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Modeling Interdependencies within a Petrochemical Industrial Complex

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Modeling Interdependencies Within A Petrochemical Industrial Complex

A Major Individual Project submitted in partial satisfaction of the requirements
for the degree of Master of Science in Geographic Information Systems

by

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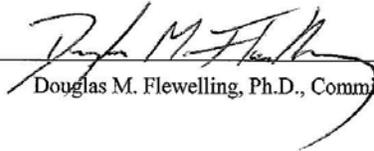The report of Abdullah Naser Binthunaiyan is approved.

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Acknowledgements

Abstract

Modeling Interdependencies Within A Petrochemical Industrial Complex

by

Abdullah Naser Binthunaiyan

Critical infrastructures are those upon which a country's health, economy, and security collectively depend. Understanding interdependencies and dynamics between critical infrastructures will enhance communication and coordination between emergency management and homeland security as well as many other authorities. This project addresses the need for assessing the supply chains of petrochemical products within a petrochemical complex. A geometric network was used to model connectivity between different supply chain networks in the petrochemical complex. ArcGIS Utility Network was used to create failure events on the failed facilities and select the impacted facilities. Then the Failure Consequences Model was used to provide graphical and statistical figures on the cascaded failure impact.

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List of Acronyms and Definitions

MOI   Ministry of Interior

NIC   National Information Center

HCIS   Higher Commission of Industrial Security

GIS   Geographical Information System

Chapter 1 – Introduction

Modeling interdependencies among petrochemical facilities in a large industrial area has become very important for security and safety officials. Modeling interdependencies within a petrochemical complex will solve issues related to supply chain management, planning new facilities, and evaluating potential threats. This report presents a study of Modeling Interdependencies Among Industrial Facilities Within an Industrial Complex. It has been conducted within the context of homeland security and supply chain management. In this project, the client needed to be able to continuously analyze critical parts of the complex, to enforce more security, and to implement safety procedures.

1.1 Client

The client for this project is Dr. Fahad Almassoud. Dr. Fahad is the GIS project manager for the National Information Center (NIC) – Ministry of Interior (MOI), Saudi Arabia. The National Information Center is a data center that serves all MOI departments. NIC was appointed by the MOI to deliver GIS solutions to its departments and to host a GIS center that ensures the continuity of solutions to these departments. Dr. Fahad has a technical background in communication networks, and he represents the MOI in many GIS-related government committees.

1.2 Problem Statement

The problem addressed in this project is to analyze interdependencies among industrial facilities that are connected by pipelines in order to move products to and from facilities. Each facility uses products that are fed into its production line to produce other products. The failure of one piece of this supply chain may result in a variety of impacts depending

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on which part has failed. For instance, the failure of a power station that is supplying electricity to an industrial facility, and at the same time using natural gas to power its generators, can severely impact the industrial facilities that depend on the products of these utilities.

For city planners, security and safety officials, and supply chain managers, the ability to analyze their dependencies which this petrochemical chain of supply has become critically important. The Higher Commission of Industrial Security (HCIS) in Saudi Arabia, which will be the ultimate user of the system proposed in this report, needs to be aware of how important a facility is to the whole industrial area or complex. This can be achieved by measuring other factors, such as the number of production lines that would stop working if a facility were to shut down. Understanding the critical importance of each facility within a given industrial area would help the HCIS undertake other tasks, such as recommending redundancies for a specific facility, or placing more security and safety procedures within a specific facility.

1.3   Proposed Solution

This project sought to remedy HCIS's lack of ability to assess risk by equipping HCIS with a desk-top GIS model that visually represents the various consequences at a failure of a specific facility. When integrated properly with other systems or fed with the proper data, this model will enhance the response and reporting mechanism of the HCIS to deal with potential threats. Figure 1.1 shows a representation of the current HCIS work flow of assessing facilities' failure consequences, and Figure 1.2 shows the desired workflow after using the model proposed in this project.

| request recieved to report on the failure consequences | → | Search, and forward this request to the facility to verify | → | report back the findings |

Figure 1.1: Current Failure Consequences Analysis Workflow

| request recieved to report on the failure consequences | → | Run the tool for the specific facilities | → | report back the findings |
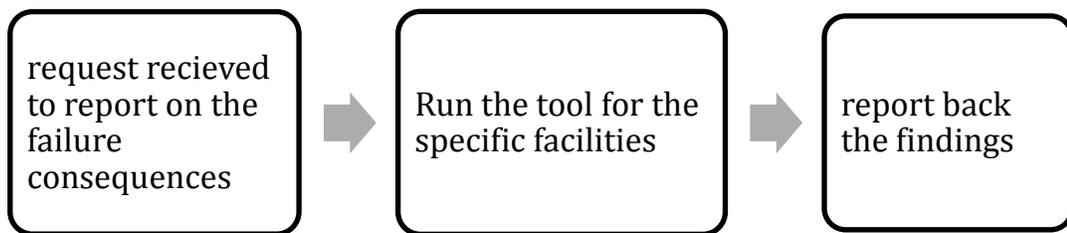
Figure 1.2: Future Failure Consequences Analysis Workflow

1.3.1   Goals and Objectives

The HCIS is monitoring compliance with safety procedures and industry standards within all major Saudi Arabian industrial facilities. Currently, there are many of these facilities, and overseeing compliance and enforcing standards at these different types of facilities has become extremely difficult.

The impact of the problem that this project addresses on the HCIS workflow is tremendously high. In the last few years, several industrial accidents took place causing many deaths and huge financial losses and environmental impacts due to improper allocation of security and safety resources. It is believed that there is a need for effective and efficient emergency management resources to be placed and enforced. A GIS is needed to achieve the following broad goals that are directly related to the HCIS workflow:

- Visualized situational awareness capability.

- Accurate risk assessment capability.

- Logical understanding of, response to, and control of potential threats.

The problems that were addressed could be solved by implementing a GIS-based system that could be used for improving emergency mitigation and preparedness within industrial areas. That system's purpose was to visually model the consequences of a failure of a facility within an industrial complex. Visualization will have a great impact on meeting the addressed needs. An extension of the system could then be delivered to the proper department within the ISD which will be responsible for risk assessment tasks. The ultimate goal of this project was to provide a GIS-based solution that solves the HCIS's addressed problems. This project served as a prototype to help the NIC in allocating proper resources for delivering a more comprehensive solution in the future. Overall benefits of the outcome of this project served the HCIS, and also served the NIC in terms of saving time and resources for planning and implementing next phases.

1.3.2   Scope

Based on the client's request, the goal of this project was to deliver a situational awareness capability to the HCIS. The client requested doing this model without having to require data from any source. However, proper attributes and data types should be determined in order to get the required model to run properly. This required working with mockup data. In addition, this project was meant to be a prototype. It served as a proof of concept for the usage of the GIS in analyzing consequences of failure of a facility to the overall industrial complex. These consequences could be measured by different units.

Determining a proper unit or units of measurement to assign to the consequences of a failure of industrial facility was one of this project's outcomes.

This GIS solution was restricted due to a tight design and implementation schedule. It was required to deliver this project within 11 months. Thus, the project deliverables were limited to a documentation of the problem, geodatabase design, and a model. The database design and the model were requested to be developed using ArcGIS software. This was due to the fact that the NIC uses this software as its core GIS technology. Moreover this report documents the needs that are out of the scope of this project to be considered in future improvements of the HCIS GIS infrastructure.

1.3.3   Methods

This project was conducted on predefined milestones. Figure 1.3 shows enumeration of these milestones and major tasks in each of them.
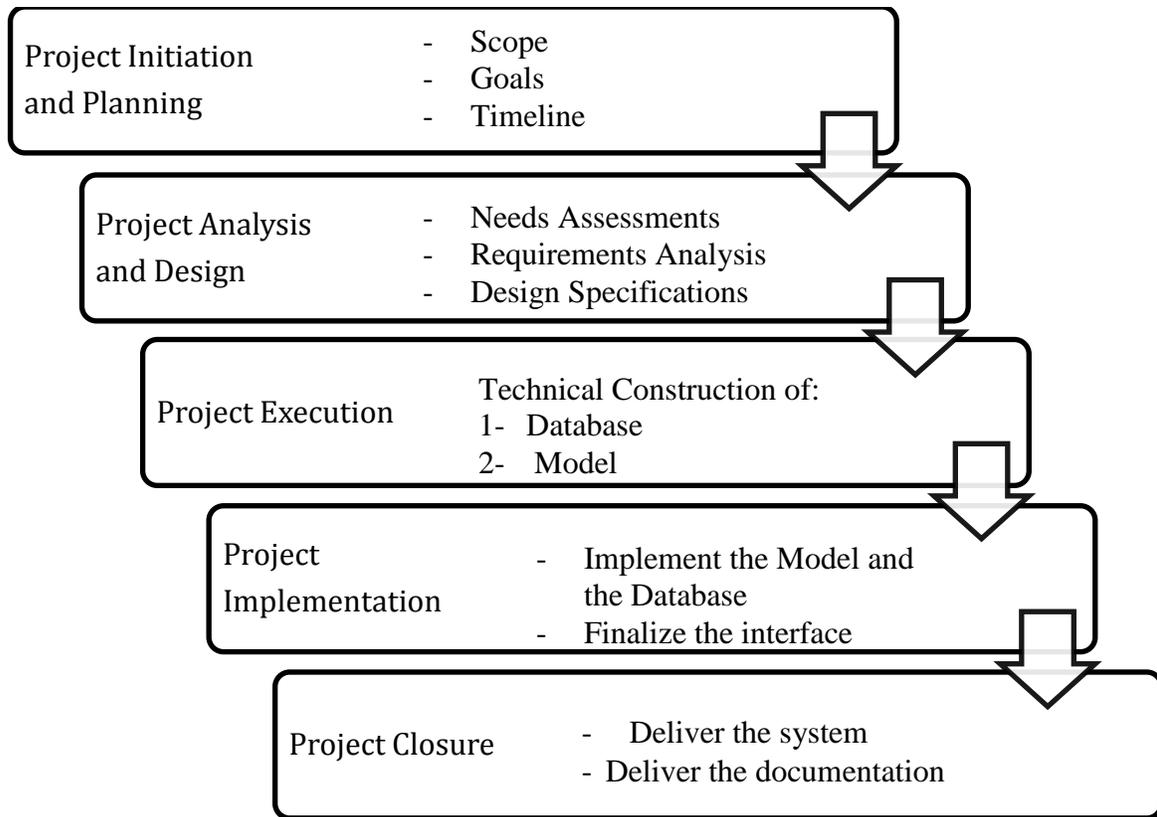
Figure 1.3: Stages taken to accomplish this project

The Project Initiation and Planning stage was done through scoping the proposed solution first. This was done by meeting the users of the system and having them answer a questionnaire. Then goals were set and the HCIS's problem was articulated. After that, a preliminary timeline was set with relatively broad defined tasks to achieve the goals.

In the Project Analysis and Design stage, three major steps were done: needs assessment, requirements analysis, and design specifications. Leads and guidelines were followed from Roger Tomlinson's book. Needs were assessed through a series of meetings, and requirement analysis led to documenting information products from which use cases were derived. Then design specifications were documented.

In the Project Execution stage, a database was created from scratch. ESRI's Building Geodatabases course was a good source in this stage. A new file geodatabase was created

and designed to contain two data sets: one for facilities, and the other for pipelines. These database elements were digitized in ArcMap to form a simple network of the supply chain of interest. Then the model was created to analyze the problem of interest.

During the Project Implementation Stage, the work of building the model and getting it to work properly was the main task. In addition, a mockup supply chain network of industrial complex was digitized and validated as a geometric network. Then, different analyses were executed using the ArcGIS Utility Network. Results returned from the Utility Network were then fed into the model. The model returned further results of the analysis, which were then documented.

The final stage was the project closure where final documentations were made and recommendations on further work were cited.

1.4   Audience

This report is intended for the Higher Commission of Industrial Areas personnel. Also, supply chain management professional, the homeland security professional, and the GIS professionals were considered when this report was prepared.

1.5   Overview of the Rest of this Report

This report is structured based on the sequence of the project's main stages. Each chapter introduces a milestone stage. Chapter two introduces background and literature review on topics related to the main problem. Chapter three addresses system design, requirements analysis, and the project plan. Chapter four present detailed description of the database design. The following chapter, chapter five, provides details on project implementation that was mainly building the geometric network and the analysis tool. Chapter six brings out the results and provides further analyses on them. Finally, Chapter

seven presents a conclusion and recommends several potential further work to this

project.

Chapter 2 – Background and Literature Review

The problem addressed in this project is to analyze a supply chain of petrochemical facilities that depend on each other's products to manufacture, in turn, their own products. These facilities are extremely valuable to a country's economy and safety. Thus, securing them and ensuring that safety procedures are followed in their operation have been supervised by the HCIS, which is a governmental agency established specifically for this purpose. This project is meant to help HCIS to do better emergency management through the analysis of petrochemical supply chains that might be impacted by either man-made crises or natural disasters. This chapter highlights some of the topics related to the problem addressed here. These topics are emergency management, GIS for supply chain management, and modeling critical infrastructure interdependencies.

2.1 Emergency Management

There are many examples of fatal disasters that have resulted from a failure to follow safety standards within industrial facilities (Federal Emergency Fire Agency, 2003). Therefore, governments require industrial facilities to adhere to safety standards and to prepare emergency plans in order to respond to potential accidents that may result from a spill, spread, or ignition of hazardous materials used or produced by the facility. In the past, the existence of hazardous materials in huge amounts within industrial facilities and accidents that caused deaths and financial loss encouraged professionals to write many articles specifically on the subject of risk management in industrial areas. However, the subject of GIS in risk management is relatively new in the academic area (Cova, 1999).

There are existing GIS applications that are deployed to provide a framework for emergency personnel to manage the risk in industrial areas. These applications employ

the principle of quantified risk assessment. The assumption that GIS can serve as a

framework for all these applications is based on the reality that industrial areas are

composed of different entities. These entities are mainly factories, pipelines, critical

equipment, and storage for used or produced hazardous materials. Each of these entities

can be assigned a risk severity. By dealing with the spatial extent of the industrial area as

a grid of (x, y) cells, GIS software like ArcGIS Spatial Analyst can be used to calculate

the risk index of each cell and provide risk maps for different incidents (G.S.Bonanos,

1997).

In addition, valuable background literature on the subject of GIS in emergency

management can be found in industry publications. Agencies regulating safety criteria

have developed well-documented safety guidelines and emergency management best

practices (Federal Emergency Fire Agency, 2003). The safety standards for chemical, oil,

or utility facilities are an important consideration in risk assessment and therefore

essential for visualizing the risk in industrial areas. In 1998, when the Phillips 66

chemical complex in Pasadena near Houston, Texas, exploded and caused the death of 23

people and severe damage to the complex, which then needed two years to rebuild.

Emergency agencies in Pasadena had limited information about facilities in their

response area, although these emergency agencies were considered to be the most well

prepared in the United States (Federal Emergency Fire Agency, 2003).

Recently, many petrochemical facilities have faced man-made threats. Spatial and

temporal studies of several terrorist attacks have shown that terrorists tend to attack

places that are easily accessible and have symbolic, cultural, infrastructure, or economic

value to the country. Both petrochemical and oil facilities are considered to be among the

most strategic targets for terrorist attacks. Damage to these facilities can cause significant collateral damage, destroying human lives, economies, and environment. Scenarios of such consequences can be best modeled through the use of GIS.

2.2   GIS for Supply Chain Management

GIS has become a very valuable tool in the supply management field because it enables supply chain personnel to better visualize the chain of supply in terms of nodes and routes, rather than spreadsheets. Supply chain managers receive data from different departments, such as maintenance, purchasing, or even the human resources. These data come in different formats, and they are of great importance to the continuity of supply. GIS as a tool is capable of sorting these data by means of, for example, changing the color of the route or the size of nodes. Therefore, graphing and network display capabilities of GIS are particularly well suited to supply chain management.

Much of the literatures that discusses the subject of GIS as a supply chain management tool refer to the network of supply in the same way transportation geography (which existed long before the inception of GIS) scholars discuss *transportation networks.* Modeling supply chains has greatly benefited from the graph theory introduced by William Garrison in 1960 (Morydas, 1975). He divided ordinary graphs into two types: polar and non-polar. The U.S. Interstate Highway System is an example of the polar ordinary graph, in which cities are considered as nodes and interstate highways are routes that connect these nodes. In his example of the Interstate Highways System, Garrison obtained several measures regarding relative location and accessibility of the nodes and the connectivity of the entire network. These measures are implemented in their broad concept in supply chain design and management.

Using mapping technologies to assure continuity of the supply chain can either help supply chain managers to avoid failure of critical assets in the chain or manage this failure. In large petrochemical complexes, which this study focuses on, a failure of an asset can cause economic losses of up to tens of billions of dollars (Samuel Ratick, December 2008). Moreover, losses to environment, human lives, and to the image of a country where these facilities are located can be even more severe. As stated earlier, supply management benefited from the graph theory which has impacted transportation geography makes mimicking this application of geography in studying risks related to failure of assets in petrochemical complex very valuable.

Failure of any part of the network in the supply chain of a petrochemical complex can happen either by an act of the nature, such as a flood or by human activity, such as a terrorist attack. Many studies have shown that terrorist tend to do the most possible destructive actions. Therefore, there is a need to rank critical infrastructure according to the relative importance of consequences resulting from their failure. The network model of supply chain can be more relevantly visualized using GIS.

2.3   Modeling Critical Infrastructure Interdependencies

Critical infrastructures are those that the country's health, economy, and security all together depend on. They might be services, factories, utilities, or even information. Critical infrastructure are interrelated whether physically, geographic proximity, procedurally, or even virtually by the reliance on exchange of information. As a field of knowledge, modeling critical infrastructure interdependencies is fairly new and its establishment dates back to the early 1990s. In the mid 1990s, several event like the report from the Defense Science Board Task Force on Information Warfare in 1996 and

the Presidential Commission on Critical Infrastructure Protection influenced researchers to further study critical infrastructure interdependencies (P. Pederson, 2006). Modeling and simulating critical infrastructure interdependencies, since then, has become an interest of counter terrorism agencies and working groups.

Different critical infrastructures are managed by different sectors, which have different structure and models. Modeling interdependencies and cascaded impact that an event at part of a critical infrastructure could cause on other infrastructures is challenging. Most interdependencies' modeling efforts were focused on assessing vulnerabilities of a chain that connects infrastructures rather than understanding the underlying dynamics of these interdependencies.

2.4   Summary

Although the body of knowledge of supply chain management and emergency management is very rich in reviews and examples of using GIS as a tool in analyzing the workflows and practices associated with them, there is no documented literature on using GIS to analyze consequences of failure of critical assets to the network of a supply chain. There are many studies on modeling and assigning terrorist attack indexes for critical infrastructure, however they lack the use of GIS in determining consequences of failure of these infrastructures.

Chapter 3 – Systems Analysis and Design

This chapter addresses requirement analysis, system design, and the project plan for a GIS that will resolve the client's broad problem of analyzing dependencies among industrial facilities. After clarifying the problem, this text will introduce both the functional and the non-functional requirements that influenced the final GIS solution. The next topic, system design, summarizes critical components of the design. The chapter concludes by reviewing the original project plan and explains key modifications that occurred as the plan and project matured.

3.1   Problem Statement

The problem addressed in this project was the analysis of dependencies among industrial facilities that are connected with pipelines in order to move products to and from facilities. Each uses products that are fed into its production line to produce another product. The failure of one part of this supply chain may have different impacts depending on which part has failed. For city planners, security and safety officials, and supply chain managers, analyzing the dependencies in this petrochemical chain of supply has become vitally important. The Higher Commission of Industrial Security (HCIS) in Saudi Arabia, which is the ultimate user of the system proposed in this report, needs to be aware of how important a facility is to the whole industrial area or complex. The HCIS accomplishes this task by measuring other factors, such as how many production lines would stop working if a particular facility were shut down. This awareness of the interdependency of each facility would help in other HCIS tasks, like recommending

redundancy establishment for a specific facility or placing more security and safety procedures in a specific facility.

3.2 Requirements Analysis

The client required the GIS-based solution to support the following functional requirements, as shown in Table 3.1.

Table 3.1: Functional Requirements

No.	Requirement
1	Must store data relevant to: facilities' importance index, product types, volume, associated R-phrase for each facility, product, or pipeline.
2	Must allow users to analyze failure consequences of one or more of either facilities or pipelines.
3	Must generate visual representation of failure consequences using dark red line symbology for pipelines and appropriate symbol for facilities to symbolize lost facilities.
4	Must be optimized to require minimum input data by allowing the user to do the analysis by choosing from drop-down lists.
5	Must provide understandable units of accumulated losses, and understandable unit of measuring losses can be the US dollar.
6	Must allow user to export and import CAD format data of pipelines, facilities, security and emergency resources.

7	Must allow user to add fields of facilities and pipelines or edit them to account for changes in volume, importance index, or associated prices, which they change occasionally.

The system utilizes the GIS flow analysis capabilities to analyze consequences of a failure of a facility. For such analysis, data regarding facilities' production need to be available. However, in the problem addressed here units associated with failure are not consistent. For example, electricity, which is supplied by the electric station, is measured in watts, and the event of electric station mal operation will result in production suspension of other facilities. For the purpose of simply quantifying the losses resulting from the electric station, as an example, the unit to measure electric energy can be expressed in US dollars. Other losses of production lines, which resulted from the loss of electricity can be expressed in US dollar values of the final products. Therefore, the software should associate weights in terms of US dollars for each asset in the complex and its production value. Since the flow of products among these assets, in reality, is not fixed in volume or US dollar value, the associated field should not be locked against editing. Therefore, the user must be able to edit these fields to account for these changes. Visual effect of losses of facilities and the associated consequences should be reflected through the use of GIS by using appropriate symbology for the affected facilities. An appropriate outage symbology for the pipelines is conveniently reddish in color. Transmission mode had to be designed to reflect which company owns it and what it transmits. Subtypes and domains were used so to meet the client's requirement of visualization effects and ease of editing. The user is more concerned about the schematics

rather than the exact location of assets for the purpose of visualizing failure

consequences. This led to the importance of enabling the user to export and import

AutoCAD files. Last but not least, a file geodatabase was used to store data in order to

allow maximum storage for future expansion of the system. See Table 3.2.

Table 3.1: Non-Functional Requirements

	Requirement	Priority
1	Use ArcGIS software version 9.3.1	Mandatory
2	Deliver file geodatabase, Schema, Metadata, and project report	Mandatory
3	Present the project to the client	Desirable
4	Provide a project poster to the client	Desirable

3.3   System Design

The model for determining interdependencies among facilities and consequences of a

facility failure is designed based on the functional requirements, system requirements,

updated use cases, and updated information product documents. The project is focused

on delivering a model and this model needs all the GIS major components in order for it

to give the desired results. A prototype database is designed, built, and implemented for

the purpose of getting this model built and implemented to the requirements' of the

client. Figure 3.1 shows a high-level view of the system design.
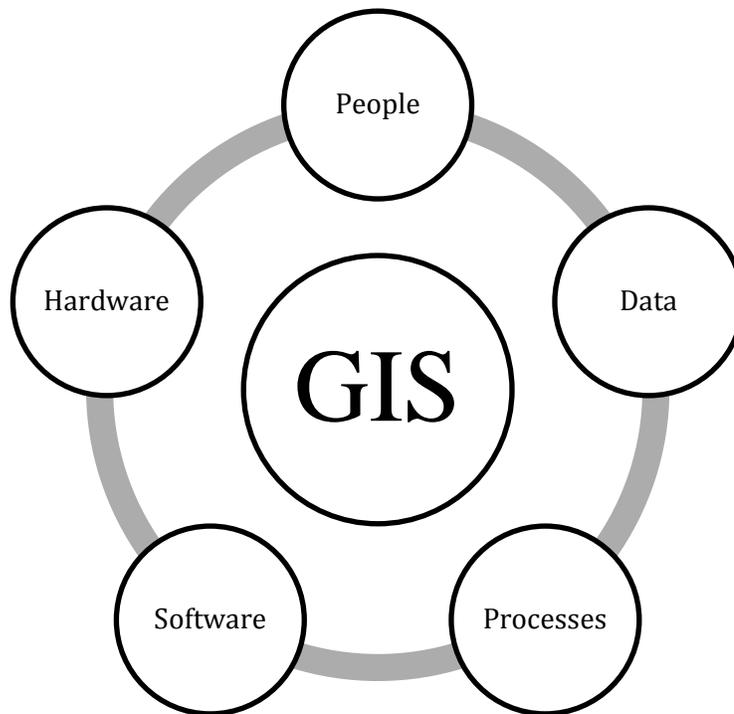
Figure 3.1: GIS components

3.3.1 People Component

People are the most important component in the GIS. The model that is the core project

deliverable is meant to be used by a GIS analyst in the HCIS, who will be using this

model to respond to the inquiries about what are most critical facilities, and what are the

consequences of failure associated with them. The user will continuously report findings

that will be used when making decisions on security and safety resources allocation. This

person is going to be a critical success factor of this model and will play a big role in

modifying the model to cover more analyses in the next phases of this project.

3.3.2 Procedures Component

Procedures include how the data will be retrieved, input into the system, stored, managed,

transformed, analyzed, and finally presented in a final output. The procedures are the

steps taken to answer the question needing to be resolved. Therefore, procedures are the

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second most important component of this project. Figure 3.2 shows an overview of the

procedure component.
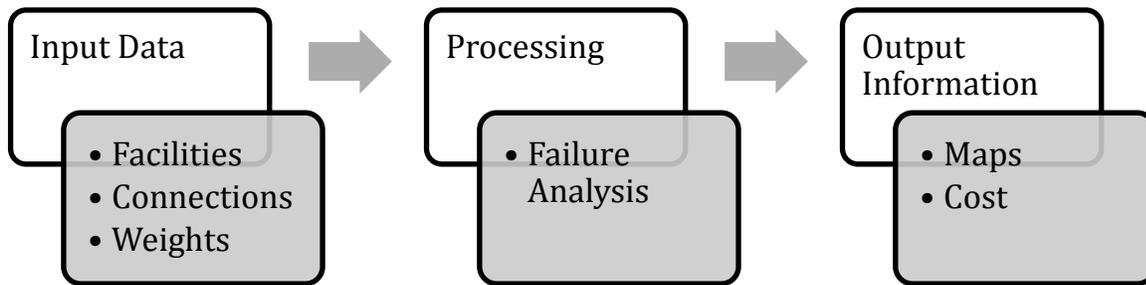
Figure3.2: Overview of this project procedure component

3.3.3   Data Component

In this project no data was provided, and the task was to implement a model and propose

the data base design and the data needed to get the information product needed. For

production implementation, making the data ready for such implementation of the model

can take from one to two years of intensive labor. Therefore, this project used dummy

data representing facilities, products, and pipelines. Figure 3.3 shows an overview of this

project's data needs.

Data						
Facilities and Pipelines						
Products	Ranks	Voluem	Value	Supply	Address	Dependencies
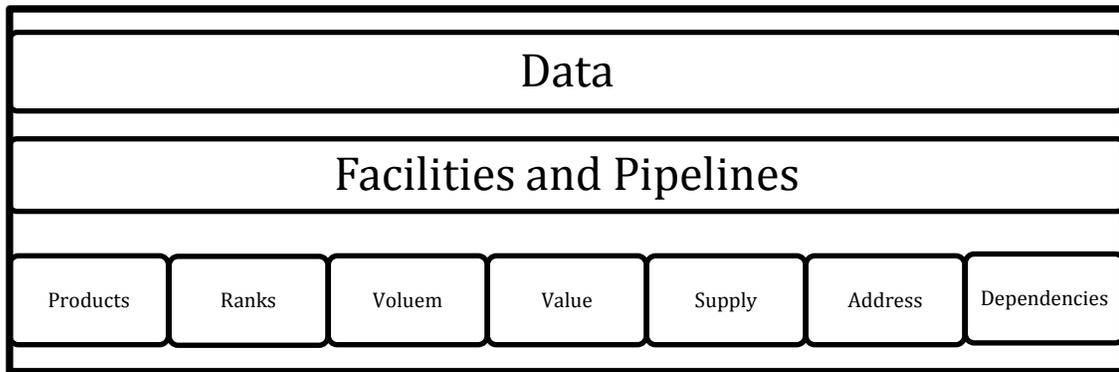
Figure 3.3: Data component overview of this project

3.3.4 Software Component

Developing the required model relays on the use of ArcGIS software. GIS software

benefited from the development of the object-oriented database which enhanced the way

they store data.

3.3.5 Hardware Component

Due to the availability and affordability of computing devises, hardware is becoming less

important as a component of GIS. The system delivered for this project can run on any

desktop computer that has windows 2003 or newer versions installed, as well as ArcGIS

9.3.

3.4 Project Plan

This project is to develop a GIS-based solution for modeling dependencies within

industrial facilities. It was developed for the National Information Center (NIC), which

in turn will deliver it to the Higher Commission of Industrial Security (HCIS). Both the

NIC and the HCIS are departments under the Ministry of Interior umbrella. While the

NIC is responsible for providing technical solutions to all MOI departments, the HCIS is

in charge of ensuring safety and security within industrial facilities.

At this point the HCIS needs to deploy business tools to increase its productivity, effectiveness, and ensure consistent safety and security compliance. HCIS personnel need to accurately assess risks and communicate the severity of violations or threats after this assessment. They need to see the big picture and details along with the words. They need to visualize locations of facilities, industrial zones, as well as other industrial infrastructures for better decision making.

GIS, which provides visualization and analytical capabilities, can enhance the workflow of HCIS by modeling it within a GIS framework. It can be used to create a profile of all facilities and, by having all needed attributes, it can model risk indexes of all facilities. Then it can provide situational awareness and support reports of the assessment task done by HCIS personnel. To be clear at this point, modeling the HCIS workflow within a GIS framework is down the hierarchy of a bigger framework of emergency management and risk assessment. Therefore, the proposed system is assumed to be one system among other systems that will help HCIS to achieve its mission.

3.4.1   Time Line

This project was the beginning of a chain of other projects meant to provide the proper GIS-based solution/applications for meeting the emergency management tasks of the HCIS. During the first quarter of 2011, phase 2 of this project should be initiated. Therefore, this project was to be closed by the end of 2010, the preliminary plan for this project was as in Table 3.2.

Table 3.2: Preliminary Project Plan

	❶	Task Name	Duration	2nd Quarter	3rd Quarter	4th Quarter	1st Quar
1		Technology Siminars	6 days				
2		Needs Assessment	1 day				
3		Assessing Available Data	8 days				
4		Document Standards For Data Products	2 days				
5		Document Communication Network between NIC and ISD	3 days				
6		Edit the Scope and the Plan of this Project	5 days				
7		Conduct Business Presentation and Project Kick off meeting	1 day				
8		On Site understanding of the ISD Workflow	1 day				
9		End of Planning Phase	1 day	6/2			
10		Analyzing Available Data	10 days				
11		Meeting in ESRI to discuss System Design Issues	2 days				
12		Creat a Conceptual System Design	5 days				
13		End of Project Analysis and Design Phase	1 day	6/28			
14		Database Design	15 days				
15		Applications Design	10 days				
16		Executing the Database	7 days				
17		Excuting Applications	11 days				
18		End of Project Excution Phase	1 day		9/8		
19		Implementing Applications	10 days				
20		Implementing System's Interfaces	15 days				
21		Test the System	5 days				
22		End of Project Implementation Phase	1 day			11/25	
23		Prepare a Final Extended Project document	10 days				
24		Prepare Future Add Ons Document	5 days				
25		Defend the Project	1 day				
26		Prepare Recommendations Document	1 day				
27		End of Project Completion Phase	1 day			12/21	
28		On SiteTesting and Dleivering the System	3 days				
29		Delivering All Project's Documents	2 days				
30		Delivering User Manual Document	2 days				
31		End of Project Closure Phase	1 day			12/27	

After the start of this project, at the needs assessment sessions, and after that at the

system test, it was determined that some tasks that were scheduled were no longer

needed. These tasks included data assessment and data analysis. This was not due to the

lack of data available at the HCIS but rather to the fact that HCIS only needed a model

that could be used to solve the problem addressed. Therefore, this project utilized

mockup data to provide the proper model, which could then be used by the HCIS to

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analyze its data. That led to a slight change in the plan that had already been itemized broadly. This broad itemization of the plan was carried out in order to avoid stating specific tasks that might be not needed. Table 3.3 shows actual steps followed in executing this project.

Table 3.3: Tasks that were executed to accomplish the project

		Task Name	Duration
1	✓	Technology Siminars	6 days
2	✓	Needs Assessment	1 day
3	✓	Document Standards For Data Products	2 days
4	✓	Document Communication Network between NIC and ISD	3 days
5	✓	Edit the Scope and the Plan of this Project	5 days
6	✓	Conduct Business Presentation and Project Kick off meeting	1 day
7	✓	On Site understanding of the ISD Workflow	1 day
8	✓	End of Planning Phase	1 day
9	✓	Meeting in ESRI to discuss System Design Issues	2 days
10	✓	Creat a Conceptual System Design	5 days
11	✓	End of Project Analysis and Design Phase	1 day
12	✓	Database Design	15 days
13	✓	Applications Design	10 days
14	✓	Executing the Database	7 days
15	✓	Excuting Applications	11 days
16	✓	End of Project Excution Phase	1 day
17	✓	Implementing Applications	10 days
18	✓	Implementing System's Interfaces	15 days
19	✓	Test the System	5 days
20	✓	End of Project Implementation Phase	1 day
21	✓	Prepare a Final Extended Project document	10 days
22	✓	Prepare Future Add Ons Document	5 days
23	✓	Defend the Project	1 day
24	✓	Prepare Recommendations Document	1 day
25	✓	End of Project Completion Phase	1 day
26	✓	On SiteTesting and Dleivering the System	3 days
27	✓	Delivering All Project's Documents	2 days
28	✓	Delivering User Manual Document	2 days
29	✓	End of Project Closure Phase	1 day

Resources for completing all the tasks were provided mostly by the University of Redlands MS GIS. Faculty members, either full-time or adjunct, were available to lead and assist in solving technical difficulties while executing this project.

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3.4.2 Deliverables

Although deliverables are listed in the Timeline section of this Project Plan document, this section lists the core deliverables again with a description of each one. This helps us to understand the scope of this project and to keep our commitment to the timeline of tasks in this project. The deliverables of this project are:

1 The main system: An application that is used to analyze dependencies among industrial areas. It is the main component of this project.

2 The final report: This report which documents future developments, recommendations, a user manual and other project documents that include a poster, a CD, is delivered at the end of this project. Documentation is a very important part of this project because it will be used to speed up the iteration process for developing the system created in this project. Schema and metadata associated with the deliverable system are also parts of project deliverables.

3.5 Summary

This project was built in line with a well-known GIS professional, Roger Tomlinson, who documented proven methodologies for executing GIS projects in his book: *Thinking About GIS*. The plan was modified due to unforeseen changes in its scope and unrealized limitations of time and resources. These changes do not seem to appear when analyzing both the initial and the modified plans. This is primarily due to the broad definition of tasks that were to be undertaken. However, these changes have not added as much risk to the project as have the limits in time and resources. This is due to the fact that both the client and the developer were fully aware of what the final product should look like.

Chapter 4 – Database Design

This chapter describes the file geodatabase that houses data of industrial area facilities. Sections describe conceptual and logical models and data sources, cleansing, and loading.

4.1   Conceptual Data Model

The functional requirements drove the database design that supports modeling dependencies among industrial facilities. Entities that were of interest to the client were the facilities, pipelines used to transmit products between these facilities, and products produced by these facilities. Per the client's request, the database had to host a minimum data volume to support the required functionality. This limited the data to hold only necessary attributes, which would then feed subsequent analyses of failure consequences, R-phrases of materials produced by the failed facilities, and the US dollar cost of failure.

　　A key concept in this project was the linkage between facilities in an industrial area by transmission networks. This concept was used to determine the failure of one facility as a consequence of the failure of another facility connected to it that fed this facility with required material. The transmission network was divided into subtypes based on the transmission mode. Product type was also an important data element since it determined the R-phrase required in the analysis. Figure 4.1 shows the preliminary design of the database.
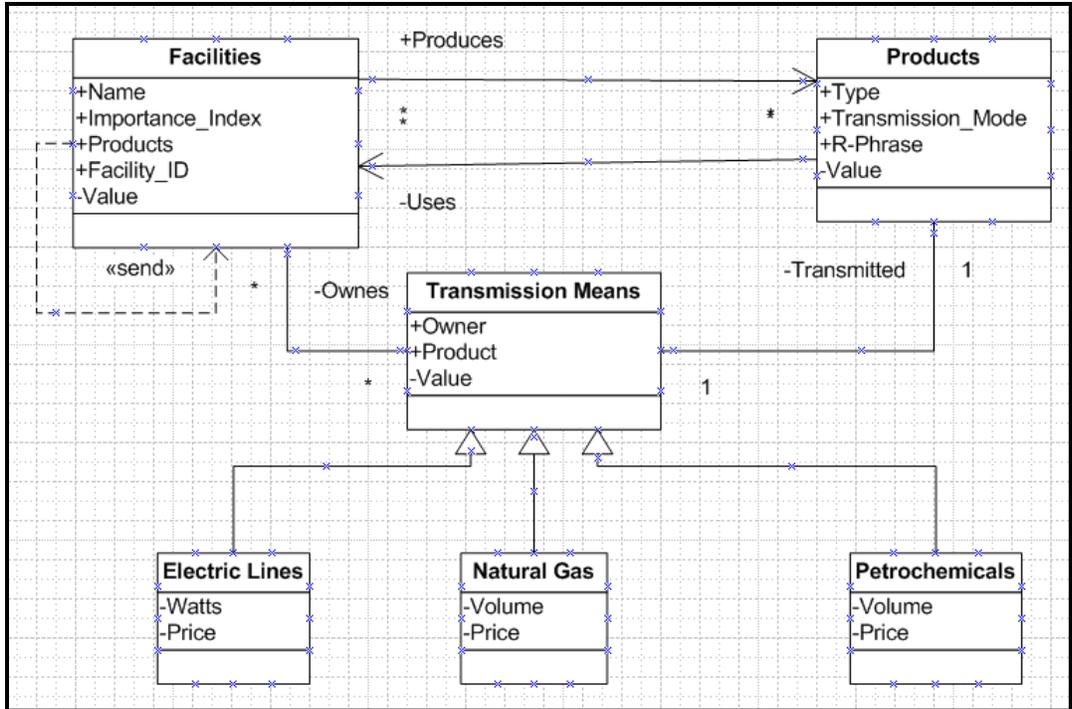
Figure 4.1: UML diagram of the dependencies data model

4.2   Logical Data Model

The logical data model was built using ArcGIS software, which was based on the non-

functional requirement of using ArcGIS 9.3.1 to implement the failure consequences

model affected by the selection of the database. Within ArcGIS, there are two options for

selecting the database which require no additional database software: personal and file

geodatabases. Although both types are semi object-relational, file geodatabases offer

more advantages related to unlocking the database for multi-editing, as well as the

flexibility to scale up. This project implemented a file geodatabase to store all data

necessary in order to feed the failure consequences model. This was primarily due to the

editing and scalability features of the file geodatabase. A folder to store symbology layers

and another model work space folder were created, as well. The basic structure of this
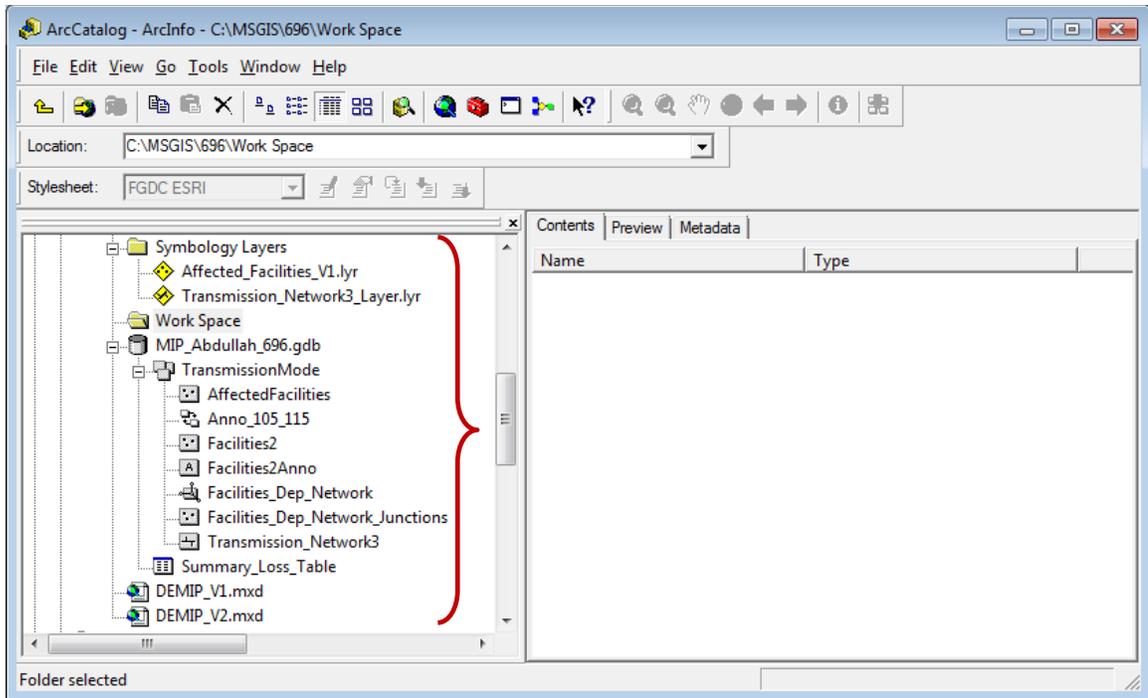
project is shown in Figure 4.2.

Figure 4.2: Basic Database Structure

The geodatabase contained only one dataset, which contained subsequent feature classes. This dataset was named Transmission Mode and it stored point feature classes of facilities, as well as transmission means line feature classes.

4.2.1 Transmission Mode Dataset

This data set contains the Facilities2 point feature class andTransmission Network3 line feature class as well as the geometric network in which they participate: Facilities_Dep_Network, and the associated Facilities_Dep_Network Junction point feature class. It is a relatively small dataset containing only the necessary feature classes to build the geometric network that is used to define connectivity rules and weights among these features, enhancing the analyses of their dependencies and failure consequences thereafter.

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4.2.1.1   Facilities Point Feature Class

This feature class is an important entity in the database. As the name indicates, it

represents facilities. Since only point or line feature classes can participate in a geometric

network, this feature class was created to represent facilities. Fields of this feature class

are as listed in Figure 4.3.
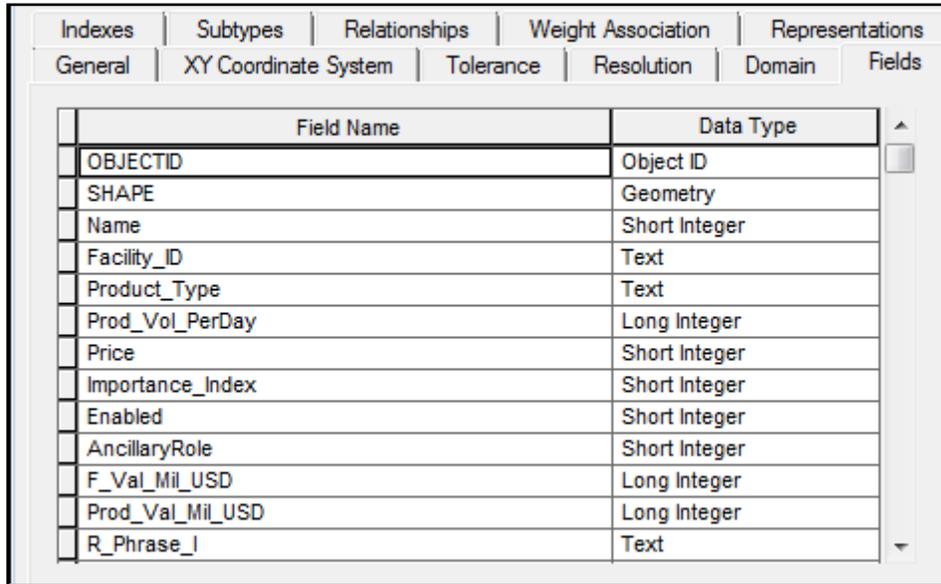
Figure 4.3: Industrial Facilities Point Feature Class Fields

    In designing attributes for the Industrial Facilities Point Feature Class, subtypes were

created based on the name field. In addition, domains were created for Product_Type,

R_Phrase_I, and Importance _Index. Other fields were left to the client to fill in the

manually.

4.2.1.2   Transmission_Network Line Feature Class

This feature class represents the means by which a product is transferred from one facility

to another. It is a key element in defining dependencies and failure consequences. Fields

of this feature, as well as their data type, are shown in Figure 4.4.

Figure 4.4: Transmission_Network Line Feature Class

The Owner field was used to classify transmission means into subtypes of: pipe lines, trucks, OH transmission lines, and UG transmission lines. Domains were created for the user to select attributes for Product_Type, Producer, Consumer, TransMode, R_Phrase, and Importance_Index fields. Other fields were left to the user to enter the proper attributes.

4.2.1.3 Facilities_Dep_Network Geometric Network

The core GIS database element that influenced the selection of GIS technology as a framework for delivering the client's need was the ability to create a geometric network from the feature classes that represent facilities and the transmission means connecting them. In general, a geometric network is used to model common networks and infrastructures found in the real world. It is a set of connected edges and junctions, along with connectivity rules, which are used to represent and model the behavior of a common network infrastructure in the real world.

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The Facilities_Dep_Network geometric network is composed of the Facilities and the Transmission_Network feature classes. By default, another point feature class was created while creating the geometric network by the ESRI ArcCatalog, called Facilities_Dep_Network _Junctions, which is created from the Facilities feature class. The Facilities_Dep_Network _Junctions feature class is created as part of the geometric network to depict a point of transfer of flow from one transmission means to another in the real world. It is drawn to be coincident with the Facilities feature class that participates in the geometric network. Figure 4.5 shows the Facilities_Dep_Network properties and features participating in it.
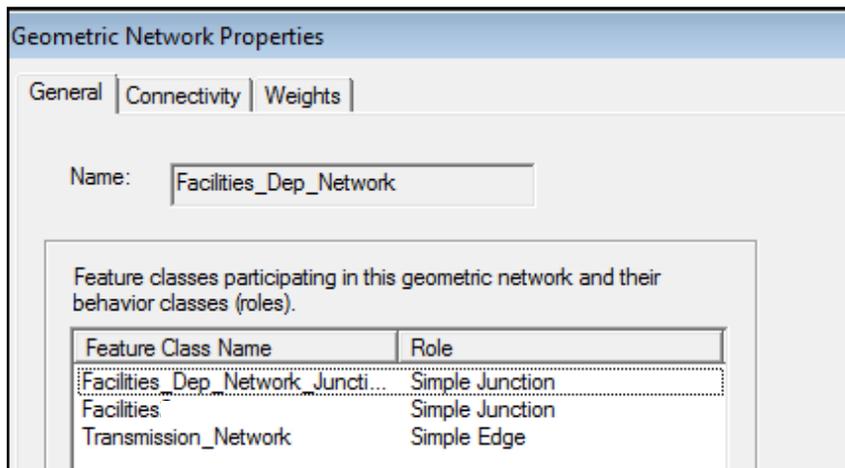

Figure 4.5: Facilities_Dep_Network properties and features participating in it

In the Facilities_Dep_Network geometric network, cardinality was specified so that all junctions may connect from one up to 50 edges. Similarly, an edge must begin and end with a junction. As stated in sections 4.2.2.1 and 4.2.2.2, the Facilities and Transmission_Network feature classes were both divided into subtypes based on the Name and Owner fields consecutively. While these fields contain the same attributes, the Name field in the Facilities refers to the facility's name, whereas the Owner field in the

Transmission_Network refers to the name of the facility that owns the transmission means. To reflect the fact that most of the time, a facility is using transmission means that it owns to transfer products, default settings were designed accordingly. Figure 4.6 and Figure 4.7 show a snapshot of connectivity properties of Facilities_Dep_Network geometric network.
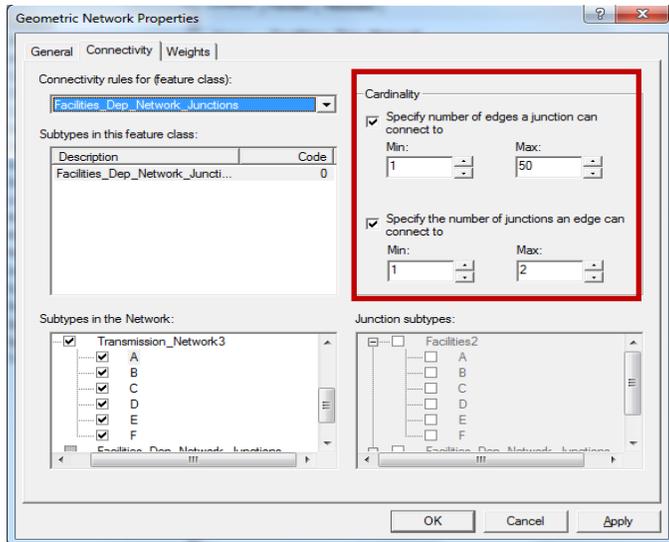

Figure 4.6: Geometric Network Properties, Connectivity Rules-Cardinality
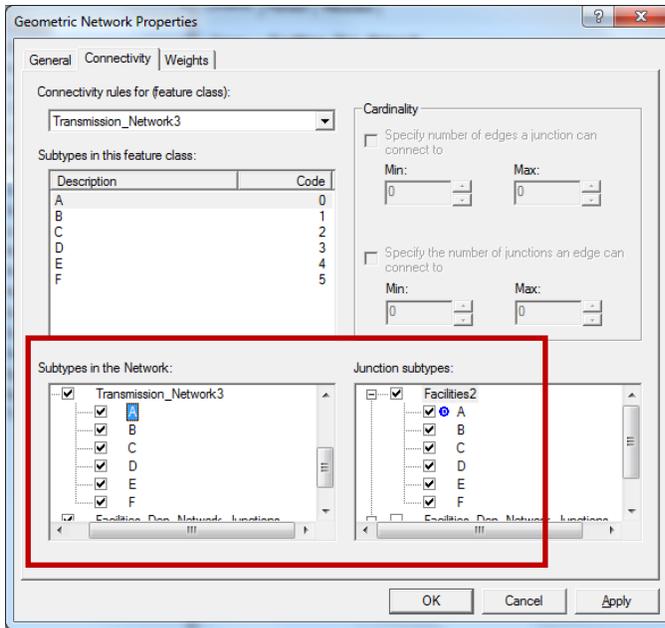
Figure 4.7: Geometric Network Properties, Connectivity Rules-Defaults

4.2.2   Domains

Since the database elements of this project share almost the same fields, domains were

created for those fields of pre-specified attributes. These fields are: Name, Owner,

Producer, Consumer, Product_Type, R_Phrase_I, Importance_Index, and

Transmission_Mode. Other domains were created by default while creating a geometric

network by ArcCatalog. These domains are AncillaryRoleDomain and EnabledDomain.

The AncillaryRoleDomain is used to specify whether a junction is a source, sink, or none

setting the flow direction thereafter. The EnabledDomain is used to enable or disable the

associated feature in the geometric network, which then affects how the flow and the

trace results are determined. AncillaryRoleDomain and EnabledDomain domains are

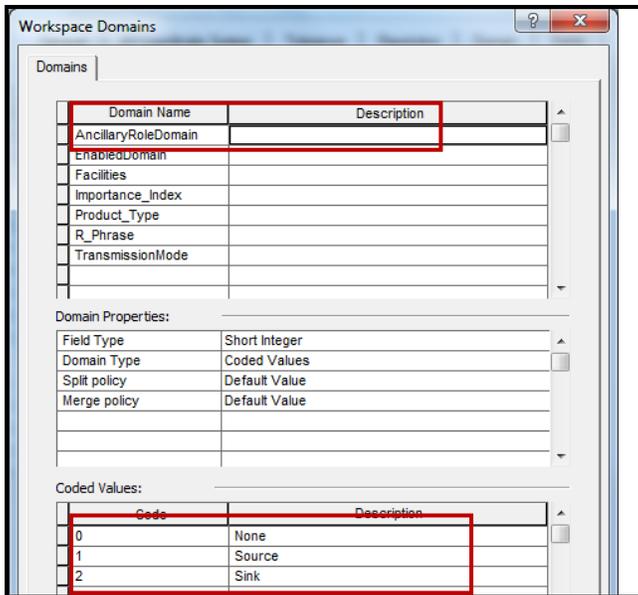shown in Figure 4.8 and Figure 4.9 respectively.

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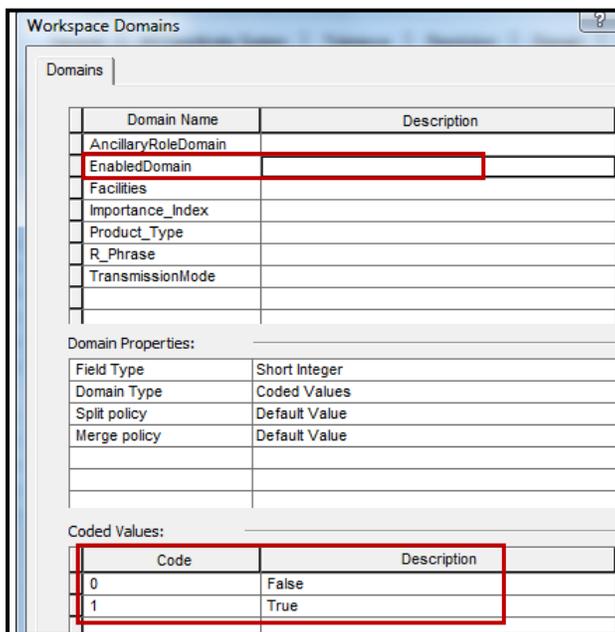
Figure 4.8: AncillaryRoleDomain

Figure 4.9: EnabledDomain

Name, Owner, Producer, and Consumer fields were assigned a domain called Facilities.

This domain stores names of facilities that were represented in this project by letters A,

B, C, D, E, and F. These letters can be replaced with actual names by the client. Figure 4.10 shows Facilities domain details.
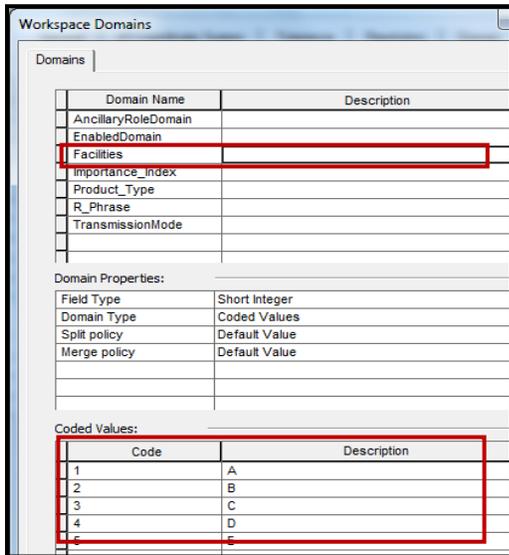

Figure 4.10: Facilities domain

The second created domain was the importance index, which is a numeric range from 1 to 10 that indicates how important either the facility or a transportation method is. The larger the number, the more importance it indicates. It was created based on the client's request to have this domain, which will be utilized to edit the Importance_Index field associated with Facilities and Transmission_Network feature classes.Figure 4.11 shows details of this domain.

Figure 4.11: Importance_Index Domain

The third user-created domain is Product_Type domain. It contains a list of

products that are of interest to the client. Details of this domain are shown in Figure 4.12.

Figure 4.12: Product_Type Domain

The fourth domain is the R_Phrase domain. It contains a list of 122 R-phrase values that indicate the health risk associated with different petrochemical products. Figure 4.13 shows R_Phrase domain details.

Figure 4.13: R_Phrase Domain

The last domain is theTransmissionMode domain. It contains a list of transmission means. Figure 4.14 shows this domain details.

Figure 4.14: TransmissionMode Domain

Restricting users to use these domains will enhance data entry of the associated fields, which will then enhance integrity and, therefore, the analyses.

4.3   Data Sources

Industrial facilities were digitized to depict -to high level of similarity- the current situation of industrial facilities. In fact, data here are mockup data meant to be used to test the functionality of the failure consequences tool. The Coordinate system was set to be Ain_el_Abd_UTM_Zone_38N, which is the proper coordinate system used in the client's area of interest. Attributes were edited in order to fulfill the purpose of the analyses. There are fields that were edited with the proper attribute by selecting them from the associated domain. Other fields were edited with appropriate data for the time of editing them.

Facility name, product type, importance index, R-phrase, and transmission means were loaded into the corresponding fields by selecting them from the domains that contain them. Other fields were either loaded with the appropriate data of the time, such as the values or the prices, or were ArcGIS auto-generated fields, like OBJECT ID, SHAP *, SHAP AREA, or SHAP LENGTH.

4.4   Data Collection Methods

The client is new to the use of GIS in analyzing problems in the HCIS domain. However, general guidelines concerning what data should be provided were given to ensure that the system would deliver the desired analyses. As stated earlier, this project used mockup data to deliver the required functionality. Moreover, the database was designed to support successful implementation of the Failure Consequences Model.

Therefore, data were collected based on previous knowledge of the industrial area that was of interest to the client. Attributes were assigned to each field respectively. Since fields are dependent on each other, their attributes were collected accordingly. For example, Facility A was assumed to produce natural gas. The importance index for such a facility was set to 10, based on the client's request. The value of this facility was set to be 1,000,000 US dollars. The price of the natural gas obtained from the market feed was four US dollars per thousand cubic feet. Consequently, the R-Phrase index associated with natural gas is R12. Similarly, all other data were specified to support the required analyses although they were not confirmed by the client.

4.5   Data Scrubbing and Loading

Since much of the work was done on the database design, and since the data were a mockup, there were few concerns while scrubbing and loading data. Data were loaded on the edit session to approximately depict the reality. Accurate data should be loaded by the client after receiving the model.

4.6   Summary

Since the client will be using different data, the database for this project was design to minimize data loading and editing overhead. This was done by implementing the proper subtypes, domains, and defaults, as well as the appropriate workspace to the appropriate coordinate system of the client's area of interest. The geometric network was the core element in the database and it should be recreated by the client to account for changes in the attributes' values. With the database built and operational, the system tools and workflows were ready to be built. These topics are addressed next.

Chapter 5 – Implementation

This chapter describes the process of project planning and setting up the proper database phases. The questions that needed to be answered by the end of this project were what are the consequences of a facility's failure are, more specifically what are the affected production lines, and what is the cost of that cascaded failure in terms of lost production value.

The implementation phase was carried out in two stages: editing the geometric network, and creating the analysis model. The implementation phase was the most tedious phase and had many trial and errors in each of its three stages. ESRI's ArcGIS Model Builder, as well as another tool called The Individual Direction Tool (ESRI Developer Network, 2010), were used to accomplish this phase.

5.1 Editing the Geometric Network

The geometric network was used to model the flow of products between industrial facilities and utilities, as well as an exporting port within the same industrial complex. In other words, the geometric network was used to model the dependencies between supply chain networks. This required creating a point for each facility that served as a supply point (source in terms of geometric network database definition) and another point to serve as a storage point that receives the products from the supplying facilities (sink in terms of geometric network database definition). The two points that depict each facility were made very close to each other so that they look coincident in the extent scale of the area of interest. The source points were assigned odd numbers in the Facility_ID field,

which was left null for the sink facilities. This field was then used to label these facilities. Figure 5.1 gives an illustration of this process.
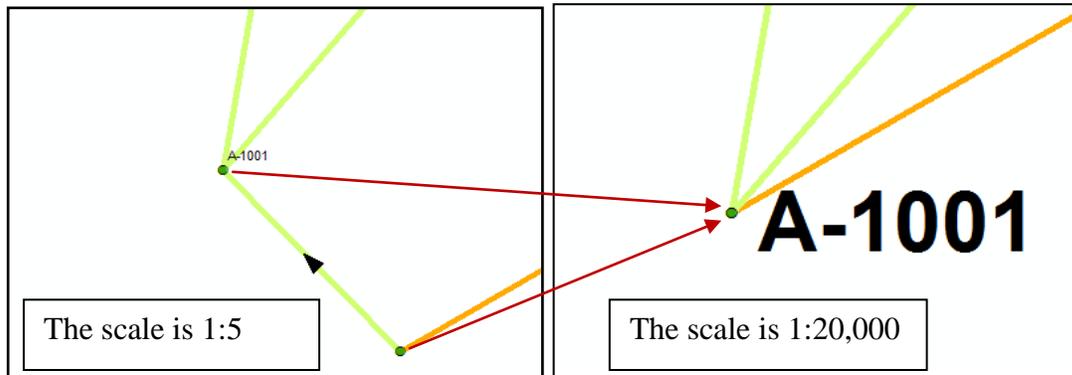
Figure 5.1: Sink and Source of a Facility, Where the Flow Direction is from the Sink to the Source. This representation is done to prepare the network of these multiple connected facilities for the interdependency analyses

The other task needed to prepare the network for analyzing dependencies between different facilities was to set up the flow direction in each edge, which represents the transmission means. The flow direction was set by default from the sink to source in ArcGIS. However, here it was necessary to set the flow direction between the two points that represent one facility's receiving and supplying points to be from sink to source. This was achieved using a tool called the Individual Direction Tool which is available in the public domain. Figure 5.1 shows the arrow direction displayed from facility A sink point that, theoretically, receives electricity and sends it to the facility A source point which, theoretically, uses electricity to pump natural gas to its customers' locations. Figure 5.2 shows a snapshot of the Individual Direction Tool dialog box.
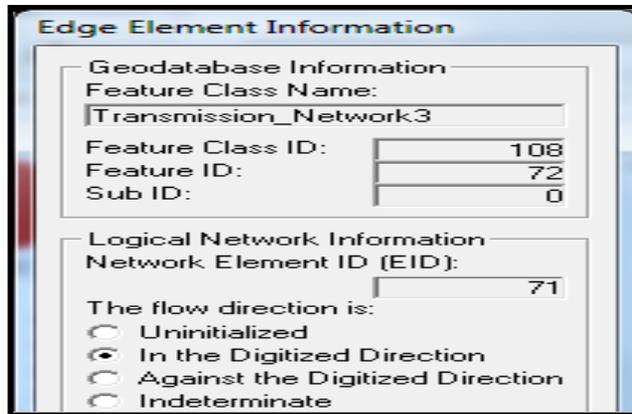
Figure 5.2: The Flow Direction Dialog Box

The Flow Direction tool, not provided or supported by ESRI, was essential to the

process of preparing the network for the analysis part of this project. This tool was

developed using Visual Basic 6 (VB6) and it works on a windows platform. In addition,

it displays better if used with ArcGIS 9.X versions, rather than the newer versions of

ArcGIS, where support for VB6 is deprecated.

5.2   ESRI ArcGIS Utility Network Analyst toolbar

The developed solution was dependent on the ability of the Utility Network Analyst

toolbar to perform the first part of the analysis. The Utility Network Analyst toolbar is

designed to enable the user to analyze geometric networks. With it, the user can select the

network to work from a drop-down list that, by default, contains all geometric networks

added to ArcMap workspace. The Utility Network Analyst toolbar also contains a set of

flag tools which are used to graphically specify the portion of the network to analyze.

Last but not least, the toolbar contains a drop-down list that contains several analyses

tasks from which the user selects one and clicks the solve button in the toolbar. After

clicking the solve button, the analysis result is returned graphically in the ArcMap

workspace. The result can be returned as a drawing with a color that is set to red as a default color or as a selection.

For this project, it was required to set the toolbar Analysis options to return the result as a selection. This is due to the fact that the model, which is the core part of the solution, needs to be fed with selected features that represent the downstream affected portions of the network in order to provide analysis results that meet the user's needs.

5.3 Failure Consequences Model, The Model Builder

The core task of this project was building a model that the client can use to answer two main questions: what are a facility's failure consequences and how much does that failure cost in terms of the value of daily production lost? Model Builder, which is an application within ArcGIS that allows users to create, edit, and manage models, was used to create the Failure Consequences model.

The option in the Network Utility to return results as Selection made it possible to build the model utilizing tools available in the ArcGIS toolbox. This was necessary to analyze and re-symbolize only the affected portion of the network. Tools used to build the model were characterized by honoring selected features during execution. The model was built to split the selected edges from the selected points, providing two different features, then re-symbolizing each of them appropriately. Another tool within the model was then built to provide a table showing statistical results of the losses. Figure 5.3 shows a snapshot of the Failure Consequences model.
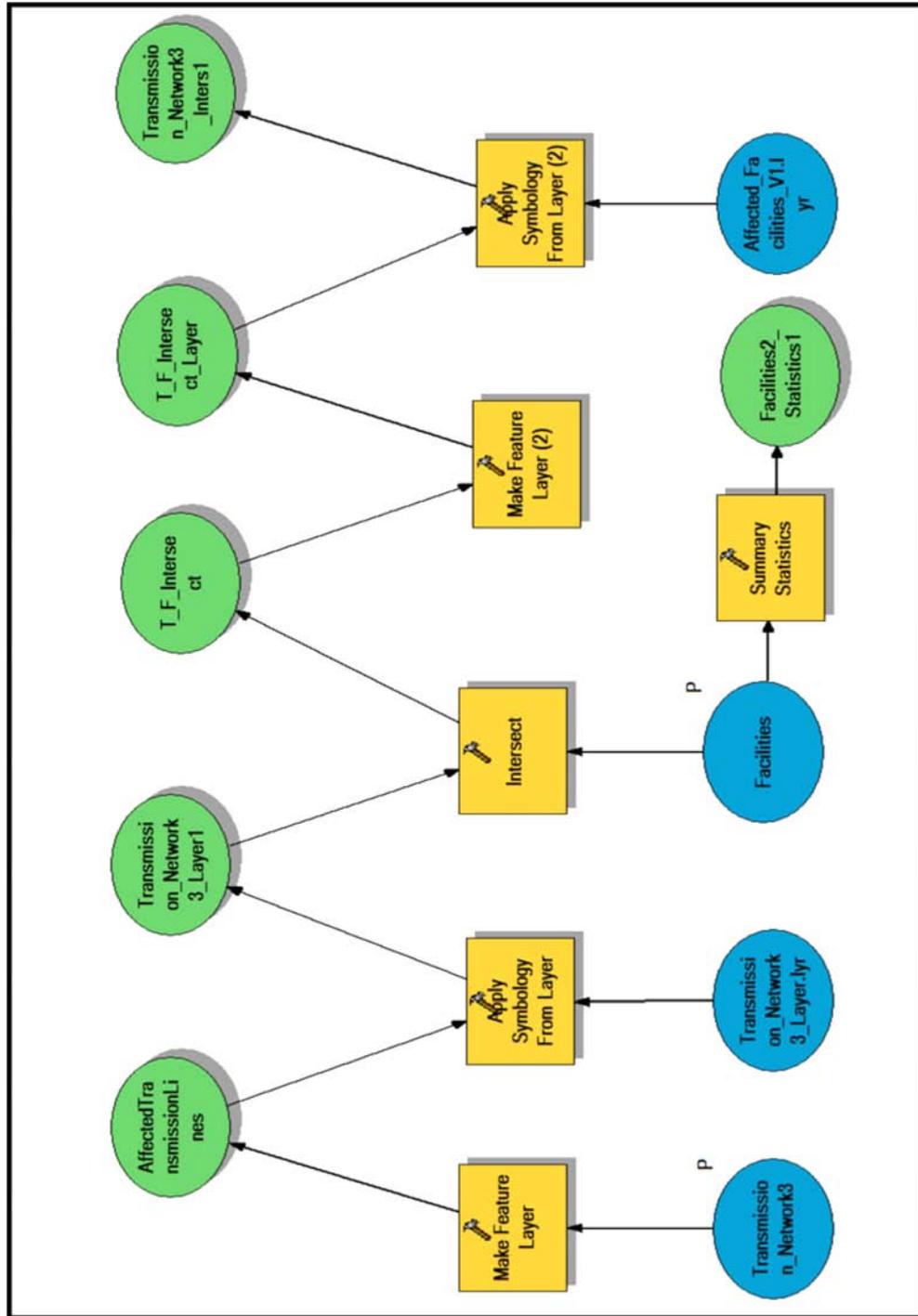
Figure 5.3: Model Builder Was Used to Create the Required Tool

The model used the Make Feature Layer tool twice, the first time was to honor the

selected portion of the network, preparing it to be symbolized; The second was to prepare

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the affected facilities within the affected portion of the network, which resulted from intersecting the affected portion of the network with the facilities point feature class to be symbolized. Appropriate symbologies were applied to the resulting output of the Make Feature Layer tools using the Apply Symbology tool. The Summary Statistics tool, which also honors selected features, was used to create a table that displayed statistical facts about the losses.

Chapter 6 – Results and Analysis

The primary goal of this project was to provide the Higher Commission of Industrial Security (HCIS) with a GIS that provides a clearer view of interdependencies within a petrochemical complex. This will then positively impact the understanding of possible threats and enhance communication with emergency management and authorities, as well as the related industrial sectors. This chapter discusses the output of the Failure Consequences model.

6.1   Results

After running the model, the results were added to the display showing the affected facilities and the physical linkages between them. The affected facilities were re-symbolized to show the magnitude of their production values. Figure 6.1 shows the affected facilities and the linkages between them, and the cascaded impacted of failure of facility C-3001.
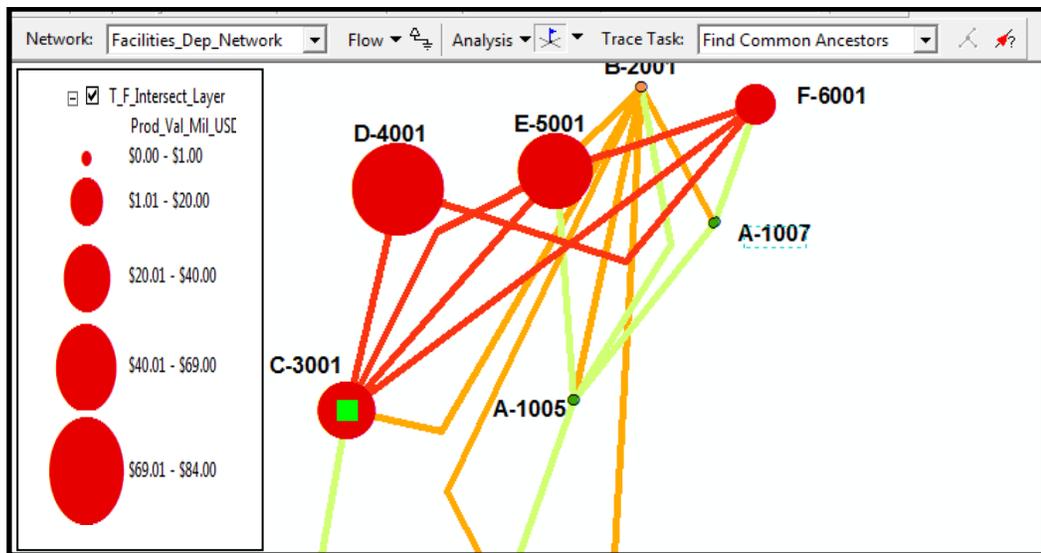

Figure 6.1: Cascaded Impact of the Failure of C-3001

The model also provided another valuable piece of information; the losses statistical table. This table answers the client's question of how much the failure costs in terms of the lost production value in the failed and the impacted facilities. Figure 6.2 shows the statistical summary of the loss caused by the failure of facility C-3001.

OBJECTID *	FREQUENCY	SUM_Prod_Val_Mil_USD	MIN_Prod_Val_Mil_USD	MAX_Prod_Val_Mil_USD
1	7	213	0	84

Figure 6.2: Summary of Losses Caused by the Failure of C-3001

The losses statistical table provides an accurate and quick summation of the losses value in the failed and affected facilities. This table, however, does not provide an accurate count of the failed and affected facilities. This will be illustrated further in the Analysis section.

6.2 Analysis

After articulating the problem and its solution in the previous section, the results were exactly what the client asked for. However, the inability to code a facility as a sink and source in the same time caused the system to analyze points that were known to have zero production values. This led to having a zero production value in the minimum production value field of the Losses Statistical Table. Consequently, this would have flawed the resulted average loss per facility, if such a value was required.

The above considerations about the results in the Losses Statistical Table did not affect the overall cost of the failure. In addition, the procedure of graphically representing the affected portion of the network displayed the results in a way that a source point received a larger representation. This representation, at the extent of the map, changed the symbol of the sink point which for all facilities had zero production values. Figure 6.2

shows the previous example of facility C-3001 after running the Failure Consequences

Model. This figure further explains why zero production value facilities were reported in

the Losses Statistical Table. In addition, it explains why the frequency of the analyzed

facilities in that table was reported to be more than the affected facilities displayed in the

map.
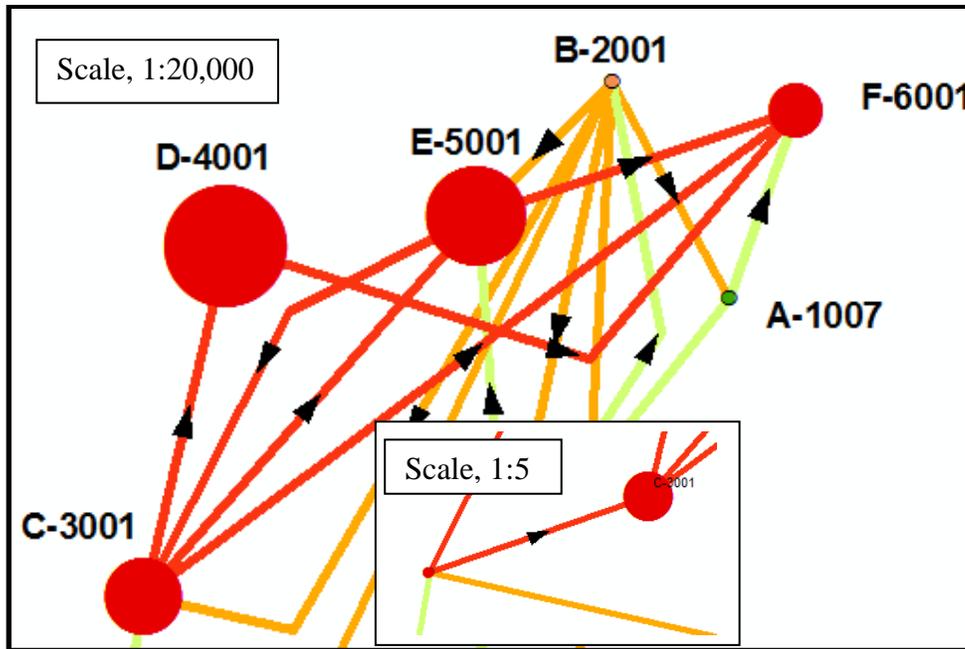
Figure 4: Impacted facilities of facility C-3001 with all facilities statistically analyzed twice except for facility F-6001 which depicts the port in the area of interest

Overall, analysis of the results provided a deep insight as to how they can be read and

used. Understanding the concepts and tricks used to build the network that represents

multiple infrastructure chain of supply networks was essential in understanding the

statistical results.

Chapter 7 – Conclusions and Future Work

This project sought to provide the Higher Commission of Industrial Security (HCIS) with a tool to examine the consequences of a facility's failure. The developed tool satisfies most of the functional and non-functional requirements.

7.1 Conclusion

To sum up, this project was carried out to provide the HCIS with a tool to analyze interdependencies within a petrochemical complex. The need for developing such a tool was driven by the fact that understanding relationships and dynamics underlying industrial facilities would help city and emergency management authorities coordinate and prevent the threat of failure to the industrial system. Assessing such interdependencies will help in allocating safety and security resources, as well as creating redundancies necessary to increase reliability and availability of the whole industrial complex.

For modeling such interdependencies of multiple supply chains networks using ArcGIS, two feature classes were created: Facilities and Transmission Networks. Both feature classes were sub-typed based on their ownership. A geometric network was then created from these feature classes. Next, the ArcGIS Utility Network Analyst toolbar, which works with geometric networks, was used to provide the cascaded impact of a facility. The result of the Utility Network analysis was then fed to the Failure Consequences Model, which was created to re-symbolize the affected facilities and to provide summary statistics about the failure and its cascaded cost.

The overall results of the analysis were in line with the client's functional and non-functional requirements. Key requirements like the database design, that extensively made use of proper domains and subtypes, and proper application implementation that resulted in proper display of the required results were met. The only requirement that was not met was to allow user to export and import CAD format data of pipelines, facilities, security, and emergency resources. This specific requirement was lacking clarity. Importing CAD data into the system would need further enhancement, and the same when exporting results to CAD. The time and scope of this project did not allow for this requirement.

7.2   Future Work

There are several potential extensions to this project. The first is to develop a database tool that could be used to create a diagram for interdependencies between several networks. The second potential extension is to analyze the health and environmental impact for each of the facilities in the event of a fire accident. The third one is to create a web application that combines the current work with further emergency management tasks.

7.2.1   Interdependencies Diagram Tool

The idea for developing such a tool is based on mimicking the way ArcCatalog creates geometric networks. However, for this tool, the user is directed to add geometric networks instead of feature classes. By setting sources and sinks of each network, what networks are connected, and clicking on finish, a geometric network for interdependencies is created in the database. The user then could add this geometric

network feature class and apply the classical Utility Network and the Failure

Consequences analyses to it to further analyze it.

7.2.2 Analyzing Health and Environmental Impact of Each Facility

Each of the facilities in the petrochemical complex produces or uses enormous amounts

of hazardous materials. By knowing the storage volumes, the production volume per day

for each of these facilities, and the material's flame spread index and R-Phrase, another

model for analyzing the severity of accidents associated with each facility could be

implemented.

7.2.3 Interdependencies and Emergency Management Web Application

This project could be extended by creating a web version of it and adding some of the

web GIS tools for emergency management. The web application should provide the user

with more understanding of the area of interest. Also the user should be more

knowledgeable about where to allocate safety and security resources by using this web

application.

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