Simulating impacts of disruption in a network of chemical manufacturing plants and supporting infrastructures[1]

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Abstract
In our study, we looked at how the impact of disruptions may be modelled in a network of chemical manufacturing plants. Given that the number of plants involved is large, it is not time-feasible to model the operation of each plant in detail. However, after 1st round of quick analysis, we can selectively model the identified critical components in greater detail. Hence, the challenge is to develop a standard template that can capture sufficient information about a plant, to give meaningful result. The standard template can be applied to all plants in our study and also allows a non-technical user to easily represent a new plant and integrate into the existing model.

Introduction

In many countries, the chemical industry, as a whole, contributes significantly to the economy. When a company decides to set up a chemical plant, this decision will also influence its suppliers to build their plants in the vicinity. Apart from economical considerations, the physical necessity of delivering the chemical in quantity to respective plants makes it necessary to site their own plants near to its customers. Hence, the chemical industry generates a huge investment potential for the country. The stability and security of the country is one major factor that a company considers when it makes investment. With the recent global terrorist threats, this makes it even more necessary to ensure that a safe working environment is in place in order to attract investment.

The fixed-asset investment of a chemical manufacturing plant is not a small amount. To recoup the huge investment cost, most plants will operate every hour of the day if possible. A disruption to the operation of the manufacturing plant will mean a large production loss, amounting to millions of dollars. The companies may suffer further monetary loss as recovery works (such as cleansing of toxic chemical spill and equipment replacement etc.) are always necessary after a disruption. For example, a sudden electricity disruption may damage some machines due to permanent solidification of the accumulated chemicals.

It is logical to build redundancy or backup in a critical system. In a chemical plant, the feedstock storage will act as safety stock when a supplier is disrupted. It is common for companies to keep spare parts for a certain critical component of the manufacturing

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process. Some plants will have multiple suppliers for a certain critical feedstock. Although this will reduce the impact of disruption, these measures create additional costs to the companies.

Given limited resources and increased security concerns, it is impossible to protect the plant operation from all possible disruptions. It is costly for a company to maintain an electrical generator that can support a plant operation. Often, most companies will only maintain a backup generator to ensure safe shutdown of the chemical process during an emergency. To keep the safety stock, the companies have to build additional storage tank or rent spot tank from logistics companies. It is not economical to keep an excessive amount of feedstock. Due to the hazardous property of certain chemicals, plants are also not allowed under safety regulations to keep additional storage.

This motivates the study to assess the impact of disruption in a network of chemical manufacturing plants. It will help to address some critical concerns of the companies and the government:

- Which public infrastructures (that support the chemical industry) should be protected?
- For a given mitigation measure, how much of the impact of a disruption be reduced?
- How much safety stock should a plant keep for each feedstock?
- What is the impact on a plant’s operation when a main customer demand is disrupted?

There are two main contributions in this work. Firstly, it presents a general framework on how disruptions in a large network of manufacturing plants may be studied on a reasonable study time scale. Based on our limited literature survey, we have not found an article that discusses this issue. Secondly, we develop a model template that facilitates the modelling of the plant’s operation. This template is useful for a quick analysis of the plants. After the critical components are identified from the analysis, the analyst can then focus on modelling these critical components in greater detail.

Methodology

Problem definition and scope

In this study, we are faced with a large number of chemical manufacturing plants. It is not feasible to model the chemical process of each plant in detail. Currently, as the companies are required to conduct own internal quantitative risk assessments before setting up their plants, we decide to focus on the physical flow interaction between plants.

It is still complicated to model the physical flow between plants. A plant may receive hundreds of chemicals from different suppliers. The suppliers may be located overseas and the chemicals are delivered via road or sea links. A finished product from a company may also be exported to an overseas customer. As we are interested in modelling the impact of disruption within a geographical location, we decide to confine our study to this designated location. A supplier or customer located outside the area will not be considered. Instead, we will only include the transportation infrastructures that link the companies and their overseas suppliers / customers in the study. To further simplify the problem, we narrow our scope to those chemicals that are critical to the main process of the plants.

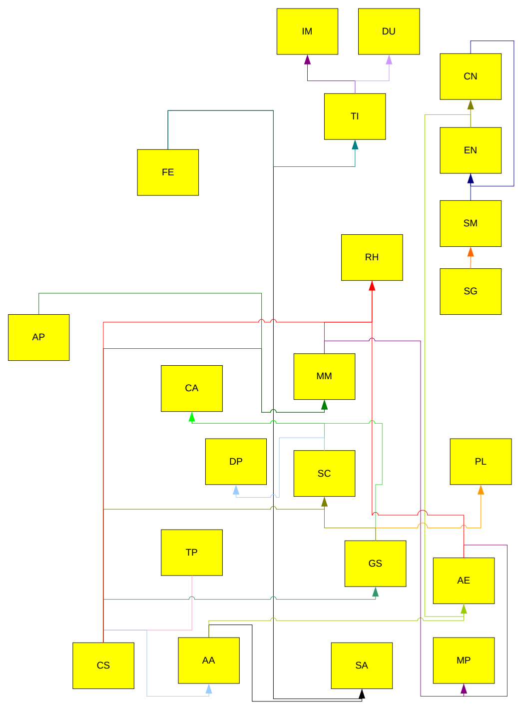

Figure 1: An illustration of the physical flow between companies

Figure 1 is an example of the physical pipe links between plants. It is observed that

- A plant may supply its products to more than one customer.
- A plant may obtain several feedstocks from different suppliers.

It is noted that transportation and utility links are not shown in the figure.

As the chemical industry is expected to grow, the study should allow easy addition of new plants to the overall model by a non-technical user. After much consideration, we decided to build a standard model template that incorporates the basic features of a chemical manufacturing plant. To model a plant, the analysts will follow the guidelines to modify the template. This will reduce the time taken to model a plant and allow a general user to develop a model with minimal difficulty.

<u>General characteristics of the manufacturing companies</u>

As explained above, it is necessary to develop a model template, owing to the complexity of the study. After a survey on all the plants in the study, we summarize the basic operation of a chemical manufacturing plant in Figure 2 and Figure 3. Figure 2 gives an overview of the inputs and outputs of a chemical plant. It illustrates how a company is linked to its suppliers and customers. Figure 3 describes the attributes of the chemical process in the particular plant.

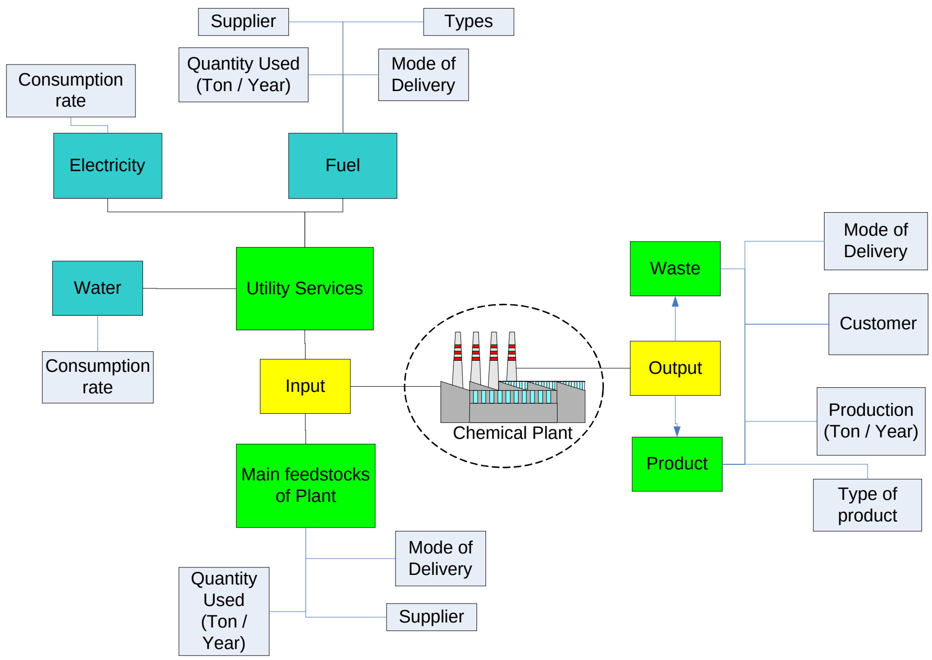

Figure 2: The summarised inputs and outputs of a chemical manufacturing plant

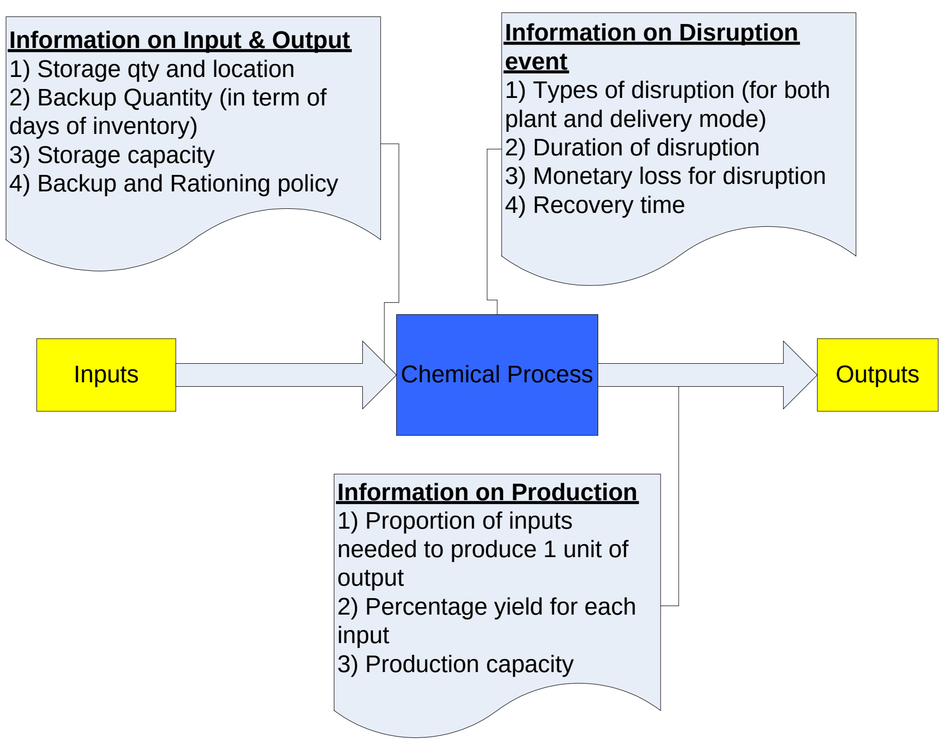

Figure 3: The summarised chemical manufacturing process of a company

Model implementation

Powersim Studio Enterprise software was chosen, for our model implementation. One useful feature of the software [1] is the ability to build hierarchical structures in simulation models. It enables users to create sub-models within the model. This allows us to divide our simulation model into smaller sections, each contained within its own sub-model. The main model will connect the various sub-models and only contain the variables that are exclusive to the "top-layer" of the model. In our study, the specific chemical process of each plant will be built in individual sub-model. The physical links between each plant will be modelled at the "top-layer" of the model.

Figure 4 shows the standard template of a chemical manufacturing plant sub-model, implemented in Powersim Studio Enterprise. The blue parameters allow the user to input the specific values of the attributes. The red parameters will be used to link the sub-model of this particular plant to the sub-models of its suppliers and customers.

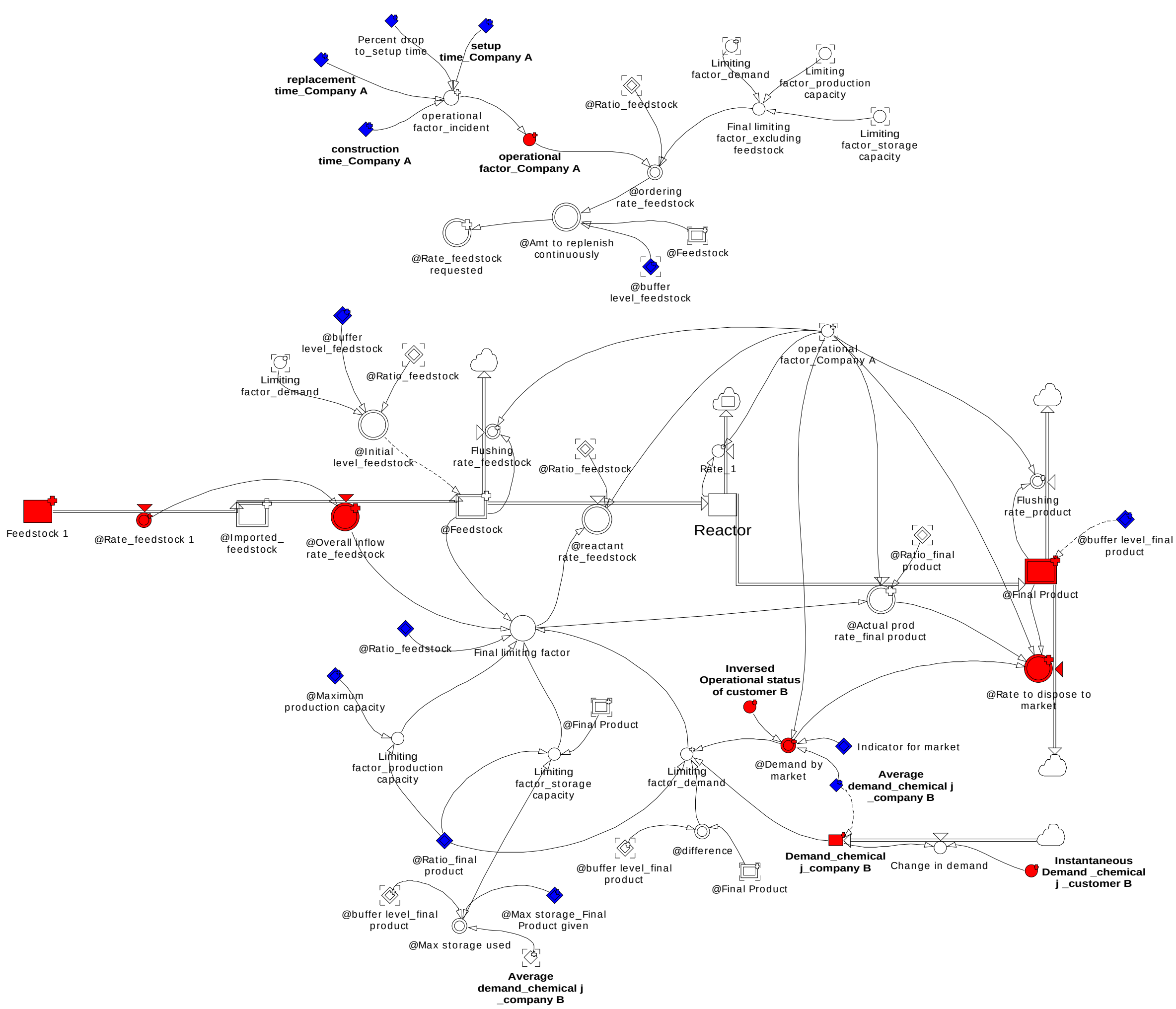

Figure 4: The standard template of a chemical manufacturing plant in Powersim

Model Demonstration

In this section we will simulate some scenarios to demonstrate the capability of the model. The total number of chemical manufacturing plants modelled here is 70. Most of the plants are considered downstream as their finished products are meant for consumers.

Consider a small fire occurs at one of the chemical manufacturing plant, it is forced to shut down. This affects the operations of its customers as they keep minimum storage of the product due to its toxicity. From Figure 5, the maximum number of plant shutdown is 24 and it occurs immediately after the fire. Although the fire lasts less than an hour, some plants will take more than two weeks to resume their operations, as illustrated in Figure 5.

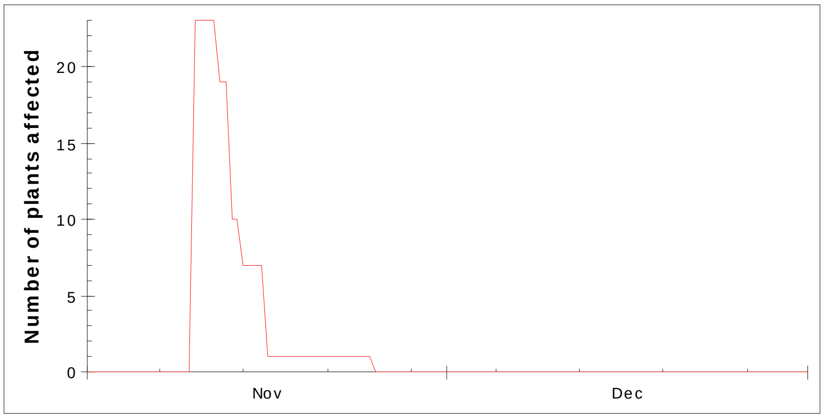

Figure 5: The number of chemical plants disrupted over time, given the occurrence of a small fire

We will next look at the disruption of a transportation link. We ran the simulation model for a range of possible disruption duration of the transportation link. Figure 6 shows the maximum number of chemical plants forced to shut down, due to the disruption of the transportation link.

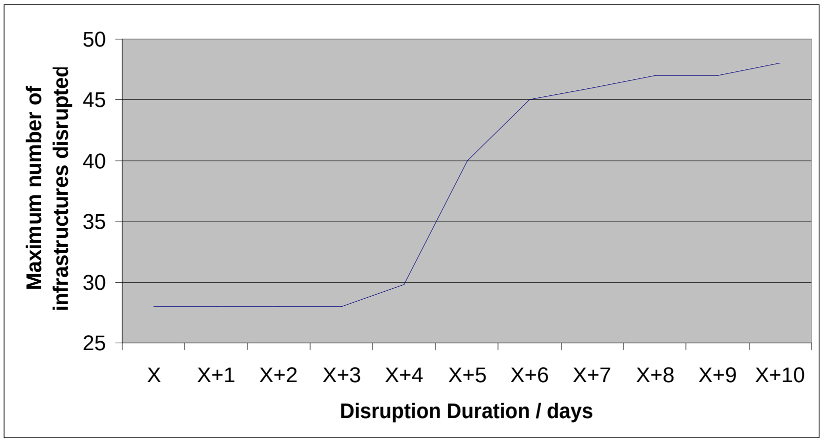

Figure 6: The number of chemical plants disrupted, given the disruption duration of a transportation link

It is observed that the maximum number of plants shutdown will increase non-linearly as the duration of disruption increases. When the duration of the disruption is less than X+5 days, the maximum number of plant shutdowns behaves rather constant. These are the plants which carry little or zero feedstock buffer storage. The model reports a sharp jump in the maximum number of plant shutdowns when the duration of the disruption is X+5 days. This is because several plants depend on the transportation link for the delivery of feedstock. When the link is cut, these plants will make use of their feedstock buffer storage. Most plants store feedstocks sufficient for X+4 days of production or less. When the disruption lasts longer than expected, their feedstock buffers are depleted. The situation worsened as some plants are forced to stop operation when they cannot deliver the finished product to their customers and their product storage tanks are used up. When the disruption is between X+6 and X+8 days, the maximum number of plant shutdowns increases at a slower rate. If the disruption last beyond X+8 days, the maximum number of plant shutdowns shows sign of stabilization as most plants that depend on the delivery mode are already affected.

Conclusion

As a summary, this paper describes the novel application of System dynamics in modelling disruptions in a network of chemical manufacturing plants. One major contribution of this study is to develop a model template that includes the key attributes of a chemical plant (in our context) necessary for studying impacts of disruption.

Reference

1. Powersim Software AS, Powersim Studio 2005 Helpfile, http://www.powersim.com