power outage in Denmark and Sweden, however, the framework of incidents development could be adopted so as to achieve the scenario planning. We made a rule to keep the scenario derived from real life, but contains reasonable hypothesis. By this way our scenario will make up its rationality and rich potential possibilities on both sides.

4. Find out problems and make dynamic hypothesis

Point to this specific scenario what we chose, these important elements can be got. Moreover some *dynamic hypothesis* {Company, Dynamic Hypothesis} can be design to help us modeling.

5. Modeling (Causal Loop Diagram)

Causal Loop Diagram can make dynamic hypothesis qualitative. *It deals with internal feedback loops and time delays that affect the behaviors of the entire system* {SDEP, MIT System Dynamics in Education Project}. A causal loop diagram is a visual representation of the feedback loops in a system.

6. Modeling (Stock and Flow)

Stock and Flow can make dynamic hypothesis Quantitative. A stock is the term for any entity that accumulates or depletes over time. A flow is the rate of change in a stock.

The causal loop diagrams are given information about each variable's dynamic property. However, causal loop diagrams are not directly connected to numerical simulation models. The stock flow diagrams focus on outflow variables and their stock variables. It causes the requirement of additional consideration of dependency relationships between any two variables in causal loop diagrams when they are examined numerically.

According to the generic scenario, we can define some specific propriety by stock and flow mode so that it can be examined numerically.

7. Run Simulation and Testing

How to ensure models reliability? Running simulation and testing of models, the results can indicate what influence the crisis make and if the measures used to avoid crisis are effective and so on. We can test them over and over in every possible condition, and then get a proper one with best-effort.

According to the analysis of generic scenario, we can get the real situation from the scenario, and abstract them as the simulation circumstance to verify our designed models.

8. Implement research production in organization

The real effect can be got by implementing these outcomes in the organization's real environment. It needs cooperation of organization with us.

9. Evaluate and get outcomes

Ultimately, a specific evaluation can be delivered by the person in charge of this organization to judge the effect of our research through the real impact of implementation.

10. New motivations appear and jump to stage 3

Through the implement and evaluation, new motivations may be got by the organization. Besides, the environment changes because of the project's implement, new elements will show up overtime. Therefore collecting these new requirements, the models can be improved through the new loop from stage 3 to stage 8.

Research of scenario and scenario planning

Scenario

What is Scenario?

Different scenarios cannot be generalized into a unique single definition, but to some extent, each scenario might be regarded as a special story or even a documentary for what might happen in the future. Predecessors have made their own definition of scenarios; Michael Porter gave a definition to scenarios in early 1985, he said: *"A scenario is an internally consistent view of what the future might turn out to be- not a forecast, but one possible future outcome"* (Michael Porter, 1985) After 6 years, Peter Schwartz gave his own description to scenario as*: "A tool for ordering one's perceptions about alternative future environments in which one's decision might be played out right"*. (Peter Schwartz, 1991)

According to predecessor's definitions as well as our self-study, to some extent, it is possible to infer that an entire scenario might not a simple ungrounded prediction, but it might well a vision. A scenario is full description of a plausible future (Mats Lindgren et al, 2003) and the way to that future. Good strategic thinkers would keep considering and ask themselves question like this: "who does what? When and where it happened? What reason this is? (Evolved from Hans Bandhold et al, 2003)", the scenario is an integrated answer to these sorts of questions.

If we hold a ideological view (M Billig, 1999) to compare human beings thoughts with scenarios, abstractly human beings thoughts might be regarded as various scenarios generating processes (R Thompson,1985) when people confront the future with anxieties or anticipations, another way of saying it is common that human beings always generating different kinds of scenarios for the near future (Mats Lindgren et al, 2003) ---the brain will continuously think ahead and process information about what might happen in the future.

Usually, human beings or organizations need a suitable feedback system (CA Desoer, M Vidyasagar, 1975) to know what has happened formerly, but to be able to make a choice which is the best way to go and get the best result, we also need to collect information of the future from feed-forward system (S Mangan, U Alon, 2003). (Figure1.1)

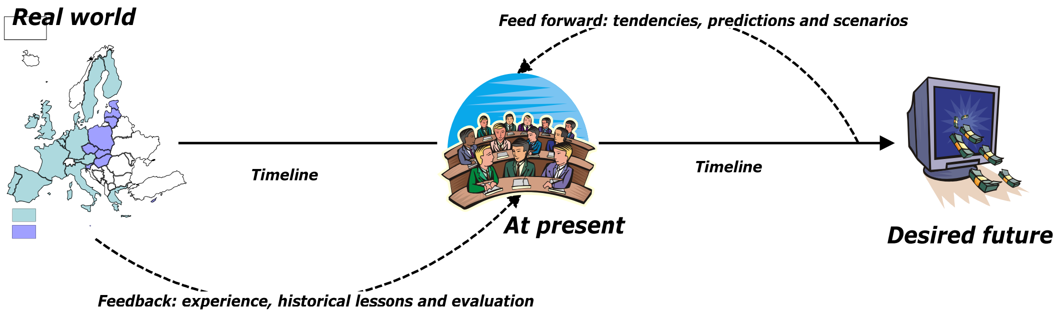

Figure 9 All times influence

Categories of Scenario

Based on learning and researching relevant scenarios to our project plus even some distinct sorts of classics scenarios, we may divide them into two categories: actual scenario (A Velazquez Lozada et al, 2006) which comes from the real life with facts that what has happened, the real world involve different actual scenarios; the virtual scenario (R Von Hanwehr et al, 1995) which is regarding to a desired future (DL Bates, JE Dillard, 1991) comes from strategic thinkers properly visions based on key factors of different actual scenarios and many reasonable probabilities. Figure1.2 illustrates the relations and distinctions of the actual scenarios, real world and virtual scenarios.

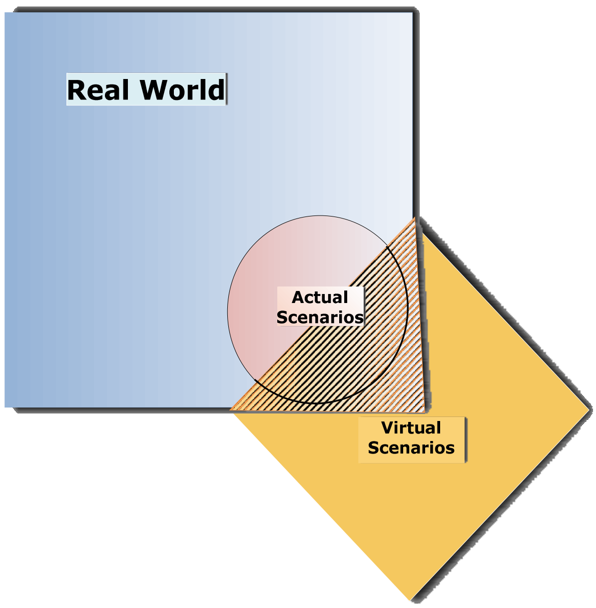

Figure 10 Relations and distinctions of the actual scenarios, real world and virtual scenarios

Use of scenario techniques

Scenarios techniques (R Bradfield et al, 2005; U Von Reibnitz et al, 1988) can be used for different application area, such as apply to financial area help to prevent financial crisis or mitigate the crisis impacts to financial market; help to prevent energy crisis occurrences as well as impacts to living environment; even help national government to prevent the terrorism outbursts. But sum all purposes up and abstract phenomenon into key factors, the usage of scenario techniques might be able to abstract by this figure. (Figure 1.3)

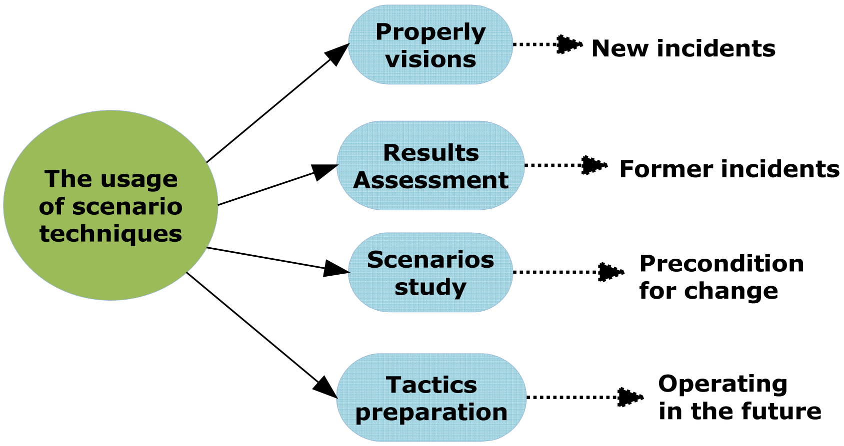

Figure 11 the usage of scenario techniques were able to be used for distinct purposes and different targets

Usually, Scenario techniques are explicitly used for future planning because of planning work is clearly aim to improve practical results (DS Hochbaum et al, 1987). For instance, financial, industry or energy scenarios can lead research development or power source development.

Scenario techniques might stimulate to bring about a properly vision so that might generate new innovative ideas (JK Larsen, R Agarwala Rogers, 1977) for the desired future incidents. And also, as sieve tools pick out from all new innovative ideas and incidents which can properly be used later on. Moreover, scenario techniques are also be able to use for assessment purposes such as test in being strategies, concepts or even operating procedures so that can help to adjust future plans timely. Another function of scenarios is that might be used for study from former related incidents in order to grasp precondition for change in the future, scenario techniques are strongly in challenging existing systems or rules, particularly some key factors or incidents who are involved from existing systems or rules, and be applied to scenario creation.

Significance of scenario in this master project

This master project research “Scenarios for crisis in European Critical Energy Infrastructure”, and the initial word ‘scenarios’ obviously let us know that scenarios are the main object in this research task.

For the energy crisis, disruptions from short energy infrastructure interruptions usually have a considerable duration, and even spread to other infrastructures as an infection with compound effects, for instance, legal, economic and social impacts. Owing to the complexity of energy infrastructure interdependencies and interoperability, effective mitigation will rely on rapid treatment in crisis incubation stage because the incomplete understanding of interdependencies between infrastructures, which results in ineffective response and poor coordination.

Our power outage crisis project is a sub-task of EU crisis management. A compulsory work of exhibit all causalities between incidents and quantify all relations by mathematical formulas are our purposes in this project. Thus may EU would pay more attention to our research results.

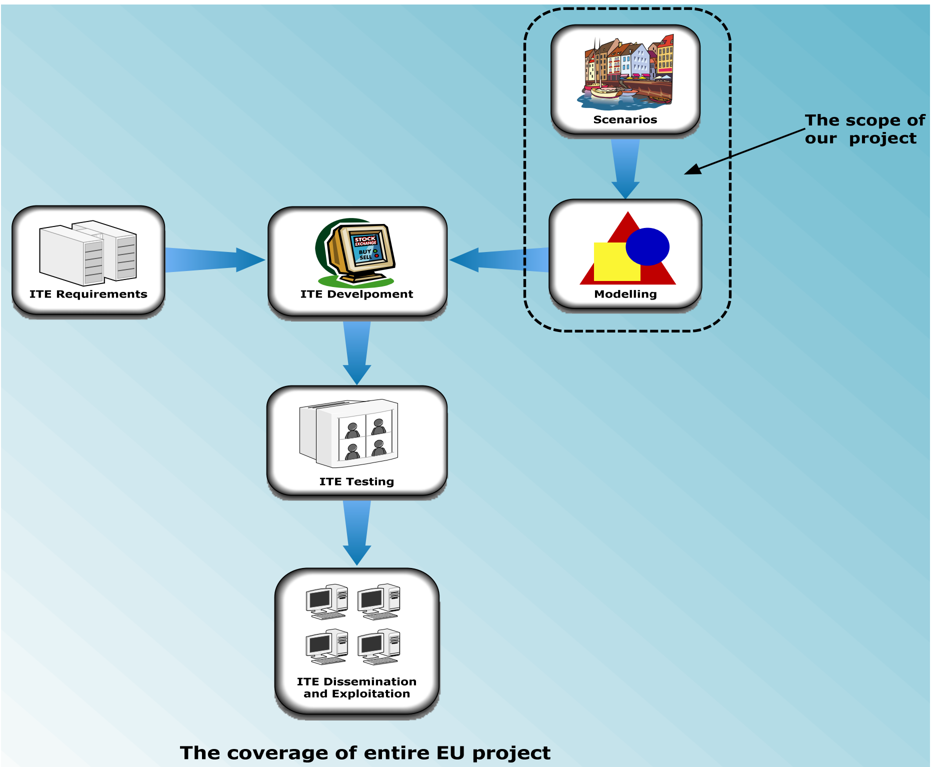

Figure 12 the relation between our master project and EU project

The figure 1.4 indicates the stage of our master project property belonged to the preceding researches of EU project which include Scenarios (The abstract generic scenarios through analyzed a lot of power cut scenarios), Modeling, ITE (Interactive training environment) requirements, ITE Development, ITE Testing as well as ITE Dissemination and Exploitation. Obviously, our project is a pilot research project with its task ‘Scenarios and Modeling’. For this project we need to search various relevant scenarios and analyze them to find out their common and general features ahead modeling and simulating by the dynamic system tool, then provide the prior research of EU project.

Scenario planning

Different strategic thinkers keep them own distinct comprehensions to Scenario planning and have been defined in several ways:

"Scenario planning is that part of strategic planning which relates to the tools and technologies for managing the uncertainties of the future" (Ringland, 1998, p. 83).

"Scenario planning is a disciplined methodology for imagining possible futures in which organizational decisions may be played out" (Schoemaker, 1995, p. 13).

"Scenario planning is a process of positing several informed, plausible and imagined alternative future environments in which decisions about the future may be played out, for the purpose of changing current thinking, improving decision making, enhancing human and organization learning and improving performance" (Chermack 2005, p. 61).

“Scenario planning is future planning in an era when traditional strategic planning is obsolete” (Mintzberg 1994)

Scenario planning, in our opinion, it is a valuable effective strategic planning tool for all forms of companies, groups or organizations to do a long-term planning (G Enderle, et al, 1998) under uncertain environments and conditions. It helps them to draw up correct future plans for unanticipated environment and keep a vision in the right direction. Thinking in scenarios is helpful to understand the logic of developments, make clear of key factors, causalities and potential relations and influence between incidents.

Scenario planning is not just only concerning about scenario writing (L Hirschhorn, 1980), it is more or less closely related to strategic planning (H Mintzberg, 1994), but it’s differ from traditional strategic planning approaches.

	Scenario planning approach	Traditional planning approach
Perspective	Overall, ‘Nothing else	Partial, ‘Everything else

	being equal'	being equal'
Variables	Qualitative, not necessarily quantitative, subjective, known or hidden	Quantitative, objective, known
Relationships	Dynamic, emerging structures	Statistical, stable structures
Explanation	The futures is the raison of the present	The past explains the present
Picture of future	Multiple and uncertain	Simple and certain
Method	Intention analysis, qualitative and stochastic models (cross impact and systems analysis)	Determinist and quantitative models (economic, mathematical)
Attitude to the future	Active and creative (the future is created)	Passive or adaptive (the future will be)

Table 2 Comparison table of scenario planning approach compared with the traditional planning approach *(Mats Lindgren &Hans Bandhold, 2003, p. 26)*

Scenario planning approach

Scenarios planning might be regarded as a powerful tool in strategic planning processes. Early, OODA Loop ("Patterns of Conflict", USAF Colonel John Boyd) **(Figure 13 Diagrammatic presentation of OODA Loop)** was generated and used by US Air Force to assess their pilot ability; actually the OODA Loop is the cycle of **O**bservation, **O**rientation, **D**ecision and **A**ction, previous researchers defined these four steps loop for original scenario planning method. Observation is the initial step which represents survey the environment changes, signs of risks and opportunities, orientation stands for a interpreting course, and then to make strategic decisions, as well as execute a response to decisions for the last.

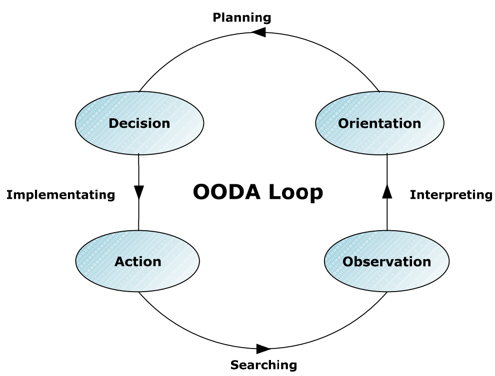

Figure 13 Diagrammatic presentation of OODA Loop *("Patterns of Conflict", USAF Colonel John Boyd)*

Subsequent researchers perfected it based on this loop, expanded moves into five steps, and name it TAIDA (Mats Lindgren &Hans Bandhold, 2003): **T**racking, **A**nalyzing, **I**maging, **D**eciding and **A**cting. Briefly, five steps could be represented as below:

Tracking: trace changes and signs of threats and opportunities.

Analyzing: analyze consequences and generate scenarios.

Imaging: we identify possibilities and generate visions of what is desired.

Deciding: we weigh up the information, identify choices and strategies.

Acting: we set up short-term goals, take the first steps and follow up our actions.

More or less, TAIDA is most the similar to OODA Loop, they keep the same basic theory, but utilize the different concept to expound their definitions, TAIDA's best possession is that it subdivided scenario planning steps. If we compare with OODA Loop, we can find that Tracking is about 'Observation' changes, Analyzing and Imaging are concern 'Orientation' changes, imaging and Deciding are regarding 'deciding' and Acting, almost, is the same as 'Action'.

If we prefer to make clearer about TAIDA and OODA, **Figure 1.6** could provide us a view to these similarities and differences. (*We really want attempt to perfect the former theories which based on OODA and TAIDA, extend it and make it become our origin design in the following time, but temporarily limited in 'thinking box'. So the mean we put this diagram here is to help us think more and jump out from 'thinking box' in order to achieve our bold try. But perhaps we may not create something later on, it's just a try.)*

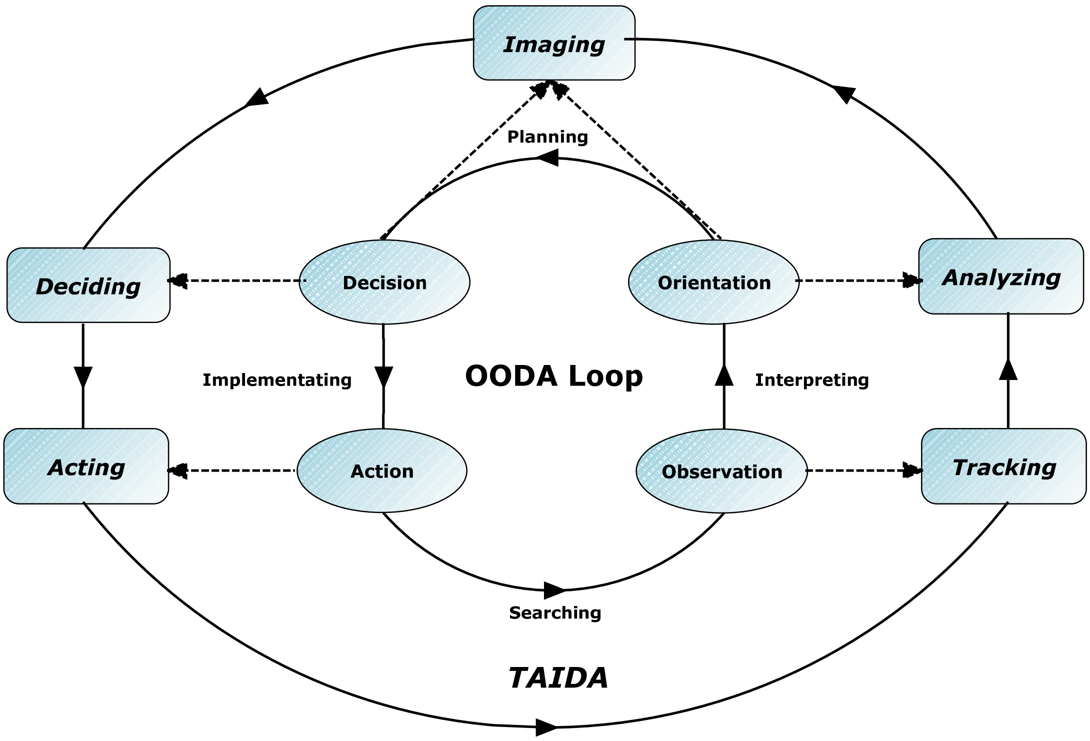

Figure 14 the comparison of TAIDA and OODA

Combining the real project circumstance of ourselves, we could utilize both OODA and TAIDA as references, and sharpen our scenario planning in our master project. So it could be illustrated as below:

(1) Read extensively relevant scenarios of power outage or blackout, find out and trace (DC Adriano, 1986) their changes or differences, key triggers and similar potential threats or risks, as well as opportunities or methods to solve crisis. Even if some key points are often difficult to detect, no evidence to collect, it is very important to find other signals or key factors in such circumstances so that can point out correct methods to be used.

(2) Collect all factors above together as much as possible, analyze consequences, and build our scenario. All evidences and factors collecting work should surround our project work in hand. Analyzing work should based on tracing problems, regarding survey future consequences of variations at present, and interplays or interdependences between tendencies or incidents.

(3) Scenarios generating works is substantial stage. After we finish our analyzing stage, several initial original virtual scenarios might be generated in this following stage, more or less all these sorts of scenarios are corresponding with our analyzing though some irrelevant non-critical points existed in them. But it is necessary to draw them for the multipurpose uses in the coming stage.

(4) As the time goes by, all these original virtual scenarios might be refined into a couple of scenarios and then sharpen into one final typical virtual scenario, this course decided which is able to used determining what kind of scenario should survive finally while what kind of scenario should be eliminated.

(5) Naturally, a multiple environment testing is necessary after we model our typical scenario, but this stage is not identified by both of us, it seems airy to get a result in a short time whether our project work is achieved or not.

As the time goes by, we discover two committed steps played an important role and should be paid more attention by us with some questions we should consider, those are: How to make sure that our scenario developing works are efficient, correct and complete? How to determine our M&S (Modeling and Simulation) result valuable?

According to this couple of questions, two additional approaches might be utilized in our project for virtual scenario construction and development as well as M&S works.

One of them is **MA** (Morphological Analysis) with advantages are when we need to use a greater number of strategic and dynamic scenarios to capture the relevant tasks and environments; consider a greater number of factors though many of these factors involve uncertain contingencies such as the risk of collateral damage. Ordinarily it's difficult to quantify and to capture using conventional computer models. MA, as an approach which uses judgmental input, might be a useful tool to supplement quantitative data or to structure and parameterize different kinds of alternatives. (Tomas Eriksson and Tom Ritchey, 2002)

The other approach is named **CIP** (Critical Infrastructure Protection) which can be used for M&S works. The advantage of such an approach is that criticalities and protection concepts can be assessed. The results will be evaluated, lessons learned derived as preparation for new challenges. These technologies allow immediate and direct information exchange between the different actors, improve the ICT-related processes and further a controlled and secure dissemination of messages and services. (W. Schmitz, 2007)

MA and CIP we mentioned above might be used in our project process in order to handle puzzles such as how to make sure that our scenario developing works are efficient, correct and complete? And how to determine our M&S (Modeling and Simulation) result valuable?

As regards the modeling tasks, we will remain use SD (System Dynamic) tool Vensim to model the entire virtual scenario, but integrate these two approaches as well.

Operational employment on crisis scenario planning for critical infrastructure

How scenario planning be utilized on crisis of critical infrastructure?

1. **Preparation and define the scope.**

Set the time frame and scope of the analysis (in terms of crisis reasons, response, recovery, economic infection, and technologies). Take into consideration how quickly changes happened in the past, and try to assess what degree it is possible to predict common trends in demographics, crisis life cycles and so forth.

Mostly time frame depends on various factors: the spread rate of crisis, the rate of technology change, crisis life cycles, political elections, and so on. Usually we can determine an appropriate time frame by the past crisis incidents to ask what knowledge would be of greatest value.

2. **Identify major stakeholders.**

Decide who will be affected and have an interest in these issues and the possible outcomes. Obviously stakeholders in crisis scenarios consist of civilian, suppliers, employees, government etc.

Identify their current roles, interests, whether and why these interests have changed over time in the past.

3. **Map basic tendencies and driving forces.**

This includes industry, economic, political, technological, legal and societal trends. Describe each trend, how and why it will affect the crisis.

In this step of the process, a causal loop diagram is needed to identify its impact on the current strategy, to judge it's positive, negative, or uncertain. As a rule the brainstorming is used, where all trends that can be thought of are presented before they are assessed, to capture possible group thinking and tunnel vision. Every participating must agree these trends will continue.

4. **Identify key uncertainties.**

Map the driving forces on two axes, assessing each force on an uncertain or relatively predictable and important or unessential scale. All driving forces that considered unessential are discarded. Important driving forces that are relatively predictable can be included in any scenario, so the scenarios should not be based on these.

This leaves us with a number of important but uncertain driving forces. Therefore it is also useful to identify relationships among these uncertainties and rule out any "impossible" scenarios (e.g. full employment and zero inflation), since not all combinations may occur.

5. Construct Initial Scenario Themes.

Once identified trends and uncertainties, the main elements for scenario construction have been confirmed. A technique must be adopted to make the most sense if some uncertainties are clearly more important than others. A simple approach is to identify extreme world by putting all positive elements in one and all negatives in another one. Notice: try to avoid pure best-case and worst-case scenarios.

6. **Check consistency and plausibility.**

Maybe what we just made are not mature scenarios yet, because of there probably have internal inconsistency or lack a noticeable story line.

At least three tests of internal consistency can be as the check method, they are dealing with the trends, the outcome combinations, and the reactions of major stakeholders. Firstly, are the trends compatible within the chosen time frame? (If not, remove them.) Secondly, do the scenarios combine outcomes of uncertainties that indeed go together? (If not, eliminate them.) Thirdly, are the major stakeholders placed in positions they do not like and can change? (If so, the scenario will evolve into another one.)

7. Define the learning scenarios (virtual scenario).

Initial scenarios provide future boundaries, but they may be implausible, inconsistent, or irrelevant. However what we needed is to identify themes that are strategically relevant and organized the possible outcomes and trends around them. Learning scenarios which are virtual synthetic scenarios are tools for research and study rather than for decision making.

A scenario is a story by capturing its essence in a title or name. Narrate what has happened and what the reasons can be for the proposed situation. Try to include good reasons why the changes have occurred as this helps the further analysis.

8. **Assess the scenarios.**

Are learning scenarios relevant for the researching goal? Are they internally consistent? Are they archetypical? Do they represent relatively stable outcome situations? We need assess them from technical angle.

9. **Identify research needs.**

Do a further research to flesh out the understanding of uncertainties and trends. Using the learning scenarios to find out blind-spots, and then assess where more information is needed. If needed, obtain more information on the motivations of stakeholders, possible innovations that may occur in the industry and so on.

10. Develop quantitative methods (or models).

After completing additional research, we can reexamine learning scenarios whether these certain interactions can be formalized. If possible, develop models to help quantify consequences of the various scenarios, such as crisis spreading rate, response time etc.

11. **Converge towards decision scenarios.**

Retrace the steps above in an iterative process until reach scenarios which address the fundamental issues facing the organization.

There have several methods to assess whether the final scenarios are good or not.

- The first criterion is relevance. To have impact, the scenarios should connect directly with the mental maps and concerns of the users.

- The second is internally consistent. The scenarios should be perceived to be effective.

- The third is archetypal. Scenarios should address different futures.

- The fourth is equilibrium. Each scenario ideally should describe a state in which the system might exist for some length of time rather than transient.

As a result, the scenarios should cover a wide range of possibilities and highlight competing perspectives while focusing on interactions and the internal logic within each future.

The application development of scenario planning

In this project, we would like to overview scenario planning as well as its application status in each development stage.

Scenario planning originated shortly after the Second World War by which military organizations used it to do military strategy planning. At that time, USAF (the United States Air Force) use scenario planning to make a guess at the potential strategic behaviors from their enemies so that USAF could prepare relevant strategies in response.

If we make a general survey to the military strategy planning, it could be summarized into specific steps as below:

- Decide on the key problems to be handled by strategic analysts.
- Restrict the time and scope of the analysis direction.
- Identify major beneficiary parties in the competition
- According to benefits, map its basic trends and driving forces.
- Try to detect key uncertainties in the specific development over time.
- Identify the extremes of the possible outcomes (Maximum outcomes and Minimum outcomes) of the driving forces and plausibility.
- Define the scenarios and write them out.
- Make a assessment to the scenarios whether they accord to the research needs
- Develop quantitative methods and simulate scenarios

After that, Harman Kahn developed original strategy planning into a commercialized tool in prediction and applied scenario techniques in industry. A famous instance of which happened in 1973 celebrated scenario planning's popularity in the world, that was Royal Dutch/Shell made a correct forecast to the oil crisis on that year by scenario planning and earn 3 billion dollar from crisis period, thus a ranking seventh oil company jump to the second one.

Though scenario planning was used in business area, the approach and techniques are more or less the same as military strategic planning. An obviously development when applied in business areas was its domain's sectionalization. Scenario planning was divided into two broad domains.

- **Known area** (Something we know and we believe it exist)
- **Unknown area** (Something we consider in uncertain and unbelievable)

Combined with literature review and self study, in our opinion 'Known area' might contained a sub-classification by which we found a same taxonomic approach (relative concept) might exist in our project;

- **Key infrastructure** was one of the main keywords in our project which is the significant factor in our scenarios and key infrastructure failures might direct trigger the crisis occurrence as well as a lengthy restoration period.

- **Subordinate infrastructure** would be ignored in our project for the reason that subordinate infrastructure failures might not cause the crisis occurrence, and social security system can cope with accidental subordinate infrastructure failures well.

Based on these analyses above, scenario planning applied in social security system was an inevitable trend and scenario planning techniques had being improved during these thirty years.

We summarized the application status of scenario planning as well as its historical development into a flow chart below:

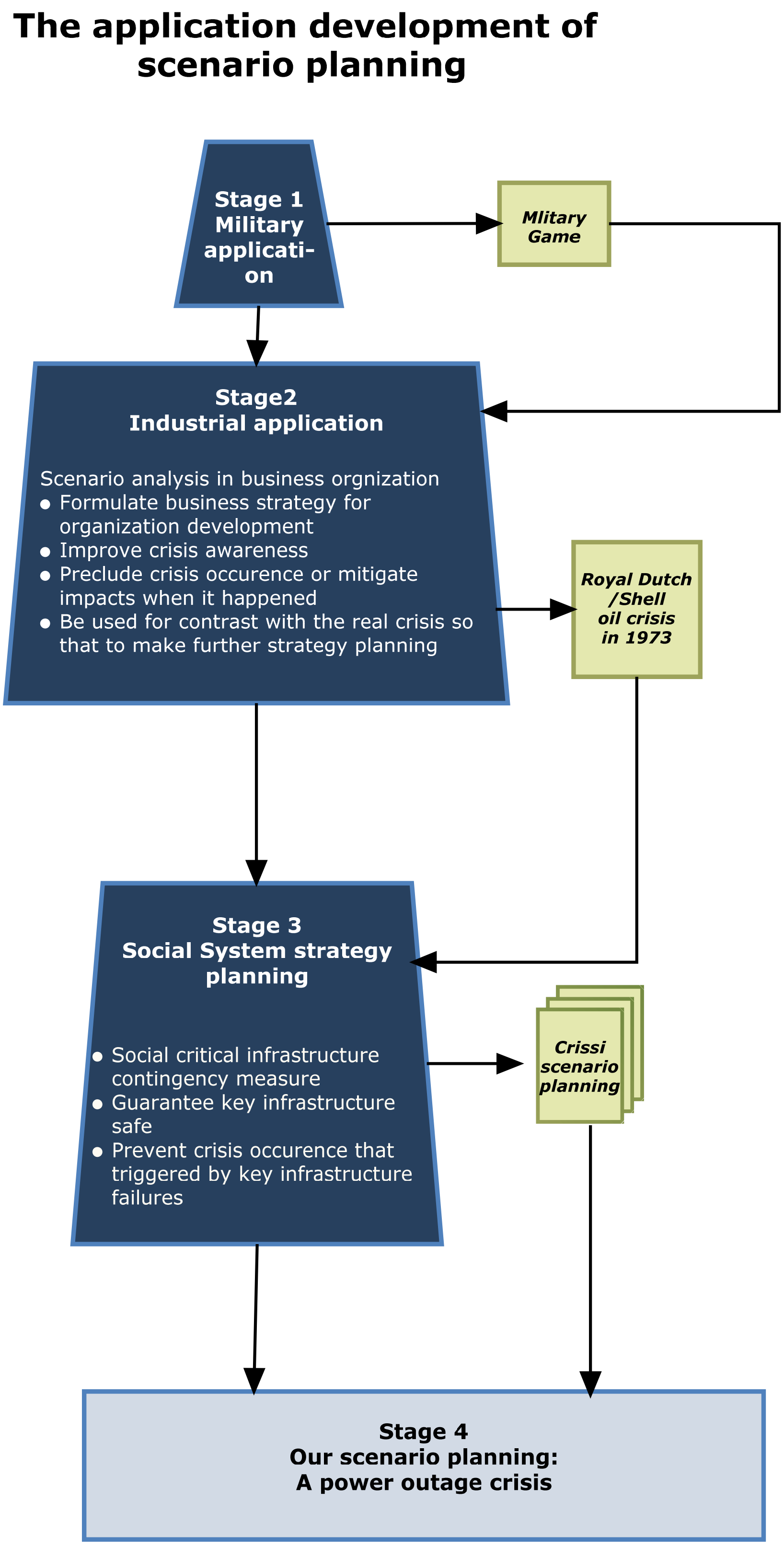

Figure 15 Application development of scenario planning

Scenario planning in power plant

As mentioned in the chapter of literature review, we achieved a research work on power outage crisis scenario and knew that a power outage crisis occurrence would accompany with various cascading effects such as communication interrupt, traffic paralysis or medical system overload. But according to our prior research work properties, we need not to consider all of the cascading effects what we mentioned above, and focus on the main power outage impacts in the location system.

Our modeling works focus on the relationship changes between elements, and provide a model about general power outage flow framework with its simulation as the reference data for the later generation of researchers.

The final Virtual Scenario (Finally Confirmed Virtual Scenario)

On December 15, 2003 the Swedish and Danish Power System experienced an electric power blackout. The blackout affected an area with approximately 180 thousand of people as well as their daily lives.

Cause of weather

It was a Friday morning in the middle of December and heavy snow had fallen across the entire southwest region of Sweden, According to the weather forecast, earlier in the December a strong cold arctic air had moved in from the North Pole with cloudy days and daytime temperatures nearly get above zero centigrade. But unfortunately, a warm front was currently arriving from the south of Europe caused by Gulf Stream effect, providing warmer air towards the southwest region of Sweden, caused heavy snow switched to rain and then strongly sleet. The sleet froze on touch such as the ground, building and important facilities immediately. The sleet had lasted for three days, and because of incessant sleet, it led to heavy icing effect and finally caused an internal valve frozen problem in Barsebäck Nuclear Power Plant, then brought about a blackout in south of Sweden and east of Denmark.

Normal State

Normally, the demand of electricity generation in Sweden was about 25000MW to satisfy *on-peak demand* during cold weather of season, especially in winter. Several fired power stations acted as back-up generation roles when needed. Prior to this time power outage, operating conditions were stable and well as usual, the workload of maintenance center still kept aggregated 50 hours a day. Likewise, a provisionally equipment inspection was smoothly afoot in a nuclear power station located at a southern city named Barsebäck with one of two generation units (unit 1) was temporarily shut down for followed inspection while the other unit (unit 2) which had been finished inspection should delay and wait to restart due to nuclear safety requirements. During this nuclear generation vacuum time, only minor hydro power plant and local CHP generation was in service in south of Sweden.

The generation in the eastern grid of Denmark would distribute 400MW per year to Sweden for sale. Two 400kV submarine lines in this area which connected to Swedish grid were out of service by maintenance work.

Initiating Event

At 9:15, the generating unit in this nuclear power plant which had been checked(unit 2) was started to restart and worked in order, but after 20 seconds this generating unit started to pull back by manual control from its initial 1175 MW generation to around 800 MW , and then a rapid inspection work immediately followed with a discovery that one certain of valves malfunctioned which was used in feed water circuit control system, this valve affected by icing effect due to the generation unit closure formerly and fail to work until the accident broke out, and then caused the feed water circuit control system malfunctioned. The attempt to solve the problem failed and the reactor scrammed to a full shut-down and stopped after around 15 seconds, **(Initial Event)** however, loss of a single generating unit occurs regularly and it is regard as a standard contingency. According to security standards applied within the Nordic Interconnected Grid, real and reactive reserves as well as spare transmission capacity shall be available to deal with this level of disturbance severity without any subsequent supply interruptions. So after that electricity from hydro in Norway, northern Sweden and Finland provided momentary reserves to this area, and the system resumed to stable operating conditions within less than one minute. Though voltages in the southern part had dropped around 5 kV, they remained within 405-409 kV, which is upon critical level. The frequency was stabilized slightly below the normal operating limit of 49.90Hz. **(Correct actions)**

Cascade events

- **Pre-crisis**

The following day at 08:05, a double busbar fault occurred in a 400 kV substation on the western coast of Sweden **(Trigger event)**. Two 900MW generating units in the nuclear power station of Ringhals were generated to support electricity output of this substation. Actually a fault on one busbar should disconnect only one of the two nuclear units and not affect the other because of the circuit breakers' protection. But then the disconnection of the busbars caused 200 hidden faults occurrence with a total output of 1750MW out of service, to the extent that triggered heavy power oscillations in the system, very low voltages and a further drop in frequency down to a level slightly over 49hz where even load-shedding schemes start to operate. The consequence was that the grid was heavily overloaded and lost its transmission capacity along the west coast and affect about 60 thousand people's electricity utilization that lived in the south-west of the area around the capital city of Stockholm.

- **Crisis (High-speed cascade)**

When the voltage collapsed to critical levels, within 1 day, the frequency and voltage had dropped to levels where generator and other grid protections reacted and this entire subsystem collapsed. The consequence was that the grid was heavily overloaded and caused 13 manifest faults appeared in power producing stations by over threshold (5 manifest faults). **(High speed cascade)** According to the statistics, all supplies south of a geographical line between the cities of Norrkoping in the east and Varberg in the west were interrupted and affected about 110 thousand people with their electricity utilization.

In total, the initial loss of electricity supply was about 4500MW in Sweden and 1850MW in Denmark.

Restoration

The national Grid Control Center Managed to energize a certain kV grid down to the southern substations with the fix capability is 0.5 hour/ fault, and then the restoration suffered from faults and energized from Sweden accomplished some **5 days** after the grid separation. In **around 28 days** all supplies in Sweden and Denmark were resumed. And the total non-supplied demand due to the disturbance was around 10GWh in Sweden and 8GWh in Denmark. **(Total non-supplied demand)**

The briefing and simplification of virtual scenario for model approach

Owing to the abstract character of modeling work, we try to summarize our scenario story into a high level framework so that the modeling work is easier to carry out. Something we should to claim that our briefing of virtual scenario will not totally consistent with the basic virtual scenario, (For instance, basic virtual scenario story gave a recital both ‘faults in power grid’ and ‘faults in the nuclear reactors’) but in this section we will only focus the faults in the power grid and brief this component into simplified scenario, for the reason that nuclear reactor might be regarded as a physical carrier which not embodies the information transmission process while power grid might be regarded as a sort of information network system which base on the information interchange, and information system research is the essence of crisis management in our project which is the core research part in our project. Another reason we are not choose to brief ‘faults in nuclear reactor’ is that it might not easy to implement the modeling and simulation for this part.

The simplified virtual scenario was shown as below:

On the normal state, the demand of electricity generation in Sweden is about 20000 MW supplied by national grid center. At the normal running state, the workload of information center in power grid is 50 hour/day totally. There would have no more manifest faults occurring because of enough resources be allocated for maintenance to do daily maintenance and faults prevention work, these resources needed for maintenance are 50 hour/day also. However once attack occur, these resources would be allocated to do corrective actions as much as possible. Usually there exist 5 hidden faults and the average, average manifesting time is 5 days, and 1 manifested fault per day become from hidden faults.

Normally, an equipment inspection is the prerequisite of power generation all year long and the duration is one month. During this period all the generators would have thorough inspection and spare critical infrastructure would stand by so that to keep generating work in regular service. However unfortunately an attack at the second day of equipment inspection caused 200 hidden faults to become manifest and caused the capability of faults detection over its threshold thus tripped more manifest faults of power grid. Great cascading incidents happened after 5 manifest faults appeared in power producing stations, in fact totally 13 manifest faults occurrences in this stage.

Since the capability of fix is 0.5 hour per fault, these faults took workers 1 day to cope with it. As a result, the power grid outage has been corrected within 5 days. All supplies were resumed after 28 days’ restoration. The total non-supplied demand due to the disturbance was around 18000MW.

Minimum Crisis Model Approach (Scenario Simulation and Demonstration)

Usually, the development of crisis management comes from steady contemplations of crisis problems, and improved treatments now offer hope of efficient solution to crisis as well as advanced precaution and protection. So modeling approaches directly affect the strategy applications.

Problem Description

The conventional crisis management has to follow a series of activities of control risk and improve security level. When hidden faults become manifest faults, the corrective action of which organizations' preference is to treat them with more resources in the quickest time. However, this corrective action might trigger dynamic feedback responses such as chain reactions. For instance, neglected maintenance will manifest even more hidden faults. And such feedback phenomena make the application of system dynamics to crisis management become a fertile and productive field of study.

In this master thesis, we build a generic system dynamic simulation model. This model is applied to crisis lifecycle by including factors and relationships that affect the progress of fault propagation in the power grid. Taking account of all possible factors would yield a very complicated system dynamics model, but we simplify the problem to obtain a "minimum conceptual model", focusing on an arguably central aspect of crisis management.

The purpose of building this minimum generic system dynamic model is to provide a generic view of crisis management to person-in-charge of what could happen in the process of a fault treatment and how to manage crisis by control resources. Hence, we hope our work can provide initial insights as "Dynamic Stories" through analyzing feedback loops in the model, so that an in-depth study of typical failures of crisis management can be conducted later.

Minimum Conceptual Model

This minimum conceptual model formalizes the critical interaction between different phases of crisis lifecycle. Through examination of the conceptual model's dynamic behavior, we can make clear how attempts to mitigate cascading impacts result in trade-off challenges in facing the dual pressure to solve manifest faults as soon as possible and to maintain the system keep steady running.

The following figure shows the structure of the conceptual model and the notation in this figure shows the linkages and feedback loops underlying the causal structure.

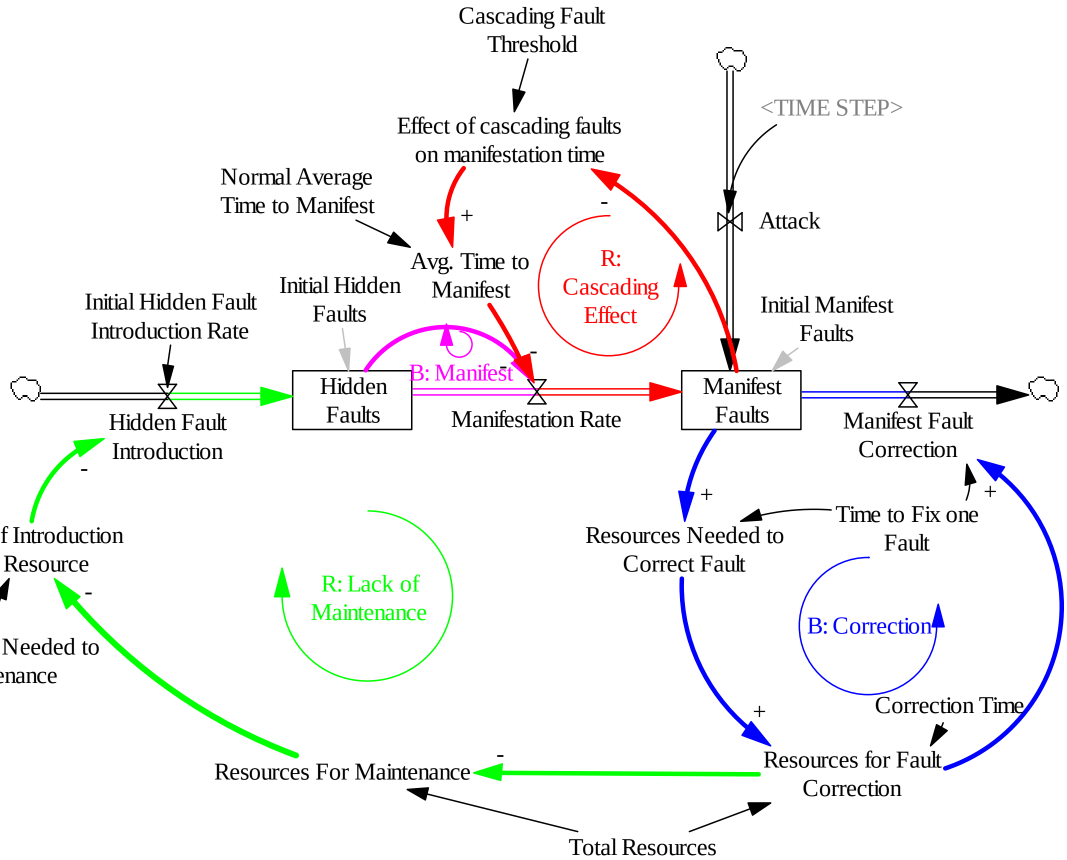

Figure 16 Minimum Crisis Model

The model compares the manifest faults and cascading faults threshold. If the manifest faults are less than the cascading faults threshold, it triggers faults cascading. The effectiveness of cascading has been decided by the lookup table that we defined at first, and it would affect the average time to manifest, and finally the Manifestation Rate would be affected. Once manifest faults have been investigated, corrective actions would be adapted to fix them up as an intended loop. However correct manifest faults need resource, this measure could arouse an unintended result, the hidden faults would boost by lack of maintenance resource. The rate of hidden faults introduction is affected by a lookup table which called rate of introduction by resource. As a result the Manifestation Rate will be affected by the amount of hidden faults and average time to manifest.

While a Causal Loop Diagram is a simplified model of the reality, a model in Vensim has to be as accurate as possible to be able to present correct behaviors. However, this model has some simplifications:

- When the amount of manifest faults are equal to the threshold of manifest faults, the effectiveness of cascading faults on manifest faults will have fifty percent of nominal effectiveness. (This would probably not be the case in real life, as the different location of faults happened, like the key infrastructure is different influence with unimportant infrastructure.) The level of effectiveness is not decided only by amount of faults, but also the level of location where faults happened.
- Several data was not available during modeling of this model. Therefore, some data comes from qualified guesses. This concerns the two tables that signify the effect of cascading on manifest faults, rate of hidden faults introduction by resource.

Although these data are not exactly from the real scenario of power outage, they are based on qualified guess and similarity with the reality. Hence, the simulation results can illustrate qualitatively how crisis develops.

Explanation of Model Structure

There are two stocks and four feedback loops in this model. The basic construct of this model is the following stock-flow structure.

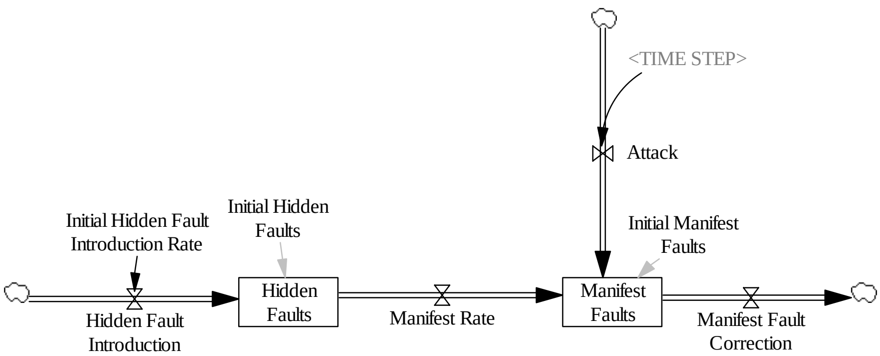

Figure 17 Basic Structure

Basic Structure: at the start of crisis, all failures are in the stock *Hidden Faults*. It's easy to imagine that hidden faults would be manifested once the system has been attacked. Hence *Manifest Faults* indicate failures that have been found and need to be corrected.

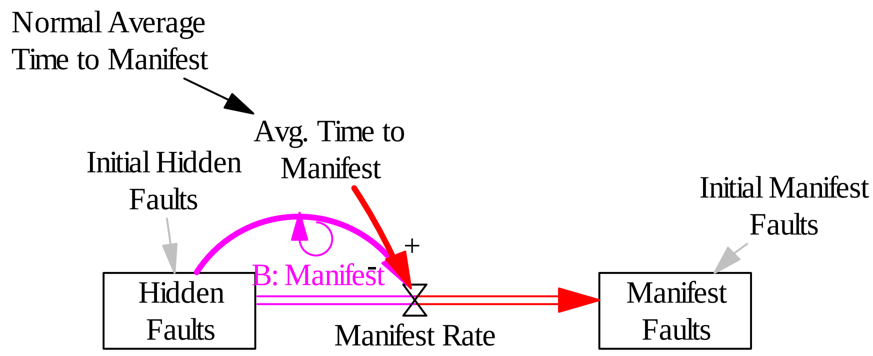

Figure 18 ‘Manifest’ Loop

‘Manifest’ Loop: This is a balancing feedback loop that seeks to reduce the *Hidden Faults* Stock.

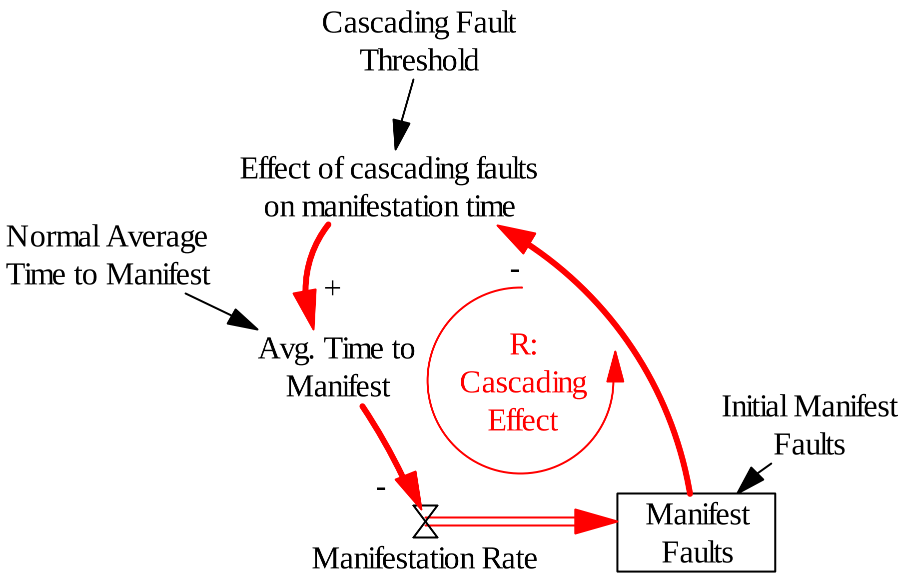

Figure 19 ‘Cascading Effect’ Loop

‘Cascading Effect’ Loop: This reinforcing feedback loop indicates how the cascading effects accelerate the occurrence of manifest faults.

A central construct in both ‘Manifest’ loop and ‘Cascading Effect’ loop is *Manifestation Rate*, the key metric to judge whether cascading faults happen or not. Once the *Manifest Faults* exceeds the *Cascading Fault Threshold*, then Manifest Faults cascade in the new *Manifestation Rate* which calculates by *Effect of cascading faults on manifestation time* and *Normal Average Time to Manifest*. The more Manifest Faults; the larger *Manifestation Rate* becomes. Meanwhile the faster Manifestation Rate runs, the less *Hidden Faults* left.

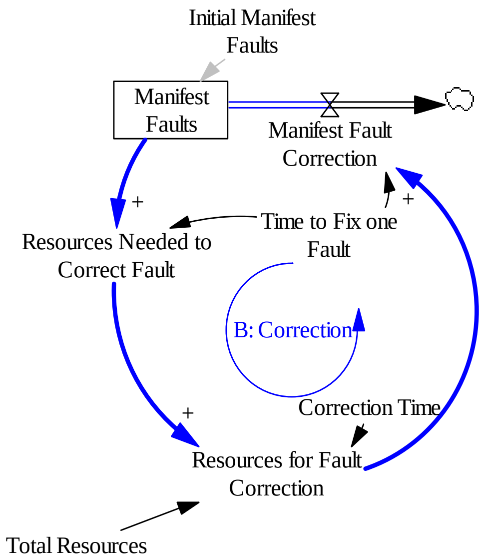

Figure 20 'Correction' Loop

'Correction' Loop: This balancing loop seeks to reduce the amount of Manifest Faults.

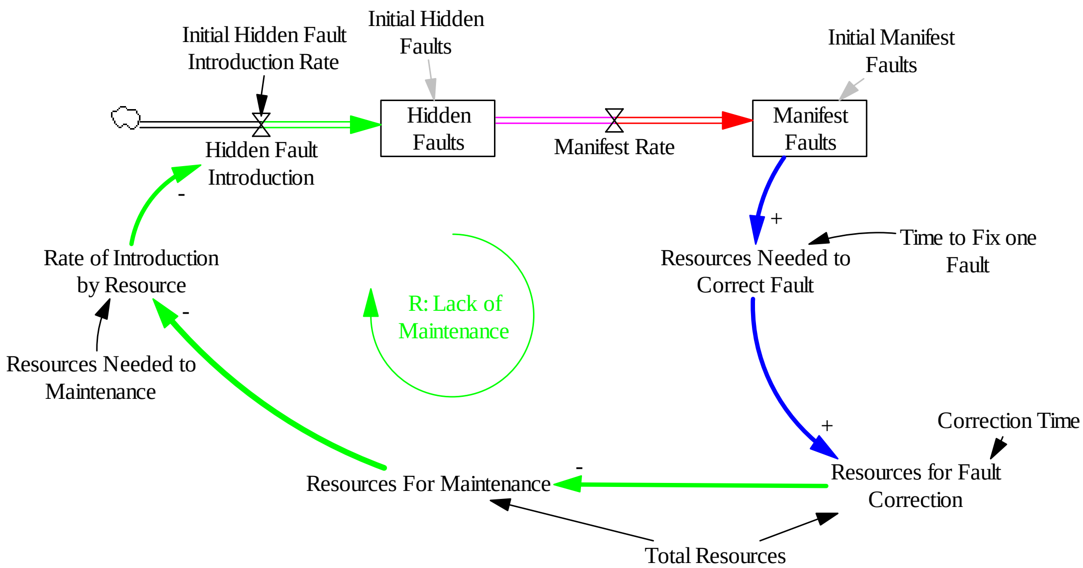

Figure 21 'Lack of Maintenance' Loop

'Lack of Maintenance' Loop: This reinforcing loop seeks to increase the *Hidden Faults*.

A central construct in both 'Correction' loop and 'Lack of Maintenance' loop is *Resources for Fault Correction*, the key factor to balance correction and maintenance. The Total **Resources** are assumed to be a constant, more resources for fault correction, faster correction rate to reduce the amount of manifest faults and less resource for maintenance, and then more rate of introduction by resource, hence more hidden faults produced by lack of resources.

Definition of parameters and formulations

Parameters

To begin with, we make some basic parameters in the procedure of model building according by the final scenario.

Parameter	Value	Unit	Mapping with scenario
Resources Needed to Maintenance	50	Hour/Day	these resources needed for maintenance are 50 hour/day
Total Resources	50	Hour/Day	the workload of information center in power grid is 50 hour/day totally
Normal Average Time to Manifest	5	Day	the average manifesting time is 5 days
Initial Hidden Fault Introduction Rate	1	Fault/Day	1 manifested fault per day become from hidden faults
Cascading Fault Threshold	5	Fault	Great cascading incidents happened after 5 manifest faults appeared in power producing stations
Correction Time	1	Day	these faults took workers 1 day to cope with it

Table 3 Initial parameters of model

Lookup tables

In addition to the parameters, we make assumptions concerning two lookup tables.

One is *Effect of cascading faults on manifestation time* as shown on the following figure. In real life, if no attack triggers cascading faults, the effect of cascading faults on manifestation time would keep its initial effect without any uncontrollable problem. On the contrary, different level of cascading faults lead different effectiveness of system handling. That's why in our model the causal relation between *Manifest Faults* and *Effect of cascading faults on manifestation time* are negative once the *Manifest Faults* exceed *Cascading Fault Threshold.* The negative polarity tells that more Manifest Faults lead to less effect of cascading faults on manifestation time.

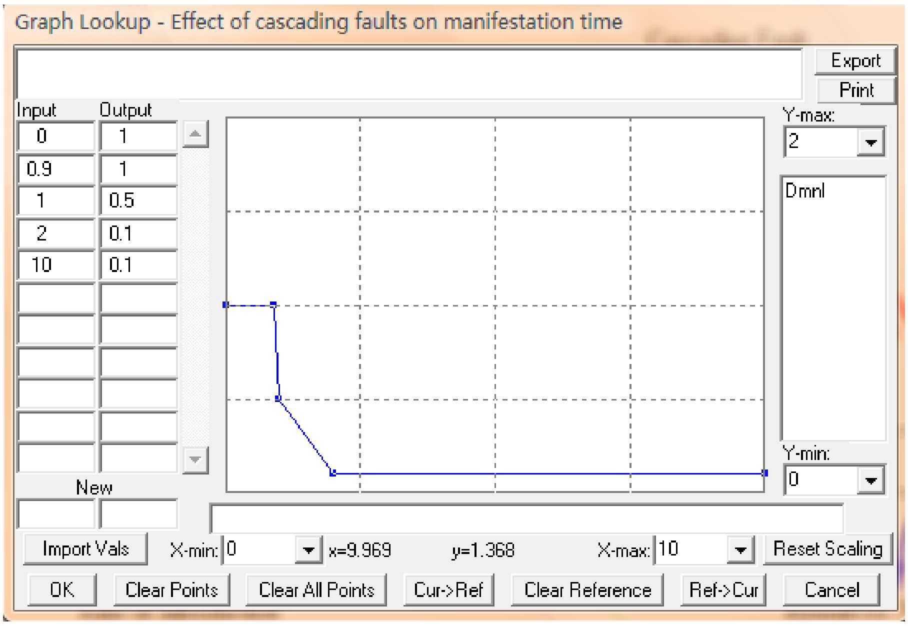

Figure 22 Effect of cascading faults on manifestation time

According to reasonable logical assumption, we think the change of *Effect of cascading faults on manifestation time* depends on the lookup of *Manifest Faults/Cascading Fault Threshold*. Three values (1, 0.5, and 0.1) that we designed represent three different levels of effectiveness on the manifestation time. When no *Manifest Faults* in the system, *Effect of cascading faults on manifestation time* keeps its nominal value, which is the effect is **1**. As long as the *Manifest Faults* increases, the effect decreases. The curve decreases quickly in low *Manifest Faults* area because cascading faults don't happen if the manifest faults keep below of the *Cascading Fault Threshold*. When the Manifest Faults are more than 1 time of threshold of cascading faults, the effect descends to **0.5** of nominal effectiveness. And the value of *Effect of cascading faults on manifestation time* can reduce to **0.1** times of its nominal value at the point that *Manifest Faults/Cascading Fault Threshold* reaches and exceed 2.

Another one is *Rate of Introduction by Resource*, its values as shown as the following figure. When manifests faults occur, a crucial problem is how to allocate available resource between correction and maintenance. This insight has been proven by many projects in the real life. Because more new potential faults would be generated by lack of enough maintenance resource if most resources be allocated to correct manifest faults. Consequently the introduction of new hidden faults would be affected by the proportion of *Resources for Maintenance* and *Resources Needed to Maintenance*.

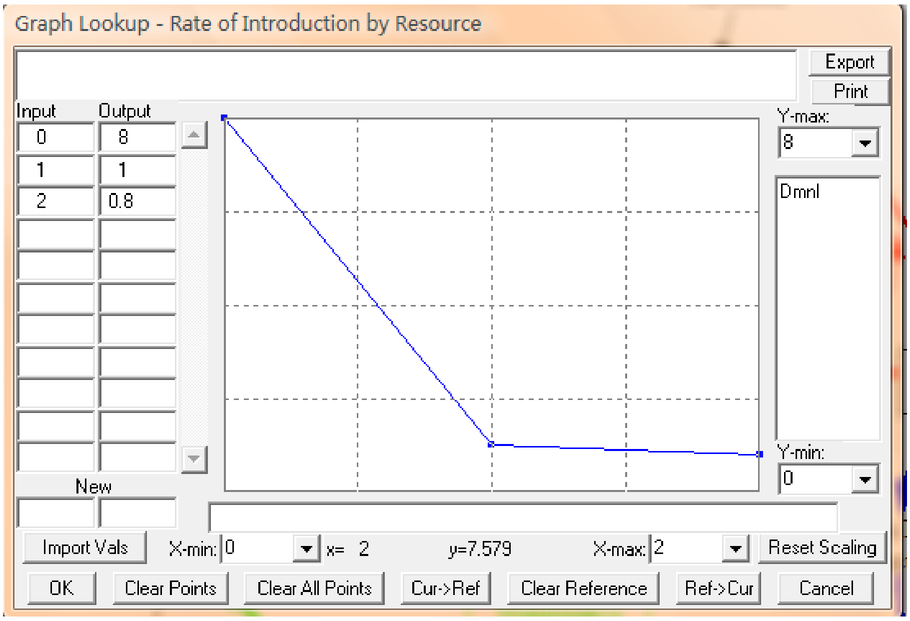

Figure 23 Rate of Introduction by Resources

The curve of *Rate of Introduction by Resources* depends on the lookup of *Resources for Maintenance/Resources Needed to Maintenance*. When the value of *Resources for Maintenance* is 0, the *Rate of Introduction by Resources* is 8. This means no resource to maintenance of system, the rate of hidden faults production would be very rapid. Increasing value of *Resources for Maintenance* decreases the rate of hidden faults generation, because when we give more attention on maintenance of system, more resource would be allocated on the maintenance, and then the possibility of hidden faults generation would decrease. When the resource we allocate to the maintenance reaches the *Resources Needed to Maintenance*, the rate of hidden faults generation would equal to the nominal value. If we still can allocate extra resources to maintenance, the rate of hidden faults generation would decrease to 0.8 times of nominal rate.

Formulations

All formulation could be defined as below:

Parameter	Formulation	Unit
"Avg. Time to Manifest"=	Normal Average Time to Manifest*Effect of cascading faults on manifestation time	Day
Hidden Fault Introduction=	Initial Hidden Fault Introduction Rate*Rate of Introduction by Resource	Fault/Day
Hidden Faults=	INTEG (Hidden Fault Introduction-Manifestation Rate, Initial Hidden Faults)	Fault
Manifest Fault Correction=	Resources for Fault Correction/Time to Fix one	Fault/Day

	Fault	
Manifest Faults=	INTEG (Manifestation Rate + Attack - Manifest Fault Correction, Initial Manifest Fault)	Fault
Manifestation Rate=	Hidden Faults/"Avg. Time to Manifest"	Fault/Day
Resources for Fault Correction=	Min(Resources Needed to Correct Fault/Correction Time, Total Resources)	Hour/Day
Resources For Maintenance=	Total Resources-Resources for Fault Correction	Hour/Day
Resources Needed to Correct Fault=	(Manifest Faults*Time to Fix one Fault)	Hour

Table 4 Formulations of model

Only two parameters, ’Initial Hidden Faults’ and ‘Initial Manifest Faults’, remain to be defined. In principle, we could give them any reasonable value, but then the model simulation behavior would not be easy to understand. Best practice is to start the analysis of the model simulation behavior by defining the model parameters so that the model is in **steady-state equilibrium**.

Three dynamic runs

In our project, we run the ‘Minimum Conceptual Model’ in three distinct runs: run “Equilibrium”, run “Attack” and run “Resource deficiency”.

Run “Equilibrium” – Desired state

Steady-state equilibrium means that the model variables state at constant values through the simulation. Mapping to the real life that is it does not have any attack, the system is in a desired equilibrium steady state.

Obviously, in order that stocks keep a constant value, the net inflow must be zero. In this case, this means the conditions:

Hidden Fault Introduction = Manifestation Rate, which ensures that the stock **‘Hidden Faults’** stays constant, and **Manifestation Rate = Manifest Fault Correction + Attack**, which ensures that the stock **‘Manifest Faults’** stays constant.

In addition, the balance loop ‘Correction’ must be in equilibrium, that is, the variable ‘**Resources Needed to Correct Fault**’ must equal the loop’s goal, viz. ‘**Resources for Fault Correction**.’

We employ the following algorithm:
1) Set 'Hidden Fault Introduction'='Initial Hidden Fault Introduction'
2) Set 'Avg. Time to Manifest '=' Normal Average Time to Manifest'
3) Set ‘Attack’=0
4) Requires that 'Hidden Fault Introduction' must equal 'Manifestation Rate' in equilibrium
5) Requires that 'Manifest Fault Correction' must equal 'Manifestation Rate' + ‘Attack’ in equilibrium
6) Computes ' Resources Needed to Correct Fault'
7) Computes 'Resources for Correct Fault' from the requirement that 'Resources Needed to Correct Fault' must equal ' Resources for Correct Fault’.
8) Compute ' Manifest Fault Correction'
9) Compute ' Resources for Maintenance ‘
10) Looking for the value of ‘Rate of Introduction by Resource’ by the Lookup Table
11) Compute ' Hidden Fault Introduction’ – it should be ‘Hidden Fault Introduction’ equal ‘Manifestation Rate’ equal ‘Manifest Fault Correction’ for consistency

Steps 1 to 11 give the remaining parameters. The last two parameters can be computed.
Initial Hidden Faults = 5.375 Fault
Initial Manifest Faults = 1.074 Fault

Run “Attack” – Controllable Crisis State

We define the threshold of manifest faults is 5 faults, that means if the manifested faults is more than 5, the cascading influence would happen. If the project has been constructed by hidden faults introduction, attack, manifest faults manifesting, cascading faults generating, correction and there has not any other problem like the resource deficiency occur, we can think it’s the controllable crisis state, and name it as the ‘Attack’ state.

Run “Resource Deficiency” –uncontrollable crisis state by lack of enough resources allocation

For better decipher their variation, we changed value of several parameters, viz. Attack = 500 * PULSE (2, TIME STEP), Total Resource = 10 Hour/Day. The target that we change these parameters is to produce the resource deficiency state.

Model Verification and Validation

After we confirm the simulation running environment, we need validate the correction of this “Minimum Conceptual Model” before we analyze its behaviors in these three distinct dynamic states. We know that behavior tests could help us to make the model verification and validation by comparing different simulated results with common sense expectation to judge if these behaviors make sense. Obviously, the main point is to make the model generate the right output for the right reason.

In this model, we define the basic parameters for testing the model’s verification and validation like this: *Initial Hidden Fault Introduction Rate* is 1 Fault/Day, *Normal Average Time to Manifest* is 5 Days, *Time to Fix one Fault* is 0.5 Hour/Fault, and *Correction Time* is 1 Day.

Since one important acquirement of our research is to confirm crisis management from point of view to lifecycle, we decide to do the verification and validation in three different conditions: Desired Condition (normal state), Pre-crisis Condition, and Crisis cascading Condition. As long as the simulation result accord with our expected result as our assumption, we can think this model is corrective.

Desired Condition – Normal State

In the desired condition, no attacks are assumed to happen, well then the cascading faults cannot occur. Accordingly, the Manifest Faults would have no change and the rate of correction, rate of hidden faults introduction, and rate of manifest would have not any change also. Therefore the simulation in a desire condition, the amount of hidden faults and amount of manifest faults keep constant, the allocation of resource keep nominal value also.

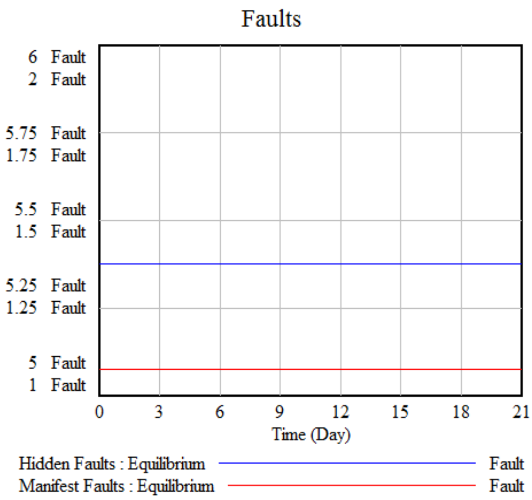

Figure 24 Faults change in desired condition

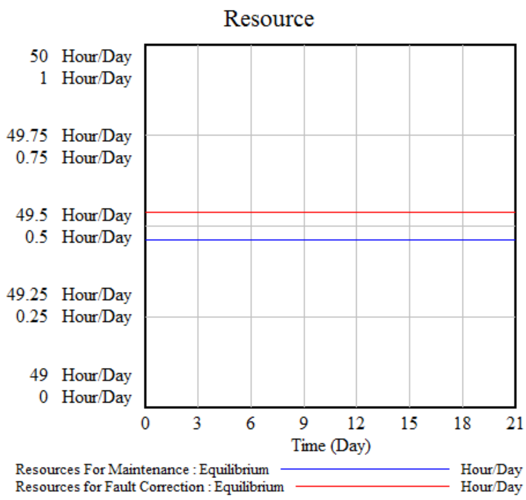

Figure 25 Resources allocation in desired condition

The simulation results illustrate our assumption is correct.

Pre-crisis Condition

The pre-crisis state is the state before the cascading faults occurrence. In our model, which means, whenever the value of manifest faults keep less than the threshold of manifest faults, it keep the state as pre-crisis state. We assume that at the 2^{nd} day a major attack triggers the cascading faults occurrence. Attack equal 200 * PULSE (2, TIME STEP), this means at the 2^{nd} day, the attack is 200 Fault/Day. In this condition, we assume the value of *Cascading Fault Threshold* is 50 Fault which means the manifest faults cannot exceed the threshold at any time and the effect of cascading would keep the value of 1.

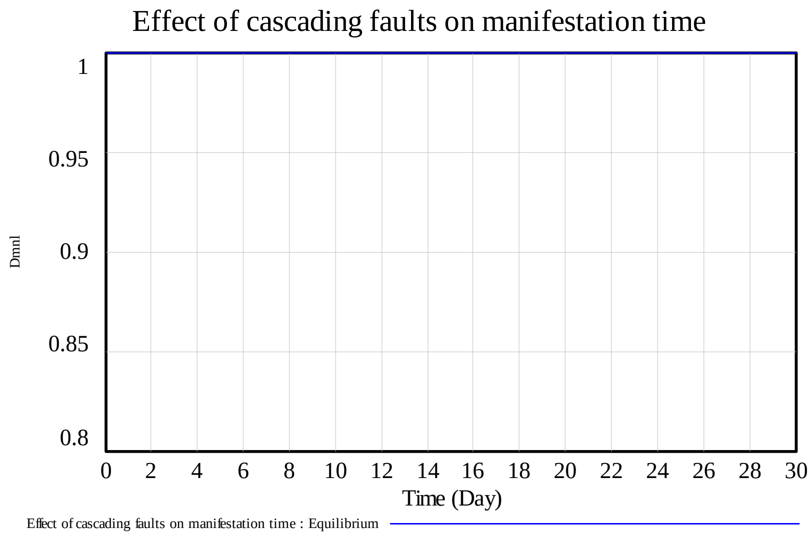

Figure 26 Effect value keep equals 1

Therefore, the only parameter affected is the *Manifestation Rate*, which will increase in a small scope. Accordingly, we can assume that the *Manifest Faults* would have a pulse increase at the 2nd day point, and then the nominal value would come back. Although these manifest faults could be corrected very quickly, but the *Hidden Faults* still would boosted several times at the point of 2nd day by lack of maintenance resource, as well it would resume to its nominal value after these rapid increased manifest has been corrected.

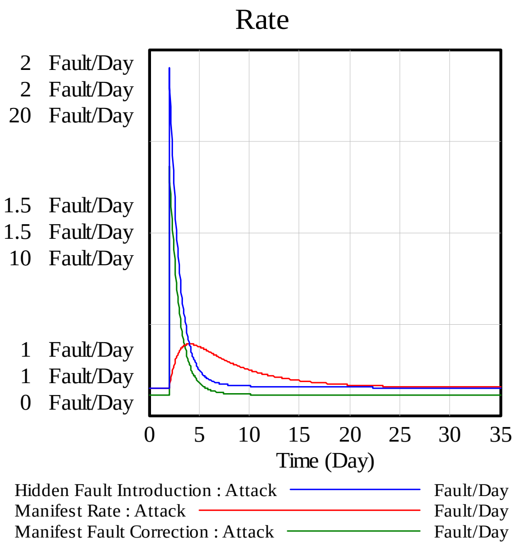

Figure 27 the curve of different rate in pre-crisis state

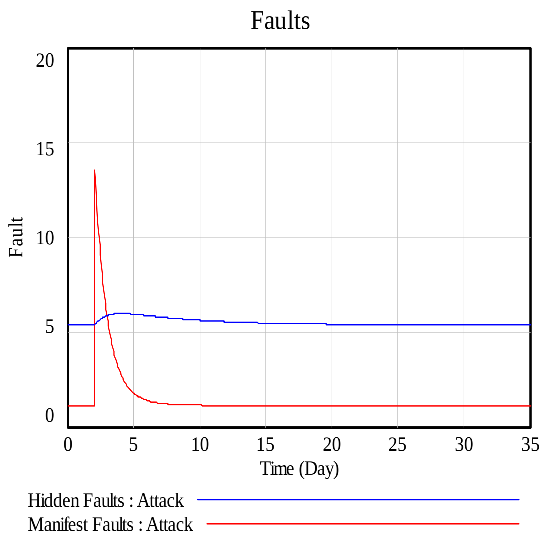

Figure 28 the curves of Hidden Faults and Manifest Faults in pre-crisis state

The simulation results validate our assumption are correct.

Crisis cascading Condition

The crisis cascading state means the high-speed cascading state which contains some cascading faults triggered by the attack of system. In our model, whenever the value of manifest faults keep greater the threshold of manifest faults could make the system in crisis cascading state. We assume that at the 2^{nd} day, a lot attack trigger cascading faults occurrence. Attack equal 200 * PULSE (2, TIME STEP), this means at the 2^{nd} day, the attack is 200 Fault/Day. In this condition, we assume the value of *Cascading Fault Threshold* is 1.5 Fault which means the manifest faults can keep greater than the threshold 2 times for a period of time (2-4.5 day) and the effect of cascading would keep the value of 0.1 in this area.

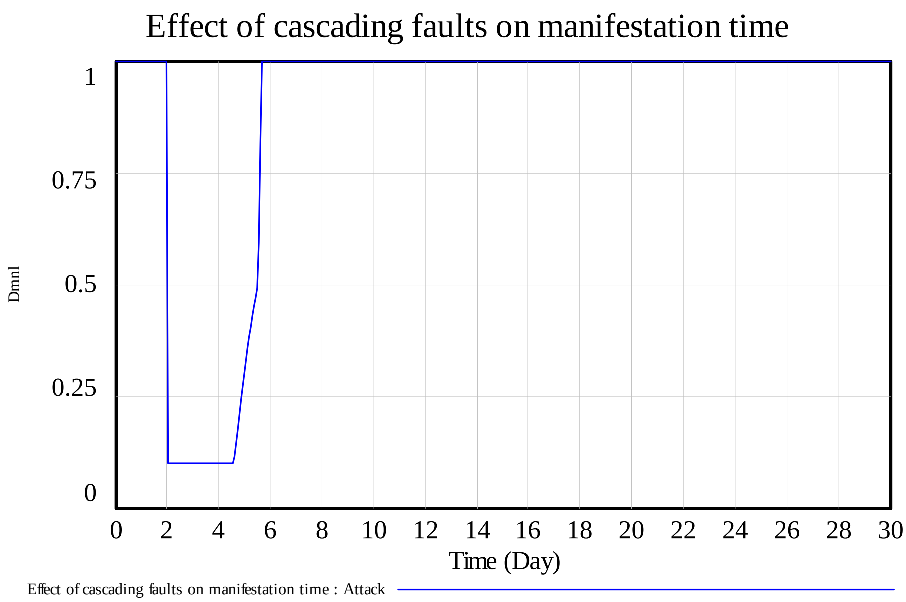

Figure 29 Effect value is 0.1 for a cycle

Hence the only parameter has been affected is the *Manifestation Rate*, which will increase in a small scope. Accordingly we can assume that the *Manifest Faults* would have a pulse increase at the 2^{nd} day point, then they would come the nominal value back; the Hidden Faults would eliminate rapidly at the point of 2^{nd} day by most of them convert to manifest faults, as well it would resume to its nominal value after the cascading procedure finish and these manifest faults has been corrected.

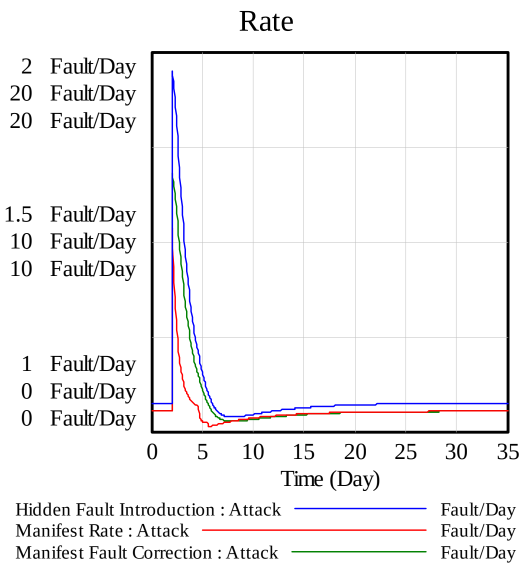

Figure 30 the curve of different rate in crisis cascading state

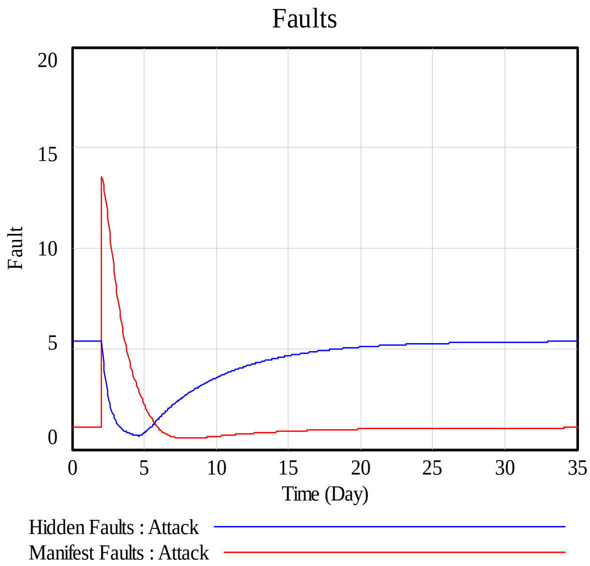

Figure 31 the curves of Hidden Faults and Manifest Faults in crisis cascading state

Dynamic behavior

The model is completed and ready for simulation to look at behaviors after all formulations have been defined and the validation has been confirmed. Behaviors will graphically illustrate the influence the different cascading faults and the allocation of resource in a period of 30 days (1 month).

We will discuss different behaviors in these three different dynamic runs what we have known: Equilibrium, Attack and Resource Deficiency.

The behavior if the system in Steady-state Equilibrium

After the equilibrium state is established, the model runs in the Vensim environment for the generation of simulation graphs to verify that the system is indeed in a steady state. The result of the simulation is shown below:

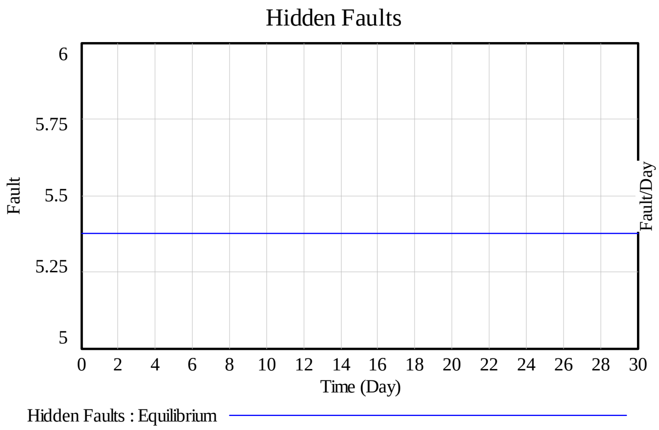

Figure 32 Hidden Faults Introduction in equilibrium state

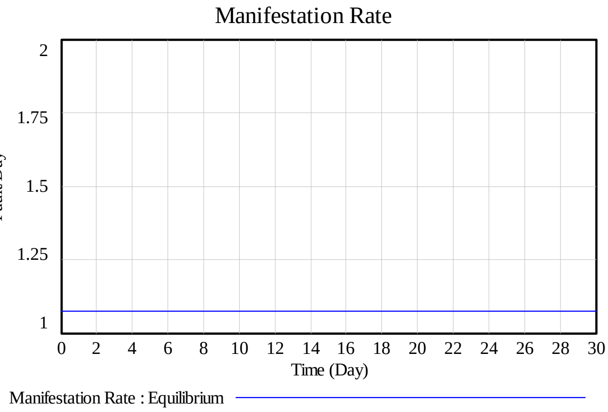

Figure 33 Manifestation Rate in equilibrium state

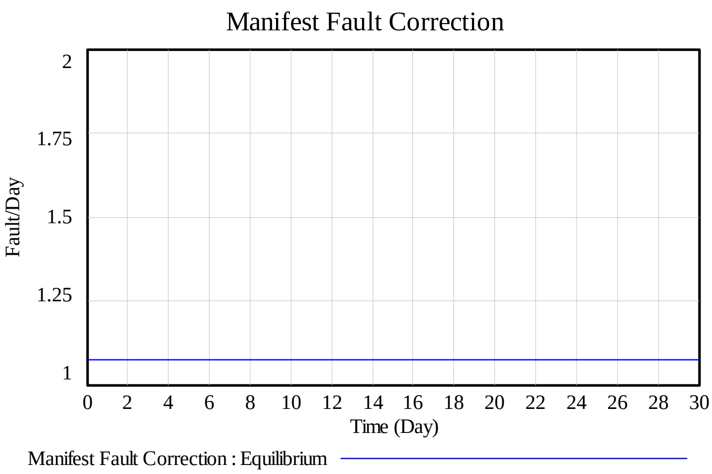

Figure 34 Manifest Faults Correction in equilibrium state

All three figures explain the inflow exactly equal the outflow of stocks in the steady-state.

Moreover faults and resource curve also can illustrate the steady-state is equilibrium.

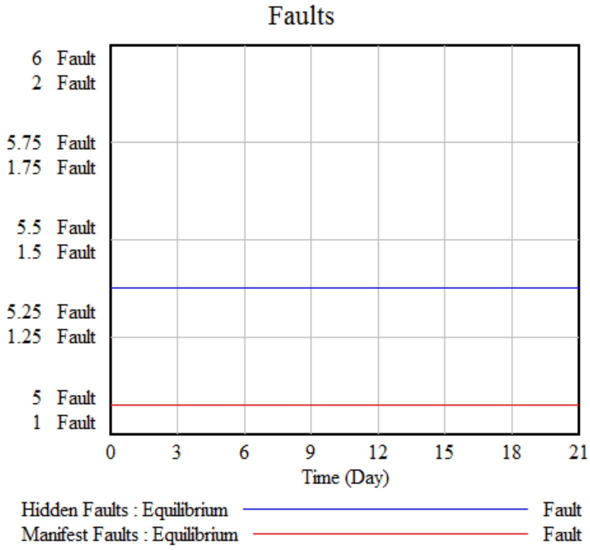

Figure 35 Steady-state behaviors of 'Hidden Faults' and ‘Manifest Faults’

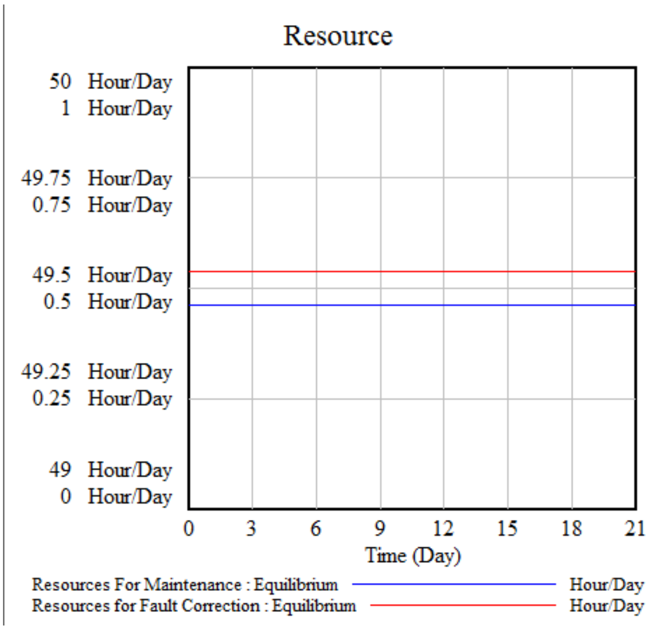

Figure 36 Steady-state behaviors of 'Resources for Maintenance' and ‘Resources for Fault Correction’

This completes the discussion of the steady-state behavior.

The behavior if they system in “Attack” state

As we have spoken, the attack happened at the 2nd day of whole project, the amount of faults triggered by attack to more than 10 faults. Since the threshold we defined is 5 faults, the cascading influence started as we designed at the 2nd day.

We illustrate the behavior through four feedback loops: “Manifest”, “Cascading Effect”, “Correction” and “Lack of Maintenance”.

As remarked before, in this project the two parameters ‘Initial Hidden Faults’ and ‘Initial Manifest Faults’ have got different values from different state. Therefore, the simulation results will differ quantitatively from the results provided in this Section.

A pulse is a very thin column (“thin” referring to the time interval during which some variable raises). In Vensim, the function PULSE (<start>, <width>) yields a pulse of height equal to unity occurring at time = <start> with width = <width> with units of time. Ideally, a pulse should be infinitely thin, but the smallest time interval in equal to TIME STEP, the simulation time step. The model defined by the equation 200 * PULSE (2, TIME STEP) ensures that the area of the pulse equals 200 – no matter which value the simulation time step gets.

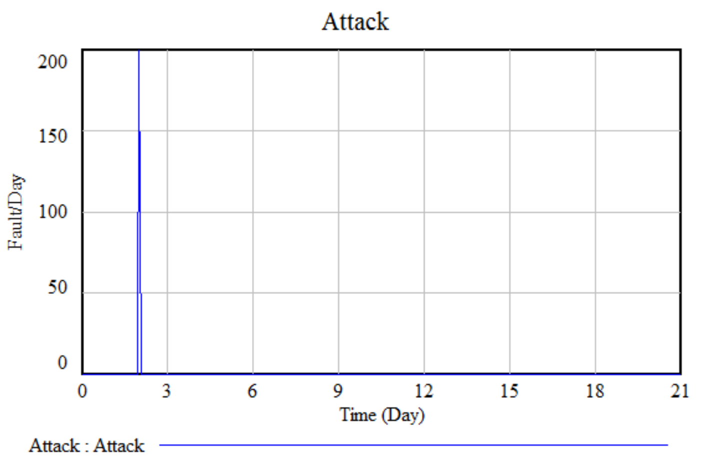

Figure 37 A pulse with width = Time Step

The simulation result is as one would expect: ‘Manifest Fault’ rises to meet the higher pulse value of Attack and then decreases to the equilibrium value.

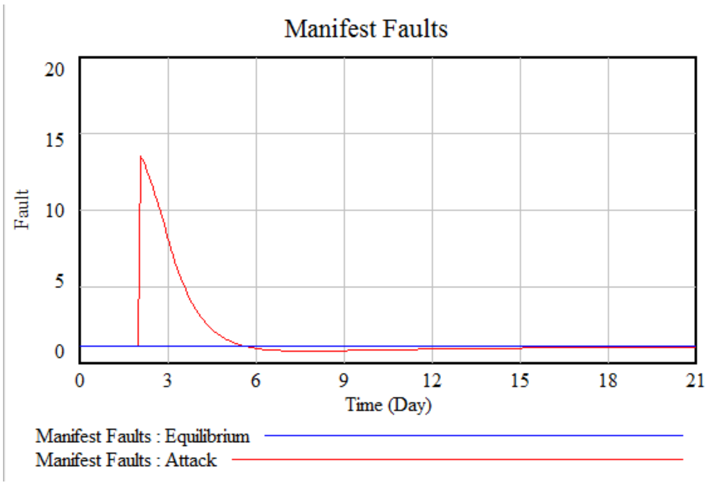

Figure 38 Response of 'Manifest Fault' to a pulse attack

Manifest

From the model, we can know faults manifesting are affected by two parameters which construct a balancing loop 'Manifest'. The following figure illustrates the behavior of this action and the comparison between "Equilibrium" state and "Attack" state.

- In the run "Equilibrium" (the desired state), the Manifestation Rate and hidden faults keep constant. The red line in follow Figures is equilibrium.

- In the "Attack" state compared with the "Equilibrium" state as a constant, when the attack happened Manifestation Rate would take a pulse increase which means much more hidden faults has been manifested in a short time. Similarly the Hidden Faults would start to decrease at point of 2nd day.

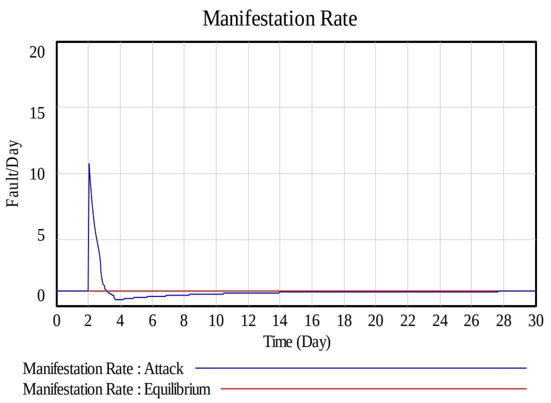

Figure 39 Comparison of Manifestation Rate in 'Equilibrium' state and 'Attack' state

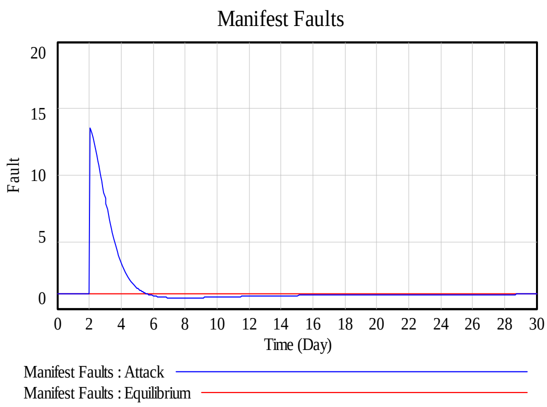

Figure 40 Comparison of Manifest Faults in 'Equilibrium' state and 'Attack' state

Based on our qualified assumption, the *Manifestation Rate* has a causal relation with *Hidden Fault*. They construct a balancing loop. Faster Manifestation Rate, less hidden fault; and less hidden fault make the rate of manifest drop down. The next simulation result shows us exactly the demonstration.

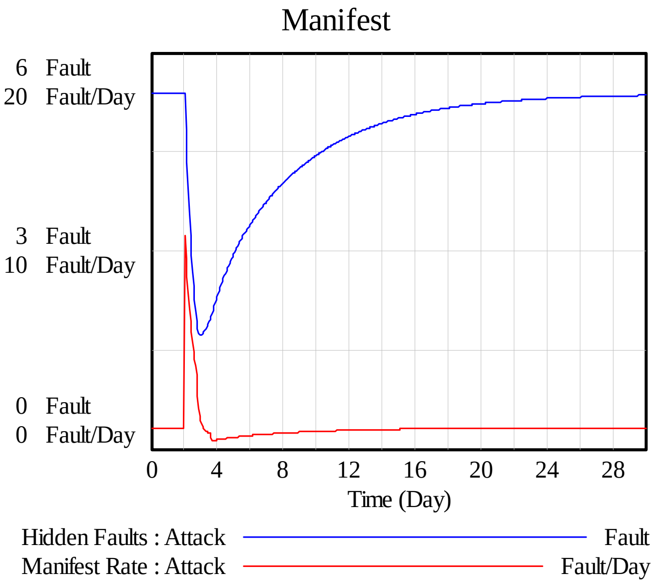

Figure 41 Attack behaviors of 'Hidden Faults' and ‘Manifest Rate’ in Manifest Loop

After the attack which is a trigger, the Manifestation Rate rapidly increases from nominal value 1.075 Fault/Day to 7.65 Fault/Day by the cascading influence and meanwhile the hidden faults drops from 5.375 Fault to 1.716 Fault. As long as the manifest faults get correction, the amount of hidden faults will increase. For the same reason the rate of manifest will smoothly increase as well until the situation become steady again.

Cascading Effect

After the attack, the *Effect of cascading on Manifestation Rate* will keep a constant 0.1 for a couple of days caused by the suddenly increased manifest faults. As long as the manifest is 2 times lower than *Cascading Faults Threshold*, the effect of cascading will increase until to the nominal value is 1, which means no influence to the manifest. The specific variation curve and their causal relation can be shown as Figure 42 Attack behaviors of 'Effect of Cascading Faults on Manifestation Time' and ‘Manifest Faults’.

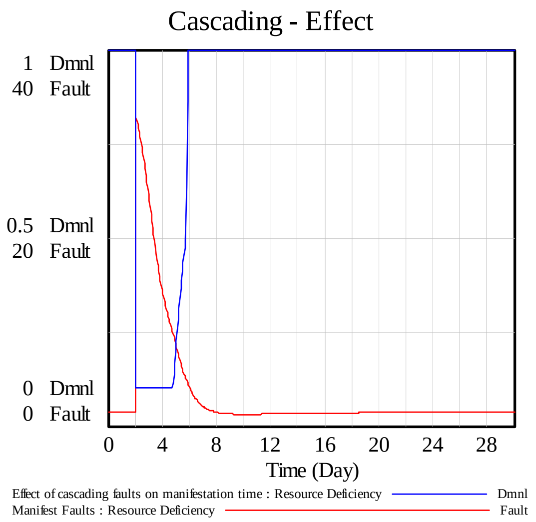

Figure 42 Attack behaviors of 'Effect of Cascading Faults on Manifestation Time' and 'Manifest Faults'

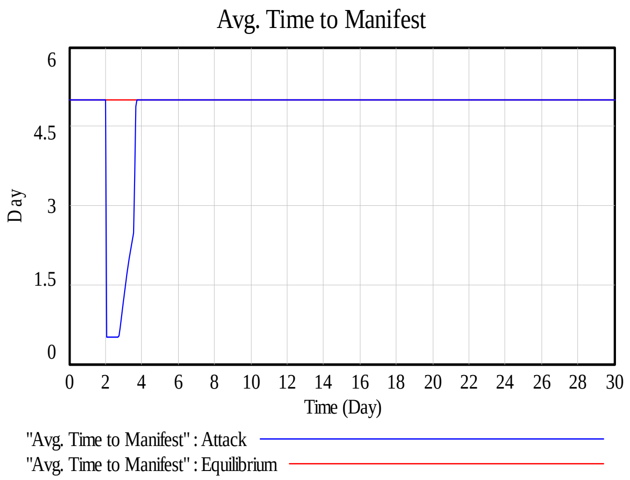

Figure 43 Comparison of Avg. Time to Manifest in Equilibrium and Attack state in Cascading Effect Loop

The variation of cascading effect leads to *Avg. Time to Manifest* being the similar change with it. The time decreases from nominal value 5 Day to 0.5 because of effect drops to 0.1 of nominal situation, and then increase to 0.5 when manifest faults go up to double amount of threshold. The effect's rise leads to the average time to manifest faults until up to 1, the maximal value, and the time recover to 5 Day.

The procedure of cascading instructs a reinforcing feedback loop. It aims to induct manifest faults that can trigger cascading procedure to increase the rate of faults manifesting and generate more manifest faults.

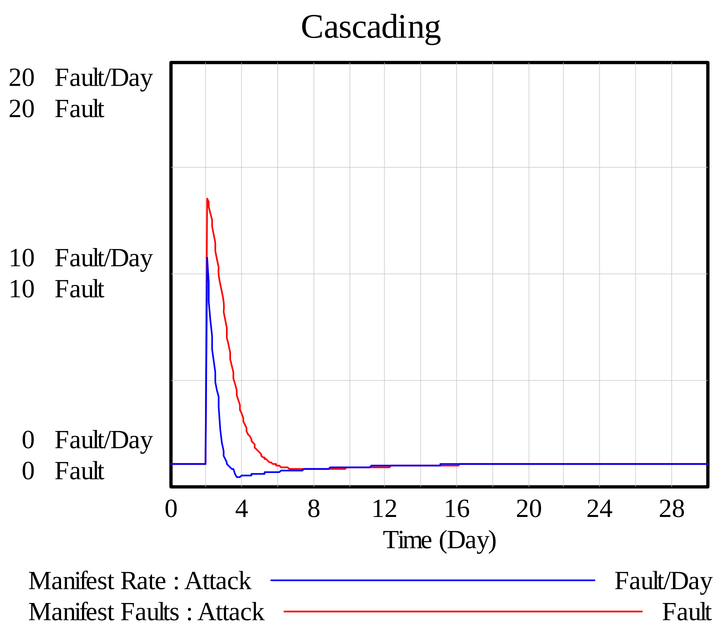

Figure 44 Attack behaviors of 'Manifest Rate' and 'Manifest Faults' in Cascading Effect Loop

Figure 44 *Attack behaviors of 'Manifest Rate' and 'Manifest Faults' in Cascading Effect Loop'* illustrates that the relation between Manifestation Rate and manifest faults are positive. All the variation of them is caused by the effect of cascading. After these cascading faults have been corrected, the situation would recover to steady equilibrium state.

The only difference is that the effect of cascading keeps the value 0.1 for 3 days instead of 1 day in the "Attack" state, and all the relevant parameters have corresponding change, but as a whole thing, the variations are similar.

Correction

The capability of correction depends on the rate of correction and the resource allocated to fix faults. As we can see in this model, the procedure of correction constructs a reinforcing feedback loop that aims to mitigate manifest faults and boost the rate of correction.

In this project, the assumed the *Time to Fix one Fault* is 0.5Hour/Fault, and the Correction time is 1 Day. As we can know according to the common sense, more manifest faults need more resource to fix it, and actual resource for correction is positive with the resource needed but cannot exceed the *Total Resource* 50 Hour/Day of this project. Because we assume the project running in a controllable crisis state without lack of correction resource, the resource needed to correct are exactly equal to the resource for correction.

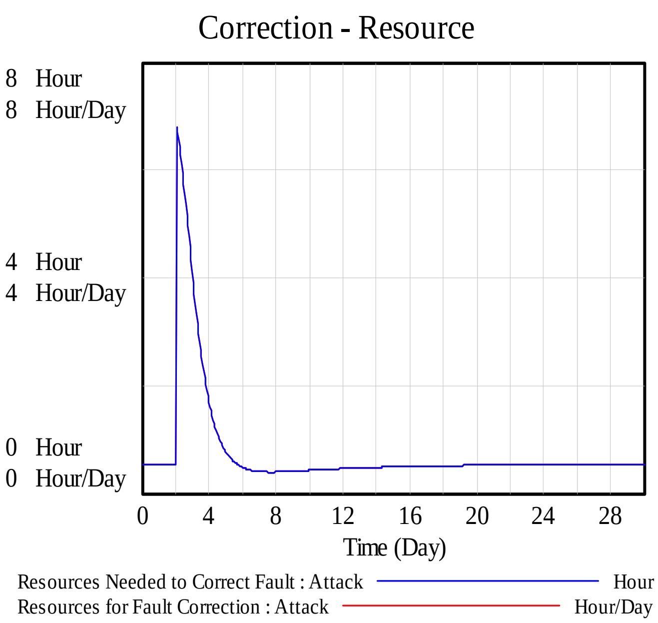

Figure 45 Attack behaviors of 'Resources to Correct Fault' and 'Resources for Fault Correction' in Correction Loop

Figure 45 '*Attack behaviors of 'Resources to Correct Fault' and 'Resources for Fault Correction' in Correction Loop* illustrates when there are enough resources can be allocated to correction, the actual resources allocated for correction are perfect match with resourced needed. After the attack occurrence, the requirement of resource to fix faults climbs from 0.5 Hour/Day to 6.78 Hour/Day. Along with the correction, the resources smoothly decrease until recover to the normal state.

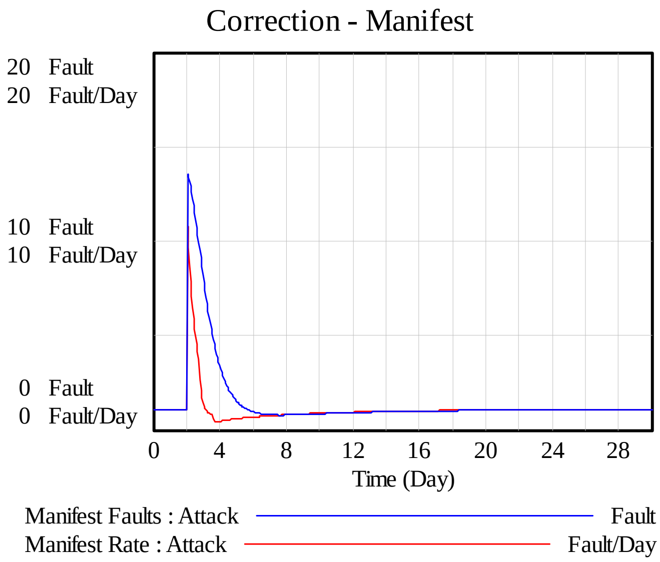

Figure 46 Attack behaviors of 'Manifest Faults' and 'Manifest Rate' in Correction Loop

Figure 46 *Attack behaviors of 'Manifest Faults' and 'Manifest Rate' in Correction Loop* illustrates the comparison of the Correction Rate and Manifest Faults in 'Attack' state. The rate of correction and manifest faults would have a gusty increase by the attack occurrence but along with the correction they would become to the original value over time.

Lack of Maintenance

Similarly the procedure of hidden faults introduction constructs a reinforcing feedback loop namely 'Lack of Maintenance'. When the attack happened, the hidden faults covert to manifest faults, and more manifest faults need more resource to do corrective actions. Nevertheless the total resource are fixed, less resources for maintenance would be achieved by more resources for correction. Furthermore maintenance decrease make the introduction of hidden faults increase, the rate of affect has been defined in the lookup table *Rate of Introduction by Resource*. Consequently the *Hidden Faults Introduction* increase and *Hidden Faults* go up.

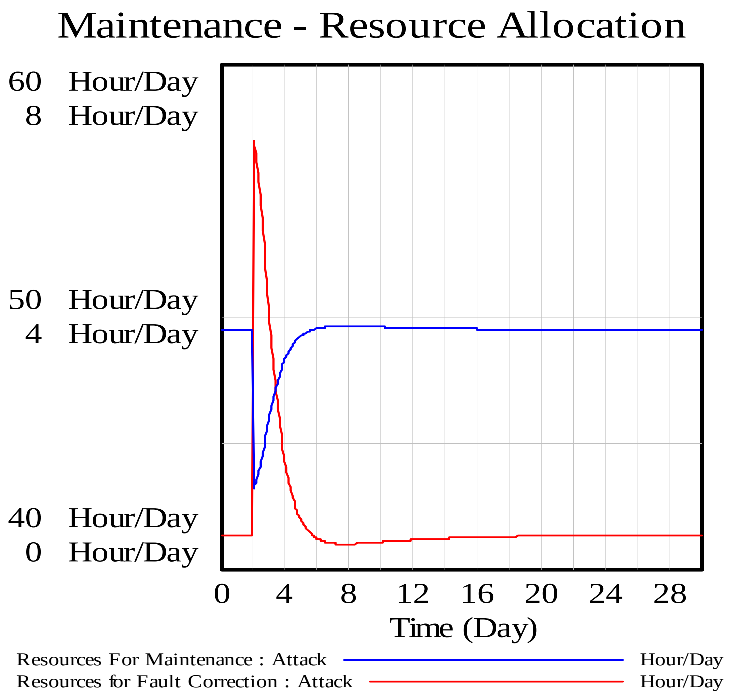

Figure 47 Attack behaviors of 'Resources for Maintenance' and 'Resources for Fault Correction' in Lack of Maintenance Loop

Through the curve of Figure 47 *Attack behaviors of 'Resources for Maintenance' and 'Resources for Fault Correction' in Lack of Maintenance Loop*, we can know the *Resource for Maintenance* and the *Resource for Fault Correction* are complementary, their sum is *Total Resource*.

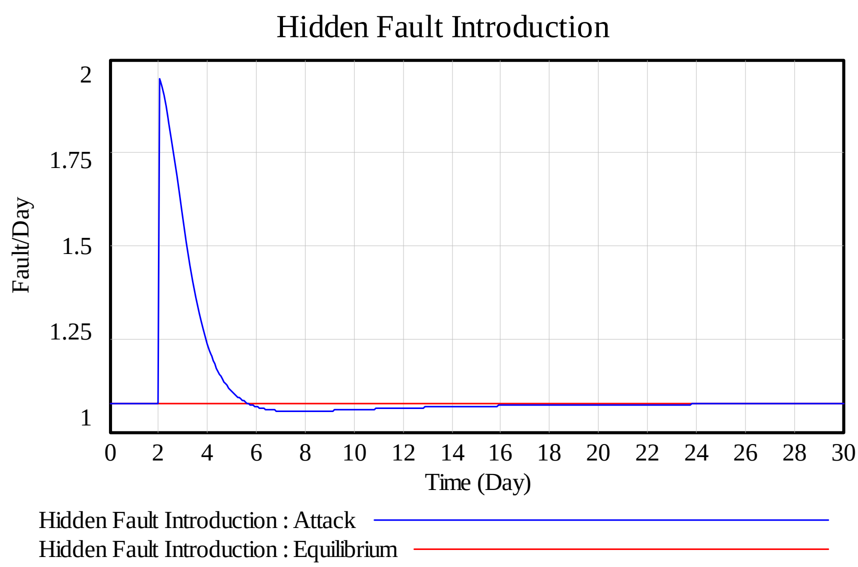

Figure 48 Comparison of Hidden Fault Introduction in Attack state and Equilibrium state

These variation curves of Figure 48 *Comparison of Hidden Fault Introduction in*

Attack state and Equilibrium state are pretty clear to explain how the *Hidden Fault Introduction* changes. In the steady equilibrium state, the introduction keeps the value of 1Fault without any attack. Once the attack happens, the rate of hidden fault generation will have a rapid growth at the 2nd day. 3 days later the introduction will fall down to the initial value with the allocation to maintenance increase to the Resources Needed to Maintenance.

For the same reason, we can understand the causal relation between *Hidden Faults* and *Manifest Faults*.

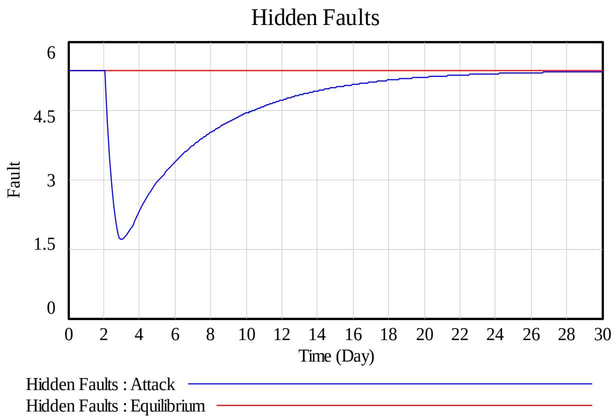

Figure 49 Comparison of Hidden Fault in Attack state and Equilibrium state

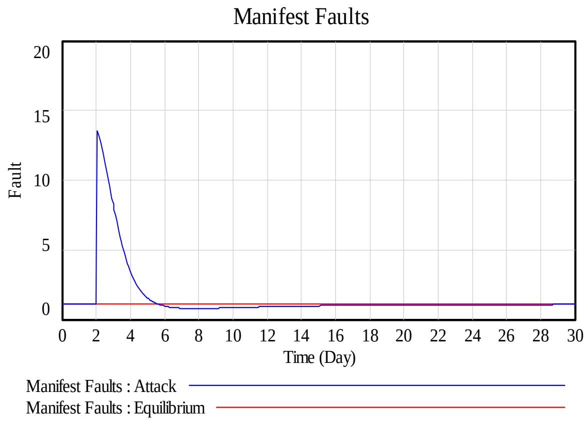

Figure 50 Comparison of Manifest Fault in Attack state and Equilibrium state

Because the introduction of hidden faults is a reinforcing feedback loop, that's obviously hidden faults and manifest faults are negative. The manifest faults are triggered by attacks and changed by rate of Manifestation Rate. The *Hidden Faults* decrease from 5.375 Fault to 1.6 Fault at the 2nd day which is the day of attack, and at the same time the *Manifest Faults* get a rapid increase from 1.074 Fault to 13.56 Fault by the same reason. Along with the correction, *Manifest Faults* decrease to its nominal 1.017 Fault in 15 days and *Hidden Faults* increase to its nominal 5.375 Fault in 28 days.

It is necessary to discuss the causal relation between *Hidden Faults* and *Manifest Faults* in the "Attack" state.

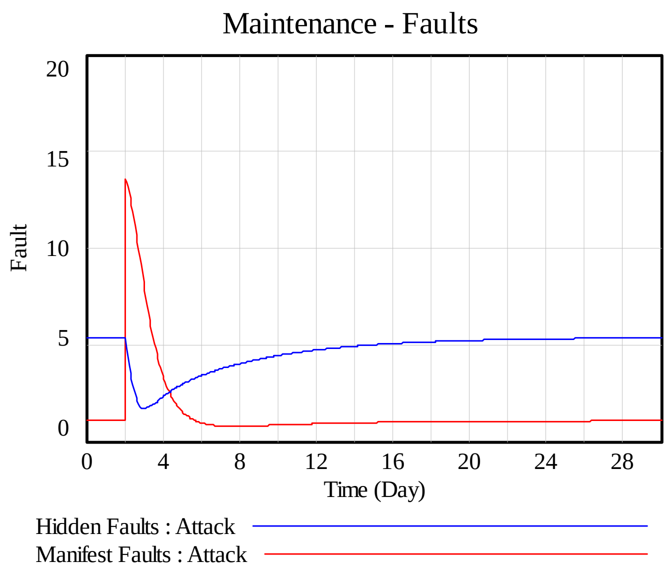

Figure 51 Attack behaviors of 'Hidden Faults' and 'Manifest Faults' in Lack of Maintenance Loop

As we have spoken, they are negative. Before the attack breaks down, they are exactly keeps the same value with the equilibrium state where the Hidden Faults are 5 Fault and Manifest Faults is 1 Fault. As soon as the attack breaks up, the *Manifest Faults* increase rapidly and the amount get extra 10 Fault because the attack flows in. At meantime, the attack triggers the cascading influence, the Manifestation Rate are faster than before. This leads the *Hidden Faults* decreasing from 5.375 Fault to the lowest point, 1.716 Fault in 1 day. Along with the correction of manifest faults, the amount of manifest faults descends and hidden faults climb. Almost 28 days later, the system can recover to the initial equilibrium state.

The behavior if they system in "Resource Deficiency" state

The resource allocation is an important problem during the correction of manifest faults, 'Resource Deficiency' state presents an uncontrollable situation which is when these corrective actions are working, and there isn't enough resource to allocate for correction.

Likewise, we illustrate the behavior through four feedback loops: "Manifest", "Cascading Effect", "Correction" and "Lack of Maintenance" also.

Manifest

Compare to 'Equilibrium' and 'Attack', 'Resource Deficiency' illustrate us more behavior in the balancing loop 'Manifest'. In the "Resource Deficiency" state, at the 3rd day the curve of Manifestation Rate and hidden faults re-increase during the decrease procedure because the problem of resource allocation.

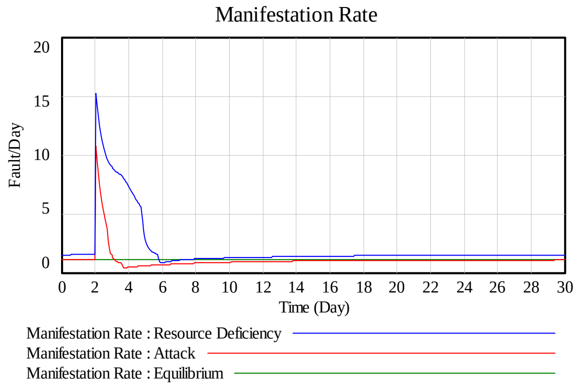

Figure 52 Comparison of Manifestation Rate in three dynamic runs

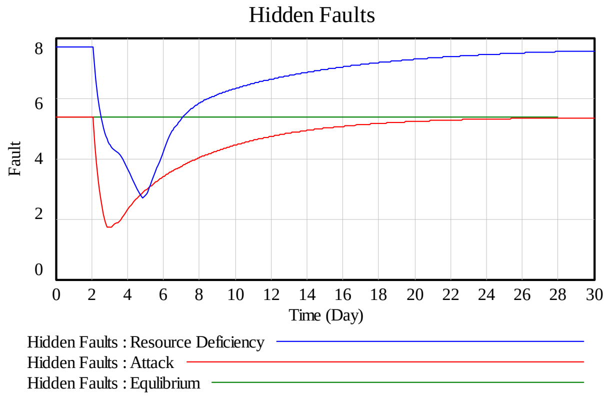

Figure 53 Comparison of Hidden Fault in three dynamic runs

Cascading Effect

In 'Resource Deficiency' state, after the attack occurrence the *Effect of cascading on Manifestation Rate* will keep a constant 0.1 for 3 days caused by the suddenly increased manifest faults. One day later, the manifest faults are 1 times lower than *Cascading Faults Threshold*, the effect of cascading increase to 0.5 of nominal effect of system. Until the manifest faults up to 2 times lower than *Cascading Faults Threshold*, the effect of cascading on manifestation rate climbs to the nominal value which is 1 means no influence to the manifest any more. The specific variation curve and their causal relation can be shown as Figure "Resource Deficiency behaviors of 'Effect of cascading faults on manifestation time' and 'Manifest Faults".

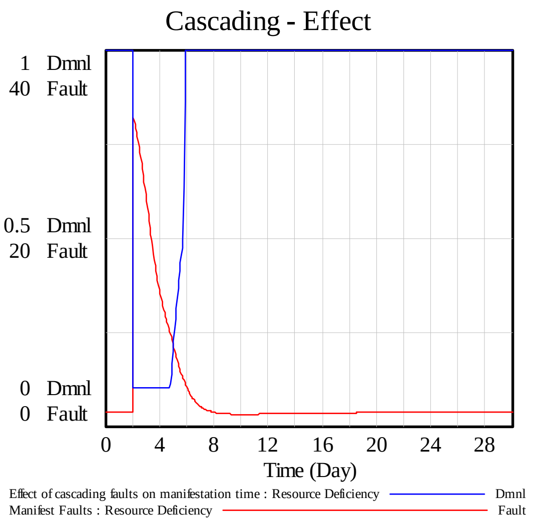

Figure 54 Resource Deficiency behaviors of 'Effect of cascading faults on manifestation time' and 'Manifest Faults'

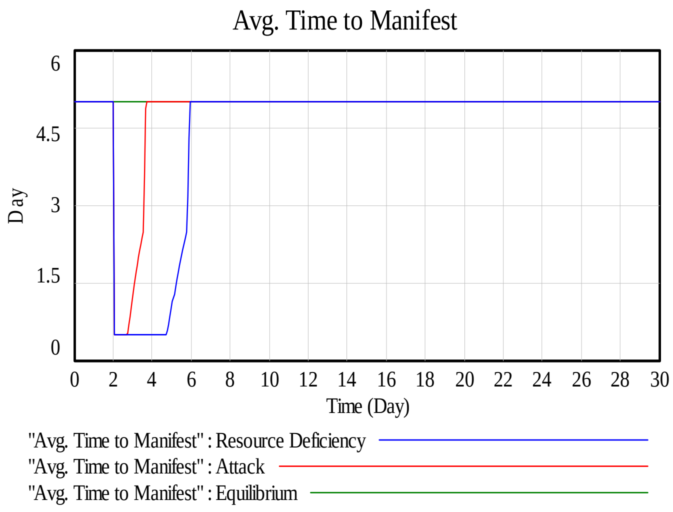

Figure 55 Comparison of Avg. Time to Manifest in Resource Deficiency, Attack, and Equilibrium state

The variation of cascading effect leads to *Avg. Time to Manifest* being the similar change with the *Avg. Time to Manifest* in ‘Attack’ state. The key difference is it keeps in the lowest point in ‘Resource Deficiency’ state is 2 days more than in ‘Attack’ state.

Correction

As we have known, in this model the procedure of correction constructs a reinforcing feedback loop that aims to mitigate manifest faults and boost the rate of correction.

Since more manifest faults need more resource to fix it, the actual resource for correction is positive with the resource needed but cannot exceed the *Total Resource* 50 Hour/Day of this project. Unfortunately the “Resource Deficiency” state presents the worst situation with allocation of resource allocation.

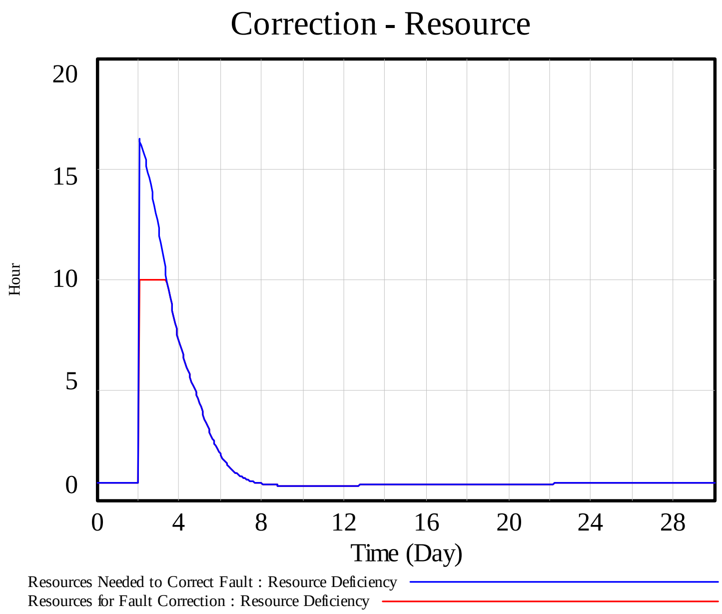

Figure 56 Resource Deficiency behaviors of 'Resources Needed to Correct Fault' and ‘Resources for Fault Correction’

Figure 56 *Resource Deficiency behaviors of 'Resources Needed to Correct Fault' and ‘Resources for Fault Correction’* illustrates when there aren’t enough resources can be allocated to correction, the correction resource gap has been generated. In another word, the needed resource is more than total resources, we can know from this figure 7 hour/day resource gap by lack of enough resources.

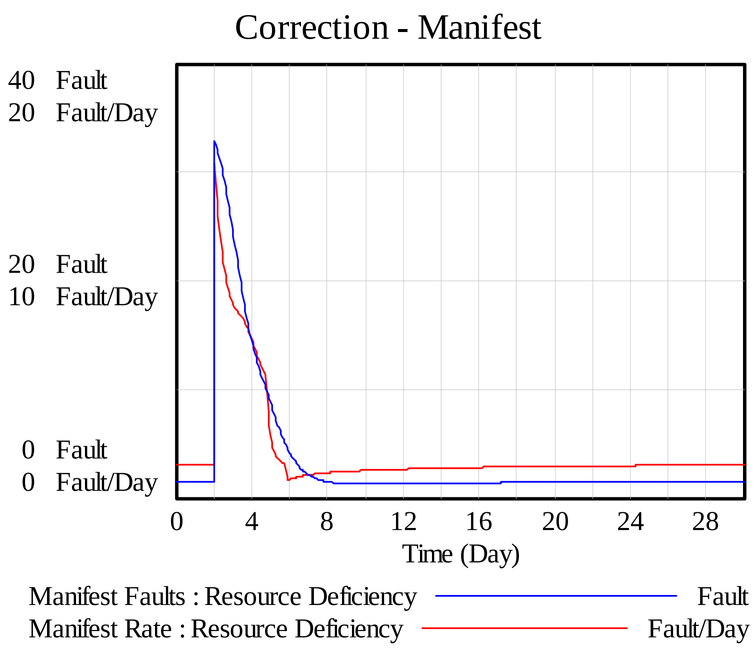

Figure 57 Resource Deficiency behaviors of 'Manifest Faults' and ‘Manifest Rate’ in Correction Loop

Likewise we can discuss the simulation results by comparing the Correction Rate and Manifest Faults in 'Resource Deficiency' state. After the attack occurrence, the *Manifest Faults* climb from 1 Fault to 31.7 Fault. Along with the reaction of correction and hidden faults introduction, the resources have slight twitter but finally they smoothly decrease until recover to the 'Attack' state. From this figure, we can see curve of the *Manifest Rate* achieve its top point (15.19 Fault/Day) and then start to decline. Comparing with the 'Attack' state, the 'Resources Deficiency' state take together the variation curve is similar but there is a key difference which is the correction time is greater than in the 'Attack' state.

Lack of Maintenance

In 'Lack of Maintenance' reinforcing feedback loop, the attack occurrence leads the hidden faults covert to manifest faults, and more manifest faults need more resource to allocate for correction. However the total resource are fixed, 'Resource Deficiency' state is be used to illustrate the reaction between resources allocation and hidden fault introduction.

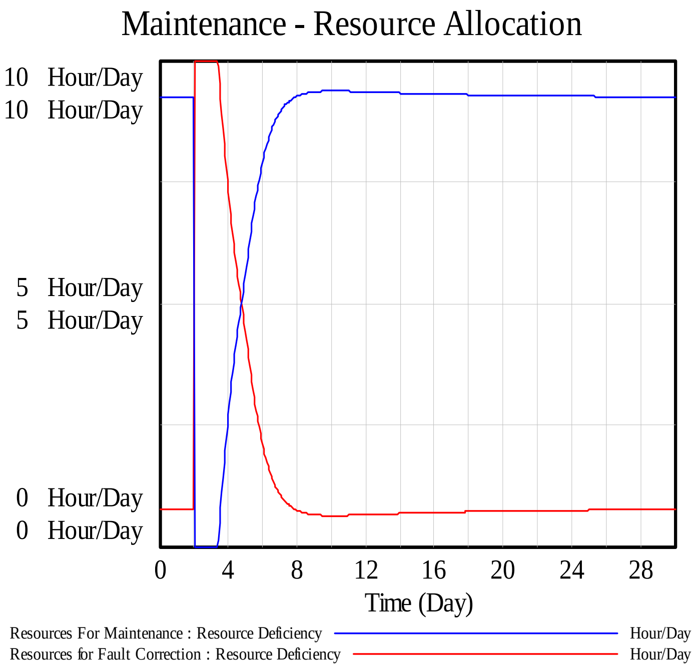

Figure 58 Resource Deficiency behaviors of 'Resources for Maintenance' and 'Resources for Fault Correction' in Lack of Maintenance Loop

Through the Figure 58 *Resource Deficiency behaviors of 'Resources for Maintenance' and 'Resources for Fault Correction' in Lack of Maintenance Loop*, we can know the *Resource for Maintenance* and the *Resource for Fault Correction* are complementary, their sum is *Total Resource*. From 2nd day to 3rd day, the correction resource up to the maximal point (10 Hour/Day), and then the maintenance resource is 0. Obviously the fact of that maintenance equals 0 causes the introduction of hidden fault introduces very fast.

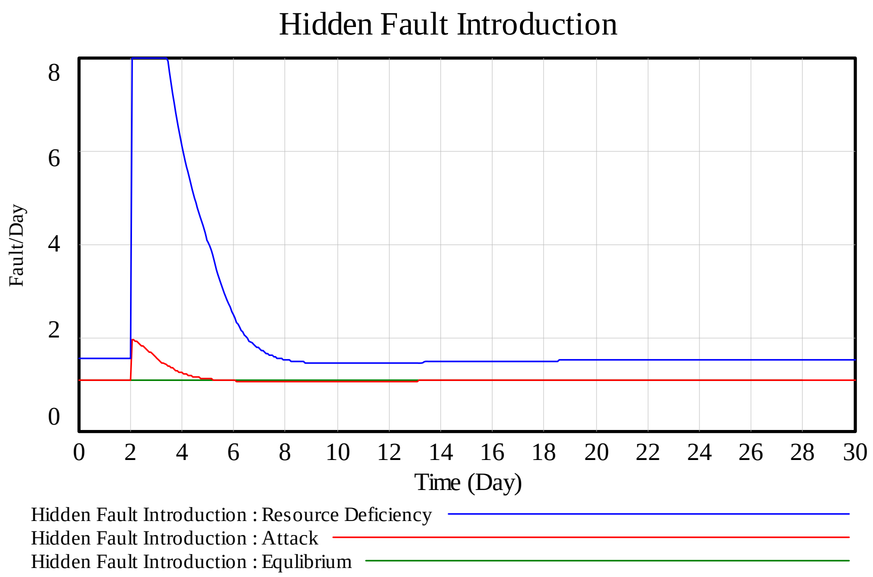

Figure 59 Comparison of Hidden Fault Introduction in three dynamic runs

These variation curves in Figure 59 *Comparison of Hidden Fault Introduction in three dynamic runs* are pretty clear to explain how the *Hidden Fault Introduction* changes. In the steady equilibrium state, the introduction keeps the value of 1Fault without any attack. However once the attack happens, the rate of hidden fault generation will have a rapid growth at the 2nd day. 3 days later the introduction will fall down to the initial value with the allocation to maintenance increase to the Resources Needed to Maintenance. The worst situation is the Resource Deficiency, the introduction will keep the highest for some time, that’s 1 day in our case, until the resource to maintenance get more allocation, the situation could be improved.

For the same reason, we can understand the causal relation between *Hidden Faults* and *Manifest Faults*.

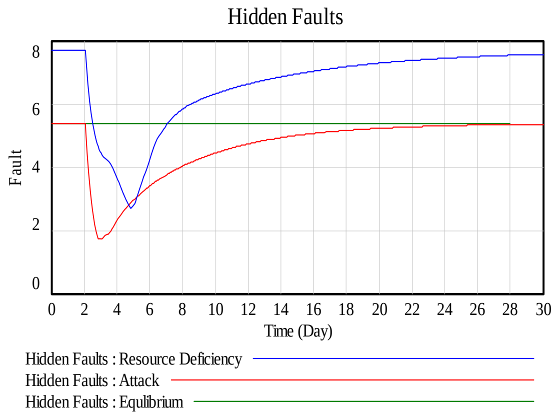

Figure 60 Comparison of Hidden Fault in three dynamic runs

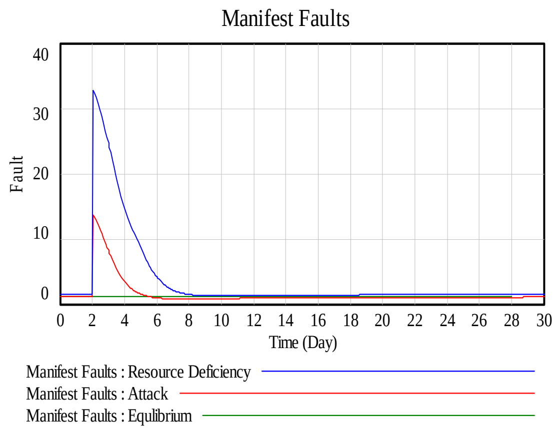

Figure 61 Comparison of Manifest Fault in three dynamic runs

Because the introduction of hidden faults is a reinforcing feedback loop, that's obviously hidden faults and manifest faults are negative. The manifest faults are triggered by attacks and changed by rate of Manifestation Rate, so the curves are similar in both situations "Attack" and "Resource Deficiency". However for the hidden faults, in the "Resource Deficiency" state at the 3rd day point the decrease stops and a little increase shows up; it lasts for 1 day, the same with period of maintenance resources equal 0. When more resource allocated to maintenance the *Hidden Resource* start to decrease again.

Conclusion

In this master thesis we have learned scenario planning dealing with the power outage crisis, and in particular we have studied the approach how to establish a scenario from nothing and simulate it in distinct environments.

We have learned how to investigate relevant scenario literatures for getting useful common senses so that they have been used in our self-built scenario. In order to make clear the essence of scenario and scenario planning, we have searched numerous papers to learn so that we could carry out the creation of power outage scenario.

We compared existed scenario planning approach such as OODA and TAIDA to grope its development patterns so that deeply understand to the effect of scenario planning.

This master thesis has discussed how to do cascading crisis management according to crisis scenarios what happened in the real life. This is to understand better how some organizations succeed with their managing crisis and resource allocation.

The thesis finds that crisis can be managed in different phase of the whole crisis lifecycle. By learning about scenario and analysis many real scenarios of power outage, a generic scenario has been abstracted to reflect common problems that happened in general information systems.

The thesis finds that the crisis have very clarity phase for management. Cascading Effects have worse impact to a running system. Different resource allocation leads correction and hidden faults introduction different effectiveness. This forms the foundation for a model in Vensim.

The model we created in this master project is a generic conceptual dynamic model that includes all primary causes of crisis — manifesting, cascading, correction, and lack of maintenance. We can get the reason why this result happens through analyzing the model. Once hidden faults have been manifested and exceed the threshold, cascading effects would be leaded. Make an adaptive resource allocation is a key point to control the time of crisis. If only pay more attention on the correction and allocate more resource on correction procedure, the maintenance would be ignored and make the entire time of restoration from crisis even longer.

Through our work, we can see that system dynamics model can be used to quantify and explain the impact of cascading faults to the crisis management and resource allocation to solution of crisis. Therefore, system dynamic models should be often used for crisis management of information system.

The model looks at future behaviours of crisis management when the crisis in different phase and resources with different allocation. It illustrates theses behaviours when the crisis in the controllable crisis state and resource deficiency state. If the resources are deficiency, uncontrolled faults would happen. This will try to extend the restoration from crisis.

These behaviours show that cascading effects can be mitigated by increasing correction faults. However, it also shows that there is a limit for how many the resources can be allocated to correction. If the resources allocation is unreasonable to make the maintenance resource deficiency, the cascading effects would be worse.

System dynamics has proven to be an effective methodology to explain the possible causes of crisis failures. Although crisis from different industries have their own particular characteristics, still some similarities exist. From our work of building this generic conceptual model, we would expect that system dynamics models are commonly used to improve crisis management.

Discussion

In this project, we accomplished a tough knowledge accumulation in scenario and scenario planning what we never touched before so that we could able to frame a methodology about scenario planning which was used in our scenario construction. After that we listed out core factors and quantified them so that we could able to use them in scenario conceptual modeling work. By using Vensim to simulate scenario model, we made certain to the power outage scenario in its lifecycle as well as presented dynamic behaviors in three distinct dynamic runs which are “Equilibrium”, “Attack” and “Resource Deficiency”.

Limitation and Acquisition

Comparison of performance against to other techniques was not achieved in our project due to the implementation approach limited, scenario planning has its own salient feature that an efficient scientific method to research plausible future, however, most of existed modeling tool was based on existed certain incidents and could not quantify the variations in the future, so most of them might not adequate this modeling work except System Dynamics modeling tool Vensim. But according to our research during this period, we still achieved some research results.

In our opinion, scenario planning is a useful method to give both **qualitative analysis** and **quantitative analysis** to the plausible future.

A comparison table shows its characteristics as below:

	System Dynamic modeling approach	***Traditional modeling approach***
Normal State	Known conditions	*Known conditions*
Cascading Effects	Qualitative analysis and quantitative analysis	*Qualitative analysis*
Destructiveness	Qualitative analysis and quantitative analysis	*Qualitative analysis*
Changing Pattern	Qualitative analysis and quantitative analysis	*Qualitative analysis*
Restoration Lifecycle	Qualitative analysis and quantitative analysis	*Qualitative analysis*
Maximum Value of Damage	Qualitative analysis and quantitative analysis	*Qualitative analysis*

Solution Validity Check	Qualitative analysis and quantitative analysis	*Qualitative analysis*
Manifestation Lifecycle	**Qualitative analysis and quantitative analysis**	***Qualitative analysis***

Table 5 Comparison of System Dynamic modeling approach against Traditional modeling approach

Obviously, system dynamics modeling approach is more efficient in cope with future incidents, not only model crisis occurrence process but also a compound analysis to plausible future both in qualitative and quantitative aspects.

Suggestion for future research

The method presented in this thesis has demonstrated its ability to understand crisis occurrence and its changing pattern. Although our approach has already demonstrated reasonable variations and mathematical formulas, there is still room for further improvements. The followed generation of researchers could perfect it based on our foundations.

Because of the achievement of modeling work is dependent on the clear model framework; we only chose one of main cascading effects of which power cut occurred in the local power plant with its impacts in correct system.

We sincerely expect that the next generation of researchers might consider more cascading effects and add them into the model so that might perfect its persuasion and reasonableness.

Reference

Company, V. "Dynamic Hypothesis." from http://www.vensim.com/documentation/html/21415.htm.

SDEP, M. "MIT System Dynamics in Education Project." from http://sysdyn.clexchange.org.

Sterman, J. D. (2000). Business dynamics systems thinking and modeling for a complex world. Boston, Irwin McGraw-Hill.

TECNUM, U., FRI-UL, SECVAL, U-FEN, ACPDR, Dplan, Iplay, Eidsiva (2008). Collaborative Project (STREP) MISSCRISIS.

Ventanna Systems, I. "Vensim Software - Linking system thinking to powerful dynamic models." from http://www.vensim.com/software.html.

Wolstenholme, E. F. (2003). "Towards the definition and use of a core set of archetypal structures in system dynamics." System Dynamics Review **19** (1): 10-11.

Porter, M.E. *Competitive Advantage*, Free Press, New York, 1985,

Schwartz, Peter. *The Art of the Long View*. Doubleday, 1991,

Gill Ringland, “*Scenario planning*”, John Wiley& sons, England, 1998,

Schoemaker, Paul J.H *Scenario Planning: A Toll for Strategic Thinking* Sloan Management Review, Winter: 1995,

Chermack, T.J. *Studying scenario planning: Theory, research suggestions and hypotheses*. Technological Forecasting and Social Change, 1995,

Mintzberg. Henry, *Towards a General Theory of Strategy Planning: Reconceiving the Roles for Planning, Plans, Planners*. 1994

Mats Lindgren &Hans Bandhold, *Scenario planning: the link between future and strategy*, 2003,

USAF Colonel John Boyd, *Patterns of Conflict*, 1976

M Billig *Discourse & Society*, 1999

R Thompson, *Journal of Financial and Quantitative Analysis*, 1985

CA Desoer, M Vidyasagar , *Feedback systems: input-output properties* Academic Press, Inc. Orlando, FL, USA, 1975

S Mangan, U Alon, *Structure and function of the feed-forward loop network motif*, Proceedings of the National Academy of Sciences, 2003

A Velazquez Lozada, JE Gonzalez, *Urban heat island effect analysis for San Juan, Puerto Rico* A Winter: Atmospheric environment, 2006

R Von Hanwehr, GF Popescu, HE Taylor, KH Winkler, Interve*ntional telemedicine for noninvasive neuroradiosurgery: Remote-site high-performance computing, mathematical optimization, and virtual scenario simulation*, Journal of Medical Systems, 1995

DL Bates, JE Dillard Desired future position—a practical tool for planning,

Long Range Planning, 1991

R Bradfield, G Wright, G Burt, G Cairns, K Van Der Hejiden *The origins and evolution of scenario techniques in long range business planning,* Futures, 2005

DS Hochbaum, DB Shmoys, *U*sing dual ap*proximation algorithms for scheduling problems theoretical and practical results,* Journal of the ACM (JACM), 1987

JK Larsen, R Agarwala-Rogers, Re-invention of innovative ideas: Modified? Adopted? None of the above, Evaluation, 1977

G Enderle, LA Tavis, A balanced concept of the firm and the measurement of its long-term planning and performance, Journal of business ethics, 1998

L Hirschhorn, Scenario writing: a developmental approach, Journal of the American Planning Association, 1980

H Mintzberg, *The fall and rise of strategic planning*, Harvard Business Review, 1994

Robert A. Taylor (2008). "Origin of System Dynamics: Jay W. Forrester and the History of System Dynamics". In: *U.S. Department of Energy's Introduction to System Dynamics*. Retrieved 23 Oktober 2008.