Risk management in Chemical Supply Chains

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Abstract

Nowadays, efficient supply chain management has become critical to all businesses with benefits ranging from reduced lead-time to improved profits. Enterprises consist of a number of departments (or entities) that perform the various business processes needed for day-to-day operation. In general, the optimal operation of the individual entities does not guarantee the optimal performance of the enterprise. So it becomes necessary to explicitly consider the entire supply chain structure while taking business decisions. Here, we describe an agent-based framework for modeling and simulating the supply chain activities in a refinery. The framework consisted of software agents that emulate the procurement, storage, sales, logistics, and operations in the refinery. Other external agents emulate the crude exchange, oil suppliers, and 3PLs. In this paper, we use this framework to provide decision support to design a supply chain that is robust to various types of risk.

1. Introduction

The chemical industry is one of the world's largest manufacturing industries, producing more than 50,000 chemicals and formulations. Starting from raw materials such as oil, coal, gas, water, air and minerals, the chemical industry produces a vast array of substances that form the basis for almost every other manufacturing activity. It operates on a global scale; it exists in nearly every country in the world, and contributes 7% of global income and accounts for 9% of international trade.

Supply chains in the electronics, automobile and other industries have received much attention in literature. Although some of these lessons can be partly extended to the chemical industry, supply chains in the chemical and process industry have distinctive features and require special attention. As an example, consider a petroleum refinery supply chain.

1.1. Petroleum Refinery Supply Chain

Figure 1 shows a schematic of a typical petroleum refinery supply chain. Refining is a complex process that transforms crude oil into valuable products such as gasoline, heating oil, and jet fuel, as well as petrochemical intermediates which are further processed to produce fertilizers, plastics, synthetic fibers, detergents, etc. A refinery supply chain begins with the production of crude oil and gas either from ground fields or offshore platforms. After pretreatment and storage, these are transported via Very Large Crude Carriers (VLCCs) and Liquefied Natural Gas (LNG) tankers to various refineries around the world. The petroleum refinery converts these into a variety of intermediate bulk chemicals that are used as feedstock in petrochemical plants as well as fuels for aviation, ground transport, electricity generation, etc. Thus the supply chain has at least three distinct centers of manufacturing, namely the oil/gas fields & platforms, the petroleum refineries, and the petrochemical plants. Each of these manufacturing entities is in turn surrounded by a host of logistics services for storage, transportation, distribution, packaging, etc.

Oil products are distributed to customers via various modes that depend on the distance, the nature of products, and demand quantities. The main oil products leave the refinery in bulk loads. Large consumers like petrochemical manufacturers may be supplied directly from the refinery via pipelines, rail, road, or sea. Smaller customers are generally supplied via storage and distribution centers known as terminals or depots. These disparate entities make the task of supplying the right product and the right quantity to the right customer at the right time with the right quality and service a very complex endeavor.

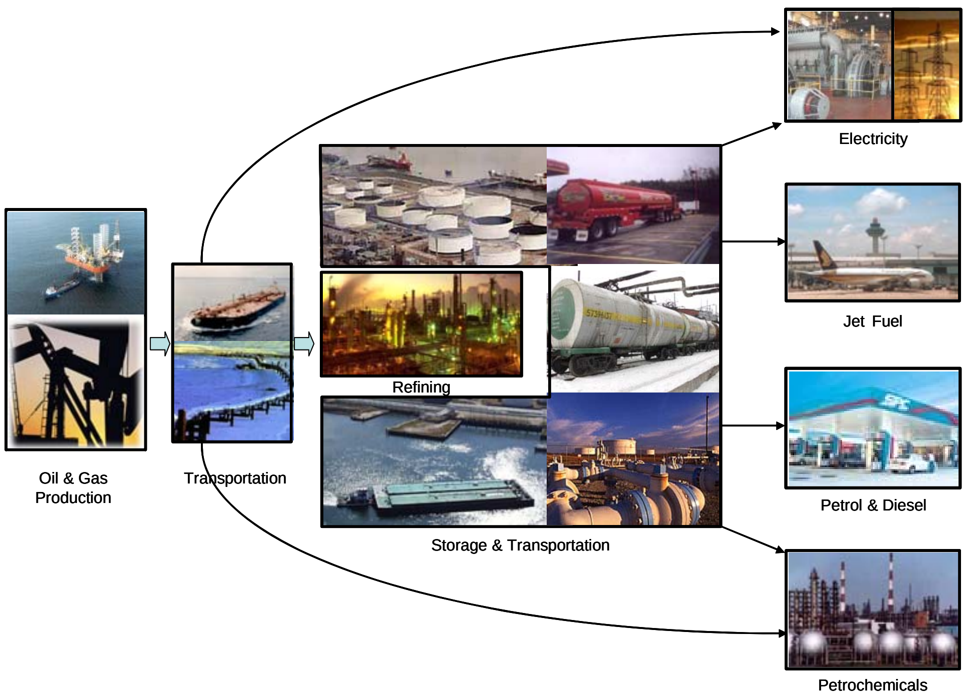

Figure 1: Petroleum Refinery supply chain

The long refinery supply chain that spans the globe suffers from long transportation times (for example, it takes 4-6 weeks to ship crude oil from the Middle East to a refinery in Asia). Further, the price of crude oil, the basic raw material for the refinery, is very volatile even on a daily basis; the demands and the prices for the products are also highly variable. These confound production planning, scheduling and supply chain management. As one example, higher than forecasted demand for products can lead to market opportunities for the refiner which can be exploited if adequate stock of crude is available at hand; however a lower than forecasted demand would lead to high inventory costs that can significantly erode refinery profits. Determining the safety stock levels for crude oil is therefore tricky. Similarly, numerous products and their variants can be produced from each crude by suitably utilizing the complex manufacturing process consisting of a highly interconnected system of reactors, separators and blenders. However the yields of the different products from different crudes are different as are the operating costs for each combination. Given forecasted demands and prices for the products, the process of determining the right mix of crudes has to account for these as well as the landed cost of the crude that includes the purchase cost as well as the costs involved in moving it to the refinery. The fluctuation in the costs, demands and prices on a daily-basis necessitates frequent and speedy re-evaluations of numerous supply chain alternatives. Each evaluation should account for the complex relationships between the raw materials, operating units, and products to arrive at a feasible and optimal solution.

Abnormal situations can lead to disruptions in the supply chain. For example, in the case of crude shipment delay, if available stock is not enough to continue the processing at the previously planned throughput, it is essential to reevaluate the processing schedule, otherwise, a feed stock-out situation would arise and processing would have to be shut down. In such situations, negotiation among the different supply chain entities is critical to reach profitable operation. The agent-based formalism provides a suitable formalism to model, simulate and support risk management in such complex supply chains. Agents can naturally model the ability of real-life supply chains to dynamically react to disruptions and suitably modify throughput, procurement, or sales strategy. In this paper, we describe the agent-based model of refinery supply chain, its simulation, and illustrate its ability to support risk management using common scenarios such as delay in crude transportation, unavailability of jetty, sudden change in demand, etc.

2. Agent Approaches for Supply Chain Modeling & Management

An agent is a computer system that is situated in some environment and that is capable of autonomous action in this environment in order to meet its design objectives (Wooldridge and Jennings, 1995). We have developed Agent Based Framework for Supply chain risk management. Software agents exhibit collaboration, intelligence, mobility and thus are ideal for modeling and analysis of supply chains (Julka, Srinivasan & Karimi, 2002). An intelligent agent must have the following properties:

- **Reactivity:** Agents should be able to respond to changes that occur in their environment.
- **Social Ability:** They should be able to interact i.e. cooperate, co-ordinate and negotiate with other agents to meet their objectives.
- **Pro-activeness:** They should be able to take the initiative to satisfy their objectives.

Supply Chain Management is concerned with coordination among its entities. In multi-agent approach, agents communicate with each other through messages. This is an important property of multi-agent approach which is utilized in modeling supply chain dynamics. Agent based technology support concurrent and distributed decision-making.

According to Bond & Gasser (1988), Multi-Agent computational environments are suitable for studying classes of coordination issues involving multiple autonomous or semiautonomous optimizing agents where knowledge is distributed and agents communicate through messages. If we compare the features of multi-agent and other conventional simulation languages then we can find out that other conventional languages are much lower level and are typically defined as extensions to standard procedural programming language constructs. Therefore development of supply chain model becomes a conventional programming task. The ability of agents to negotiate clearly distinguishes agent-approach from other approaches. Agent based approach is more versatile and can easily capture the qualitative as well as the transactional nature of supply chain. Agents (Weiss, 1999; Woolridge, 2002) are now being championed as the next generation paradigm to design and build complex and distributed software systems.

An Agent toolkit is defined as any software package, application or development environment that provides agent builders with a sufficient level of abstraction to allow them to implement intelligent agents with desired attributes, features and rules (Serenko & Detlor, 2002). In the last few years, several Agent toolkits have been developed with a special attention paid to interoperability and compatibility issues. Foundation for intelligent physical agent (FIPA) reference model has emerged as a standard for developing Agent Platforms (APs). The APs reference model of the FIPA has four components: Agents, Directory Facilitator (DF), Agent Management System (AMS), and Message Transport System (MTS).

Most Agent Development Environments have been developed in Java language, such as JADE, JATlite, Zeus, etc. JADE (Java Agent Development Environment) is used to develop multi-agent systems (MASs) and can be considered middle-ware that complies with the FIPA specifications. JADE also contains a useful set of graphical tools that supports the debugging and deployment phases. The agent platform can be distributed across machines (that does not even need to share the same OS) and the configuration can be controlled via a remote GUI. JADE has all the advantages of Java based systems, such as platform independence. Supply chain can also be modeled on JATlite (Java Agent Template Lite). It is a package of programs written in the Java language that allows users to quickly create new software agents that communicate robustly over the internet. Interactions between agents are made through the common agent communication language knowledge query message language (KQML) Agents send and receive messages, transfer files with FTP, and generally exchange information with other agents on the various computers where they are running.

2.1. Supply chain management

Ahn and Park (2003) presented a multi-agent system for supply chain coordination named MADC (Multi-agent System for Distributed Coordination of Supply Chains) where companies can increase the efficiency of a supply chain by only local information sharing. It is shown that the Bullwhip effect is significantly reduced in MADC when the estimation of market demand is more accurate. However, the limitation of the research is that the approach cannot be used if we cannot observe market demand directly. Also, the approach of MADC is more meaning for supply chains with complexity and uncertainty rather than one that is simple and where global information sharing is possible.

Gjerdrum et al. (2001) applied the multi-agent modeling techniques to simulate and control a simple demand driven supply chain network system using JATLite (Java Agent Template Lite). The approach combined optimization with agent-based simulation to access the performance of the supply chain. The tactical decision making and control policy was determined by the agent system while the scheduling problem was solved by a numerical optimization program, gBSS. Policies such as reorder point, reorder quantity and lead time are tested using this approach to determine the appropriate policy to reduce operating cost while maintaining a high level of customer order fulfillment.

Fu et al. (2000) addressed a preliminary approach towards the collaborative inventory management in supply chains, taking advantage of multi-agent technology in terms of modeling and simulation. The scenario is simulated using the software EXTEND developed by Imagine That, Inc. and validated the modeling methodology of SCM support model. Demand and lead time uncertainty was shown to impact the inventory, particularly safety stocks and hence this calls for the need of collaborative inventory management. The framework of collaborative inventory management is shown to provide some distinctive processes for synchronization of supply chain partners, however, future approaches would include refining the framework of collaborative inventory management and evaluating the framework using EXTEND.

Julka et al. (2002a) presented a unified framework for modeling, monitoring and management of supply chain using Agent Development Environment (ADE), which is build on G2, Gensym's expert system shell. The framework integrates the various elements in the supply chain and represents them in an object-oriented fashion. The entities in the supply chain were emulated by software agents while information and material flows was modeled as objects. Two Decision Support System (DSS) were developed based on the framework, one to manage an industrial cluster and another to provide decision support of the crude oil procurement process in a refinery.

2.2. Belief-Desire-Intention (BDI) model

Many different and contrasting single-agent architecture have been proposed, however the most successful are those based on the belief-desire-intention (BDI) framework. The BDI model evolved from a theory of human practical reasoning which focuses on the role that intentions play in practical reasoning. The conceptual framework of the BDI model is described in Bratman et al. (1988).

The BDI model consists of the concept of belief, desire and intention as mental attitudes that generate human action. In particular, for rational agents, the agent's beliefs correspond to information the agent has about itself and the environment. The agent's desires represents state of affair that the agent would, in an ideal world, wish to be brought about. And finally, the agent's intentions represent desires that it has committed to achieve. What makes the BDI model particularly compelling is that it combines three important elements:

1. It is founded upon a well-known and highly respected theory of rational action in humans.

2. It has been implemented and successfully in a number of complex fielded applications.
3. The theory has been rigorously formalized in a family of BDI logics.

In particular, rational agents incorporating the BDI model give a more natural (human-like) modeling. It is able to weigh alternative courses of action through deliberation and choose the action that best reflects its current state of belief and desire. These properties are particularly important for agent-based modeling and simulation of a supply chain since different entities in the supply chain often have conflicting objectives. Also, different entities exhibit complex human behavior that typical modeling may not be able to capture.

Jadex, which incorporate the BDI model into JADE agents, was thus chosen as the agent development environment (ADE) for this research project. Unlike traditional BDI systems, which treat goals merely as a special kind of event, goals are a central concept in Jadex. In Jadex, agents have beliefs, which can be any kind of Java object and are stored in a beliefbase. Goals represent the concrete motivations (e.g. states to be achieved) that influence an agent's behaviour. To achieve its goal the agent execute plans, which are procedural recipes coded in Java.

3. Agent-Based Model of Refinery Supply Chain

In this section, we describe the agent-based model of the refinery supply chain.

3.1. Ontology Development using Protégé

In this research project, Protégé is used as the ontology development environment used to develop the supply chain ontology. An ontology defines a common vocabulary for researchers who need to share information in a domain, and includes machine-interpretable definition of basic concepts in the domain and relations among them.

Some of the reasons for the development of an ontology are:

- To share common understanding of the structure of information among people or software agents
- To enable reuse of domain knowledge

- To make domain assumptions explicit
- To separate domain knowledge from the operation knowledge
- To analyze domain knowledge

In practical terms, developing an ontology includes:

1. Defining classes in the ontology,
2. Arranging the classes in a taxonomic (subclass-superclass) hierarchy,
3. Defining slots and describing allowed values for these slots,
4. Filling in the values for slots for instances.

The Jadex Beanynizer is a plugin for Protégé which allows the user to generate JavaBeans and a JADE ontology file for a modeled ontology. It supports the creation of ontologies for use with the JADE platform, or pure Java ontologies for use with the Jadex Java-XML encoding. Classes and slots are then added to the ontology.

In particular, the refinery supply chain ontology consists of various messages that are being communicated by the agents as well as other important class definitions such as *Crude, Product* and *Location* as shown in Figure 2. Each of these is further described with detailed attributes. For example, the *Crude* object has the following attributes (or slots) – assay (crude assay), location (location of crude), name (name of crude), price (price of crude) and sulphur-content (sulphur content of crude).

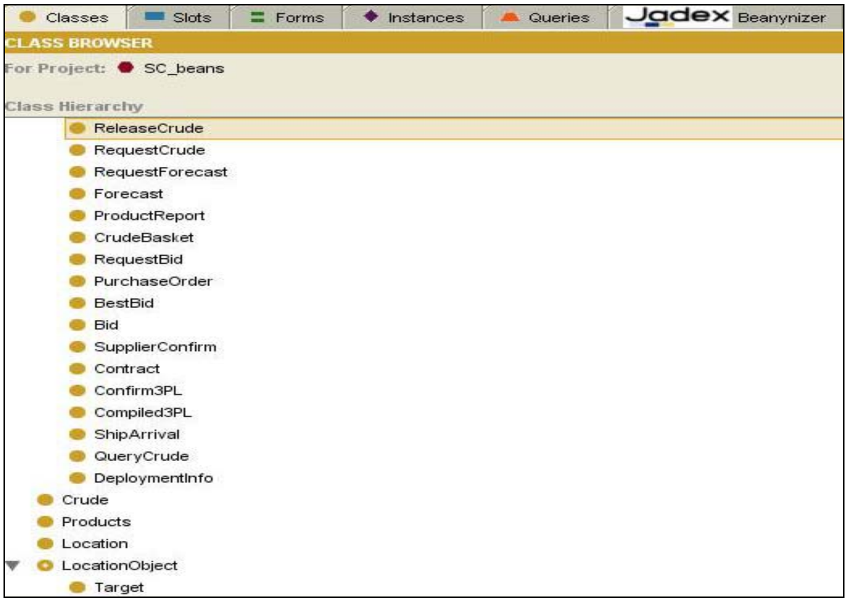

Figure 2: Ontology for Refinery Supply Chain

3.2. Agent Modeling in Jadex

Jadex is an agent-oriented reasoning engine for writing rational agents with XML and the Java programming language. It is an extension to the Java Agent Development Environment (JADE), a well known open-source multi-agent platform. We have used the Jadex Standalone adapter since it is a small yet fast environment with a minimal memory footprint.

In this work, all the entities in the refinery supply chain were modeled as agents using Jadex. All message objects were generated by Protégé and compiled into .class files.

For the refinery the following assumptions were made:

- The refinery makes five products: light hydrocarbons, gasoline, kerosene, gas oil and residue.
- Up to two crude can be brought in each procurement cycle.
- Each crude storage tank can only store a specific type of crude.
- The refinery has one jetty and tankers unload crude directly into storage tanks.
- The refining operations is modeled as a batch process with a cycle time of 1 day.

- The refinery operates on a push mechanism, i.e. the refinery processes as much crude as its capacity allows and all products are presumed to be sold at the end of the day.
- The crude stock is not allowed to dip below the minimum inventory level.
- Each ship deployed by a 3PL can only deliver one crude.

3.2.1 The refinery agents

The refinery consists of several departments which play a vital role in the refinery supply chain. An overview of their roles is given below:

Procurement. this department coordinates the crude procurement process and has the highest interaction with all the other departments. The available crude was retrieved from the oil exchange and evaluated to decide the amount and type of crude to be purchased.

- Operations: this department decides the amount and type of crude to be processed daily. It also assists the crude evaluation during the procurement process by providing feedbacks to the Procurement department on any operational constraints.
- Sales: this department provides the present and forecasted product prices and demand.
- Storage: this department manages the tank farm and schedules the jetties. It provides the crude supply that Operations requested daily.
- Logistics: this department coordinates the transportation of crude from the oil supplier to the refinery. It selects the 3PLs based on a bidding process.

For instance, the procurement agent emulates the procurement department of the refinery. It handles the procurement of the crude during the procurement cycle and coordinates between the logistics department, storage department, sales departments and the operations departments. The Agent Definition File (ADF) of the procurement agent is shown in Figure 3, its beliefs in Figure 4, and plans in Figure 5. Similar models were developed for the other refinery departments as well.

```xml
<!--
  Procurement Agent
-->

<agent  xmlns="http://jadex.sourceforge.net/jadex"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="http://jadex.sourceforge.net/jadex
    http://jadex.sourceforge.net/jadex-0.94.xsd"
    name="procurement"
    package="supplychain.refinery.procurement">

    <imports>
        <import>supplychain.*</import>
        <import>jadex.adapter.fipa.*</import>
        <import>jadex.runtime.*</import>
        <import>jadex.planlib.*</import>
        <import>jadex.util.*</import>
        <import>java.util.logging.*</import>
        <import>java.util.*</import>
        <import>java.lang.*</import>
    </imports>

    <capabilities>
        <capability name="dfcap" file="jadex.planlib.DF"/>
        <capability name="amscap" file="jadex.planlib.AMS"/>
    </capabilities>

```

Figure 3: Procurement Agent’s Agent Definition File (ADF)

External agents refer to those entities that are not included in the refinery departments, but are involved in the refinery supply chain. Such entities include the supplier, third party logistics (3PL), oil exchange and also the refinery’s customer base. Separate agent models have been developed for these as well. Coordination agents are involved in the coordination of the supply chain activities. They facilitate the supply chain simulation and decision support. Several such agents have been developed as well.

```
<beliefs>
    <belief name="environment" class="Environment">
        <fact>Environment.getInstance()</fact>
    </belief>

    <belief name="sales" class="jadex.adapter.fipa.AgentIdentifier">
        <fact>$args.length>1? (jadex.adapter.fipa.AgentIdentifier)$args[1]:null</fact>
    </belief>

    <belief name="logistics" class="jadex.adapter.fipa.AgentIdentifier">
        <fact>$args.length>1? (jadex.adapter.fipa.AgentIdentifier)$args[1]:null</fact>
    </belief>

    <belief name="operations" class="jadex.adapter.fipa.AgentIdentifier">
        <fact>$args.length>1? (jadex.adapter.fipa.AgentIdentifier)$args[1]:null</fact>
    </belief>

    <belief name="supplier" class="jadex.adapter.fipa.AgentIdentifier">
        <fact>$args.length>1? (jadex.adapter.fipa.AgentIdentifier)$args[1]:null</fact>
    </belief>

    <belief name="storage" class="jadex.adapter.fipa.AgentIdentifier">
        <fact>$args.length>1? (jadex.adapter.fipa.AgentIdentifier)$args[1]:null</fact>
    </belief>

    <beliefset name="crudes" class="Crude"/>

    <belief name="crude_optimal" class="Experience"/>

    <belief name="current_day" class="Integer">
        <fact>-1</fact>
    </belief>
</beliefs>
```

Figure 4: Procurement Agent's Beliefs

```
<plans>
    <plan name="procure_crude">
        <body>new CrudeProcurementPlan()</body>
        <trigger>
            <messageevent ref="start_procurement_cycle"/>
        </trigger>
    </plan>

    <plan name="update">
        <body>new UpdatePlan()</body>
    </plan>

    <plan name="update_day">
        <body>new UpdateDayPlan()</body>
        <waitqueue>
            <messageevent ref="new_day"/>
        </waitqueue>
    </plan>
</plans>
```

Figure 5: Procurement Agent's Plans

Table 1: Refinery Supply Chain Parameters

Minimum throughput of refinery	T_{min}	70 kbbl/day
Maximum throughput of refinery	T_{max}	120 kbbl/day
Planning horizon	A	50 days
Simulation horizon	B	105 days
Length of procurement cycles	F	7 days
Number of procurement cycles	J	10
Safety stock	W	150 kbbl

4. Results

In this section, we illustrate some typical results that can be obtained from the simulation. The parameter values are used for the refinery and its supply chain operation are shown in Table 1. In the following studies, results are shown from Day 35 of the simulation when the refinery and the supply chain has reached steady state after initialization.

4.1. Study 1: Normal Scenario

In this study, the normal operation of the supply chain is illustrated. Figure 6 shows the planned stock versus actual stock of refinery for ten procurement cycles. In the first procurement cycle, products have to be delivered on the 50th day. In this cycle, crude is delivered by ship on the 35th and 42nd day, consequently stock levels go up on these days. Inventory level trend down on other days due to production. The same saw-tooth trend occurs in other procurement cycles as well. Table 2 shows the projected and actual demand for the first ten procurement cycles. Figure 7 plots the crude procured to fulfill the forecasted demand for each procurement cycle. To fulfill the demand for the first procurement cycle 702 kbbl of crude is procured. The actual demand is the same as the planned demand for the first and second procurement cycles. Therefore, the planned and actual inventory profiles match. In subsequent procurement cycles, forecast and real demands differ, resulting in the CDU throughput differing from the original plan. In the 4th – 6th procurement cycles, actual demand is less than the forecasted demand, so the actual throughputs are lower and stocks higher than planned. This effect is carried forward to the 7th procurement cycle. The refinery throughput changes to meet actual demands. Similar responsiveness of the supply chain can be seen in other procurement cycles as well.

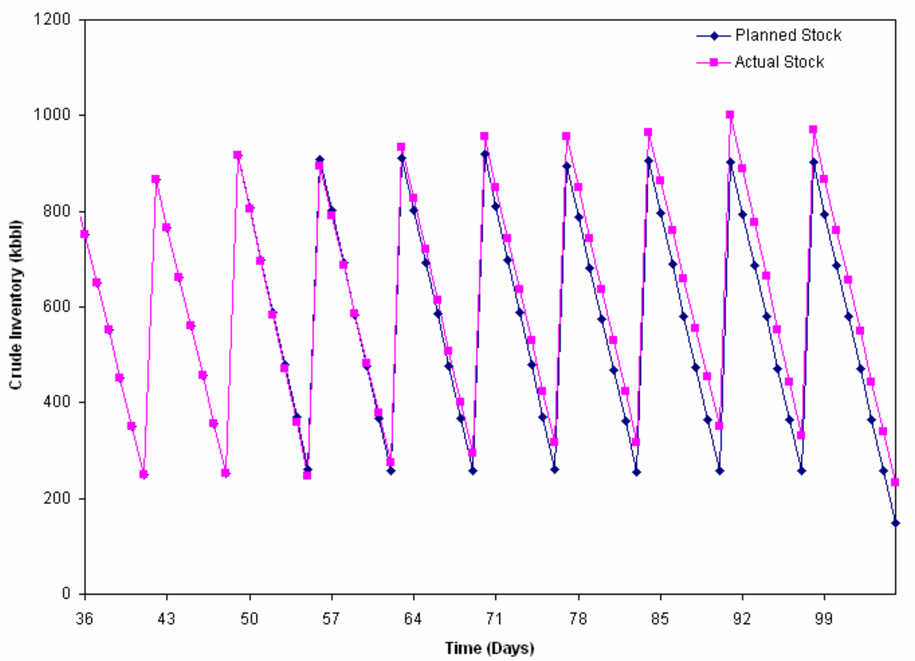

Figure 6. Crude Inventory profile over simulation horizon

Table 2. Forecasted and actual crude demand in the first 10 procurement cycles

Procurement Cycle	Delivery Date	Crude Procured based on forecasted demand (kbbl)	Crude needed to meet the actual demand (kbbl)
1	50	702	702
2	57	717	717
3	64	768	783
4	71	759	721
5	78	761	745
6	85	769	746
7	92	744	744
8	99	754	717
9	106	752	782
10	113	752	737

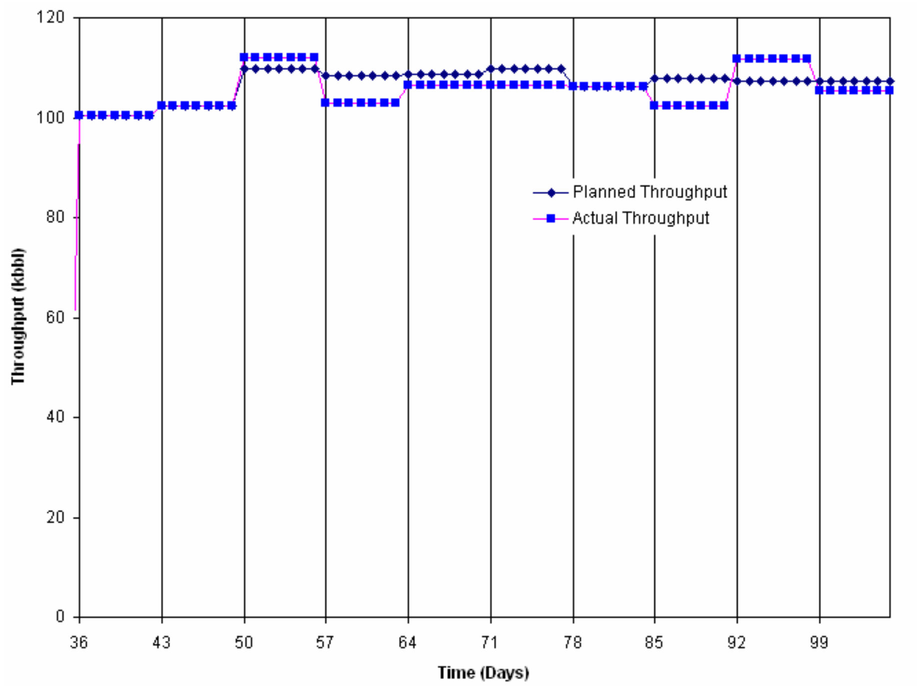

Figure 7. Actual versus Planned throughput over simulation horizon

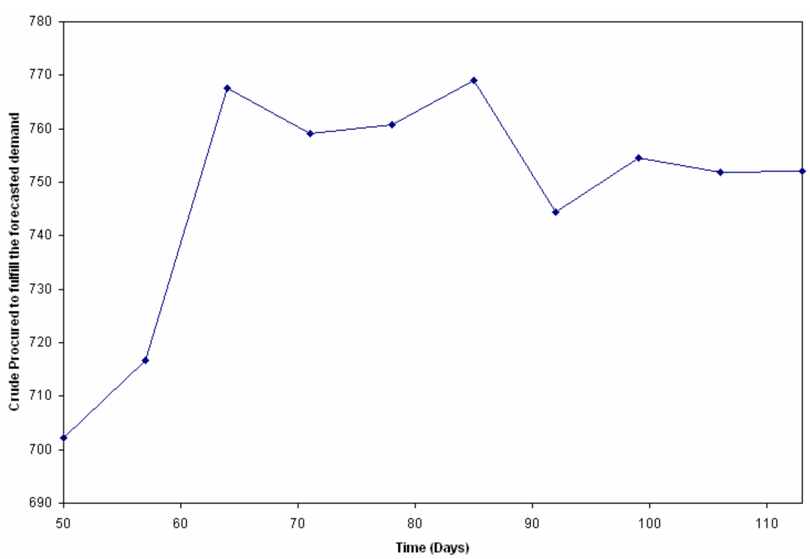

Figure 8. Crude procurement in each procurement cycle

4.2. Study 2: Transportation Disruption

One use of the supply chain model above is to understand the effect of disruptions on the supply chain. The effect can be studied in terms of impact on various performance indicators such as inventory, refinery operation, demand fulfilled, etc. In this case, transportation disruption – an important and frequent disruption in the supply chain – is considered. The disruption is introduced through a stochastic increase in the crude transportation time. For example, a ship scheduled to arrive on day 42nd is delayed at sea and arrives on the 48th day instead. Because of the ship delay, there is stock out in the refinery from the 44th to 48th day when even the safety stock is used up. Figure 9 plots the planned versus actual stock. Stock falls to 51.3 kbbl at the end of day 43, which is inadequate to operate the refinery even at minimum throughput. As seen in Figure 10, the throughput over this period goes to zero and the refinery unit has to be shutdown. This would result in the inability to meet demands and customer dissatisfaction. When the delay ship arrives on the 48th day, the inventory level goes up. The crude for the third procurement cycle also arrives on the 49th day and the stock becomes much higher than planned. Throughput is increased to maximum (120kbbl/ day) to meet demands.

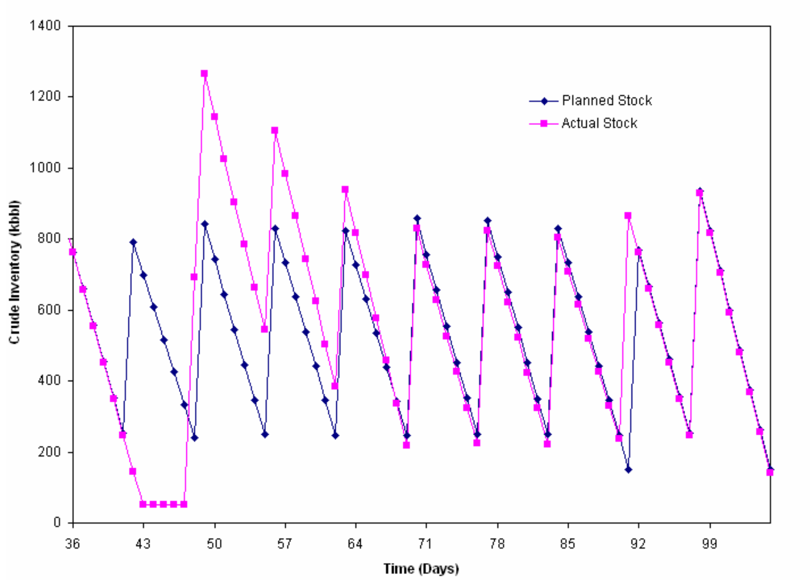

Figure 9. Crude inventory in case of transport disruption

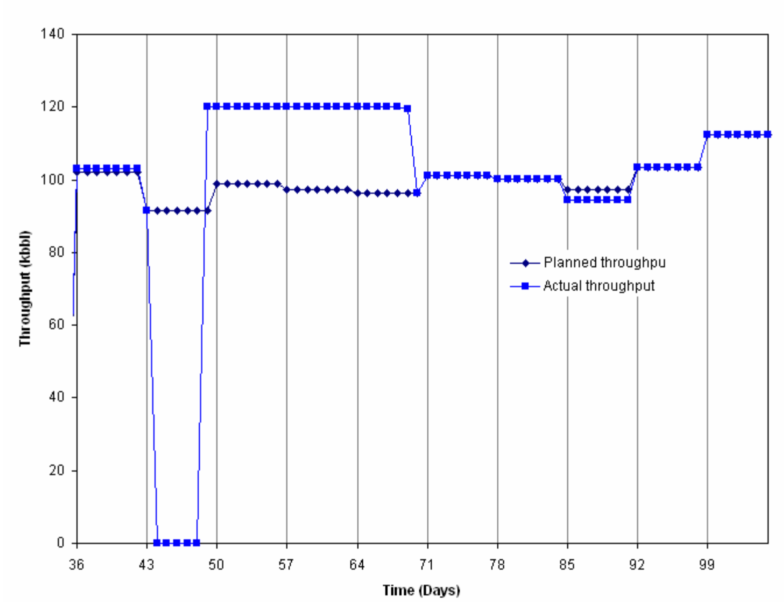

Figure 10. Actual versus Planned throughput in case of transport disruption

4.3. Study 3: Demand High

The normal operations of the refinery are designed to handle a 5% difference between projected and actual demand. Order fulfillment can be expected to be 100% in these cases since the refinery keeps a safety stock of 150 kbbl to handle small demand increases. In this study, we evaluate the effect of larger demand increases. Figure 11 shows the order fulfillment (%) along with uncertain demand. The small demand variations during cycles 1-6 are absorbed completely and order fulfillment remains at 100%. A large increase in demand during cycles 7–9 however leads to a drop in fulfillment to 64% – 69% since adequate crude inventories are not available. These lead to missed market opportunities, which could have been exploited if the supply chain can be made more nimble.

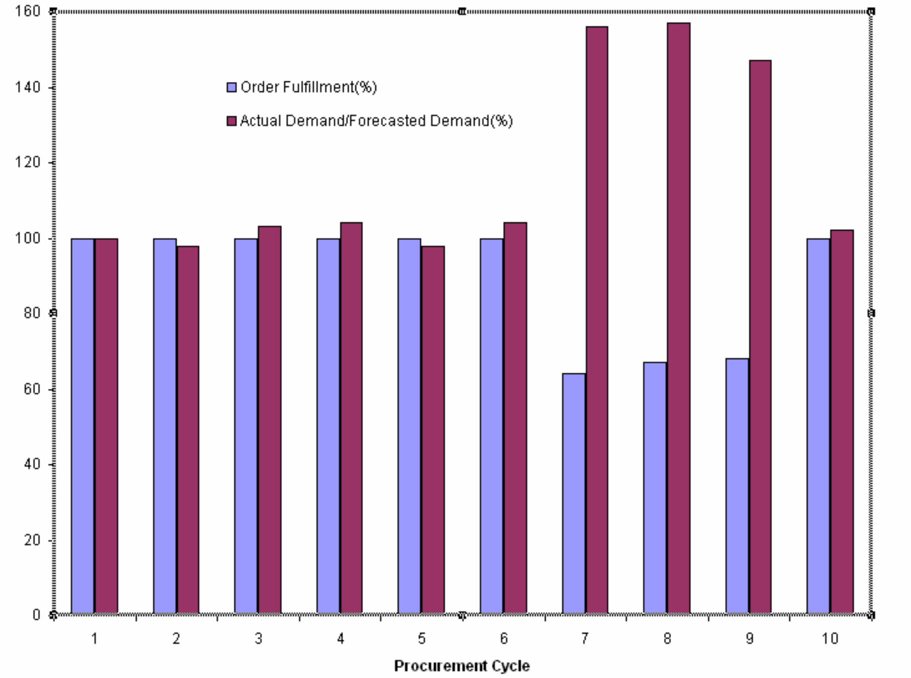

Figure 11. Order Fulfillment in case of increase in demand

5. Discussion

Chemical Industries supply chain are unlike other industries supply chain due to specific features such as longer chains, complex transportation process, large inventory, complex manufacturing process, etc. These features of the chemical supply chain pose challenges to its effective management. The multi-agent approach is suitable for modeling the behavior of such supply chains as it can capture the dynamics and complexity of the supply chain and in a comprehensive and extendable fashion. The example illustrates one easy to use framework to model the functions and activities within a supply chain. A model and simulation developed using the agent-based approach can then be used to study the dynamics of the supply chain in its normal as well as disrupted states.

Unhindered and timely material, information, and finance flow between different entities of supply chain is important. Blockage in any of these would lead to undesirable events like process shutdown, financial loss, under-supply or over-supply, etc. Hence, there is a greater need for risk and disruption management. The agent-based refinery supply chain model described above can be extended to provide decision support during disruptions. An agent-based disruption management system should be capable of detecting abnormal situations before they occur, diagnose the root cause, and propose corrective actions as required (Bansal et al, 2005). The agents that model the department can be endowed with additional capabilities to measure entity-specific key performance indicators (KPIs). These KPIs can also be monitored by the agents by comparing their day-to-day values against pre-planned limits. Alarms can be generated when a sustained deviation in any KPI is detected. Corrective agents can be proposed and scheduled into the supply chain operation as necessary.

References

1. Ahn. H. J. and Park, S. J. (2003), "Modeling of a Multi-agent System for Coordination of Supply Chains with complexity and Uncertainty", Springer, Berlin, 13 – 24.
2. Bansal, M., Adhitya, A., Srinivasan, R., Karimi, I., (2005). An Online Decision Support Framework for Managing Abnormal Supply Chain Events, Presented in the European Symposium on Computer Aided Process Engineering – 15, Barcelona, Spain, May 29 – Jun, 2005.
3. Bond, A. H., & Gasser, L. (1988). An analysis of problems and research in DAI. Readings in distributed artificial intelligence. San Mateo, CA: Morgan Kaufman.
4. Bratman, M. E., Israel, D. J. and Pollack, M. E. (1988), "Plans and Resource-Bounded Practical Reasoning", Computational Intelligence, 4, 349 – 355.
5. Fu, Y., Piplani, R., de Souza, R. and Wu, J. (2000), "Multi-agent enabled modeling and simulation towards collaborative inventory management in Supply Chains", in Proceedings of the 2000 Winter Simulation Conference, December 10-13(pp.1763 – 1771), Orlando, Florida.
6. Gjerdrum, J., Shah, N. and Papageorgiou, L. G. (2001), "A combined optimization and agent-based approach to supply chain modeling and performance assessment", Production Planning & Control, 12(1), 81-88.
7. Julka, N., Srinivasan, R., Karimi, I., (2002). Agent-based supply chain management-1: Framework. Computers and Chemical Engineering 26 (2002) 1755-1769.
8. Julka, N., Karimi, I., Srinivasan, R., (2002). Agent-based supply chain management-2: a refinery application. Computers and Chemical Engineering 26 (2002) 1771-1781.
9. Serenko, A., Detlor, B., (2002), Agent Toolkits: A general overview of the market and an assessment of instructor satisfaction with utilizing toolkits in the classroom.
10. Weiss, G. (1999). Multiagent systems. A modern approach to distributed artificial intelligence. Cambridge, MA: MIT Press
11. Woolridge, M. and Jenning, N.R. (1995), "Intelligent agents: theory and practice", The Knowledge Engineering Review, 10(2), 115 – 152.
12. Woolridge, M., (2002), An Introduction to MultiAgent Systems, John Wiley & Sons.