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BULK PETROLEUM SUPPLY CHAIN SIMULATION MODELING

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ABSTRACT

This paper describes the simulation modeling of bulk petroleum supply chains through an object-oriented simulation library. The paper focuses on the conceptual modeling that is useful for resource and transportation capacity analysis during contingency and war gaming analysis. In addition, the modeling provides the capability to understand how surges in demand will affect inventory service. The methods, insights, and capabilities developed within this research facilitate the analysis of bulk petroleum military supply chains and also permit the analysis of the resilience of commercial bulk petroleum supply chains under conditions of disruption.

1 INTRODUCTION

The Defense Logistics Agency (DLA) Energy Division is responsible for supplying fuel to all US military bases worldwide. Operating such a supply chain involves sourcing different fuel products from suppliers, transporting them through their own network of fuel terminals using varying modes of transport, handling fuel at each terminal in the network, and finally delivering the fuel to the customer locations on time.

Because of the complex interactions between the various system components, the planning and execution of this supply chain is extremely challenging. A major challenge in this process is respecting storage and capacity limitations throughout the supply chain. In addition, short- and long-term acquisition options must be evaluated to ensure high availability of supply. These challenges are made even more complex because of the uncertainty of supply due to disruptions (e.g., geopolitical actions, weather, military actions, equipment or refinery shut downs, etc.) and due to the uncertainty of demand. Acquisition planners require the ability to perform what-if analyses in order to evaluate acquisition policies and procurement actions, especially for contingency planning for military actions.

This paper describes the modeling of DLA Energy's supply chain for the purpose of applying simulation techniques to war gaming and contingency analysis, logistics capability analysis, and understanding risk and resilience within such networks. The goal here is not to present a detailed analysis of DLA Energy's supply chain, but rather to report on the modeling requirements and capabilities needed to meet such analysis. Thus, the emphasis of this paper is on modeling constructs, rather than statistical analysis of specific scenarios. We also briefly overview the simulation library that has been constructed. A notional example is presented. Future papers will elaborate on the details of the simulation library as well as the analysis of the application of the modeling methods described within this paper, and discuss applications of simulation tools to the three overall use case scenarios.

The rest of this paper is structured as follows. First, we provide background literature on the simulation modeling of supply chains and for bulk petroleum, in particular. Then, in Section 3, we describe the conceptual modeling that serves as the basis for the bulk petroleum supply chain simulation (BPSCS) library. In Section 4, we overview implementation aspects and present a notational example to illustrate how they might be used in practice. Finally, we summarize with some conclusions and future modeling efforts within this domain.

2 BACKGROUND

Supply chains represent complex systems involving the satisfaction of customer demand through distribution and inventory control practices. Because of the complexity of supply chains, simulation has long been utilized as a method for analyzing supply chain systems. For some starting references in this immense field, see for example, Bowersox et al. (1972), Swaminathan et al. (1998), and Terzi and Cavalieri (2004). For a more recent review, see Oliveira et al. (2016). All major types of simulation methods (system dynamics, agent-based, and discrete-event) have been applied within the analysis of supply chain systems. This paper focuses on the discrete-event paradigm and provides background to position this research effort.

Supply chains deliver multiple commodities. In this research, the focus is on bulk petroleum fuels, especially military grade fuels, primarily used within aircraft. Because of its importance, there have been a number of applications of simulation modeling to the analysis of oil and fuel networks. We highlight a few here. Cheng and Duran (2004) describe the application of discrete-event simulation to the world-wide transportation system for ExxonMobil. They present a framework for making stochastic optimal control decisions combined with simulated supply chain performance. The modeling provides for understanding the optimal fleet size under complex routing and optimization methods while balancing the trade-off between ownership or renting and the effect on meeting demand. The model allows for changing the size or composition of the tanker fleet to assess the response of the system to those changes using a what-if analysis. In addition, they use stochastic control to make optimal decisions concerning numbers and types of tankers, whether to rent or return. The modeling accounts for the cost of transportation and inventory. Pitty et al. (2008) consider the various supply chain activities, such as supply and transportation, along with intra-refinery supply chain activities such as procurement planning, scheduling, and operations management. Discrete supply chain activities are integrated along with continuous production through bridging procurement, production, and demand management activities. The model allows various scheduling and policies for being evaluated and the effects on stocks relative to supply and demand measures. Xiong et al. (2017) describe the modeling of military supply chain networks, with a focus on evaluating their effectiveness, especially under conditions of disruption. They provide effectiveness measures that are more pertinent to military supply networks related to network architecture and supply capability. Their modeling example involves a military network that contains vehicle and pipeline deliveries. An Arena simulation model measures the availability of inventory over time and the transportation capacity requirements needed across various demand scenarios. One of the complexities of modeling bulk petroleum supply chains is the modeling of distribution via pipelines. Costa et al. (2014) examine a case study of a Brazilian fuel supply chain. They present some useful conceptual models of ship movements within the system and how batches are sequenced within a pipeline system. Cafaro et al. (2010) also describe the simulation of pipeline transport, especially with respect to pipeline scheduling.

This paper builds on the work of Rossetti et al. (2008) by extending the concepts within that paper to bulk petroleum supply chain modeling. The conceptual modeling constructs described in the next section are encapsulated within an object-oriented library based on the Java Simulation Library (JSL) (Rossetti 2008). The object-oriented nature of Rossetti et al. (2008) provides for similar elements within a bulk petroleum supply network, with the major enhancements related to how bulk fuel terminals specifically process fuel. This work also builds off of the concepts of Rossetti and Chen (2012) by utilizing a database driven architecture for instantiating and simulating the supply chain model. The following section describes the key system components at a conceptual level.

3 CONCEPTUAL MODELING

As Banks and Chwif (2011) and Robinson (2008a,b) contend, conceptual modeling is one of the key elements of simulation modeling and is essential to validation efforts. This section presents a conceptual model for a bulk petroleum supply chain that is based on the requirements articulated by DLA Energy. While the context is motivated by DLA Energy requirements, the conceptual model should be useful to other simulation researchers and practitioners interested in simulating bulk petroleum supply chains.

The bulk fuel supply chain system's purpose is to meet end user fuel requirements over time. Figure 1 presents a conceptualization of the bulk fuel supply chain. The components of this system are suppliers and customers, who are located on bases at the end of the supply chain; products, namely, bulk petroleum fuels and additives; facilities such as defense fuel supply points (DFSPs), intermediate terminals and bases; and means of transportation between facilities, such as tanker ships, river barges, and tanker trucks.

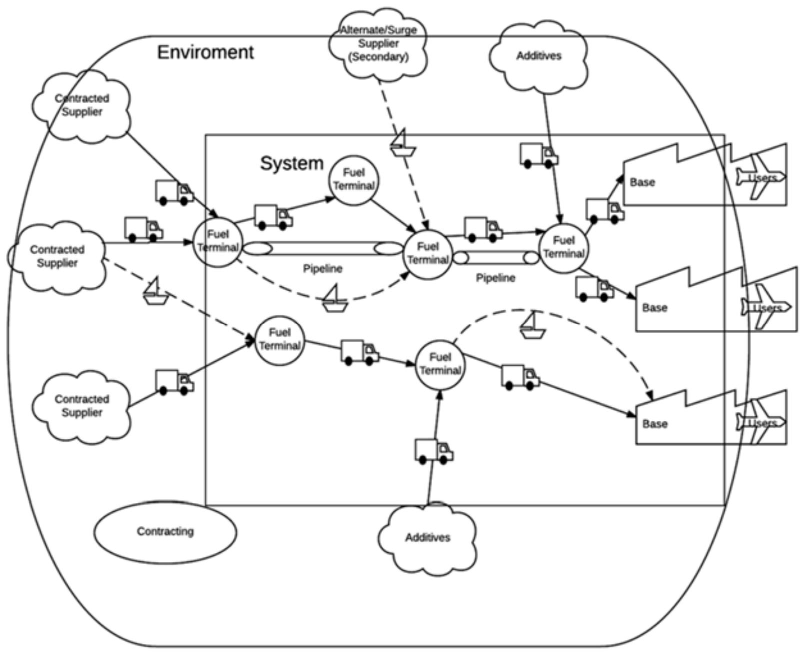

Figure 1: Conceptual elements of the bulk petroleum supply chain.

Suppliers and customers form inputs and outputs of the system. Suppliers provide fuel to the system. They are often refineries. Contracts with major commercial suppliers or pipeline operators form the basis for the supply. Suppliers may have limits on how much fuel can be ordered at a time or how often orders can be placed. Locations within the network may have multiple suppliers (primary, secondary) to handle unexpected increases in demand requirements. End customers indicate their planned fuel requirements (by product) allocated over time, with a typical planning horizon of three months. The primary product within the supply chain is jet fuel, both military and commercial grade and additives for converting commercial grade fuel to military grade. Once demand from end customers has been received and processed, planners must decide how to meet the demand via fuel terminals that supply to the end customers (e.g., bases). Fuel transport between suppliers and terminals, between terminals, and between terminals and customers must be planned over time in order to meet end customer demand while maintaining planned inventory levels at the terminals.

The primary conveyances for fuel transport include pipeline, tanker ship, tanker barge, tanker trucks, and rail tanker cars. Bulk petroleum enters the system from supplier sources (e.g., refineries) mainly by pipeline. Fuel moves through the system and may pass from different conveyances (pipeline to tanker ship to tanker truck) before being received at the final destination. Time into and out of the system depends on final destination distance and number of conveyance transfers from origin to destination. On average, 3 to 7 days is normal with some times between 23 and 30 days. Once at location, fuel is normally consumed within a 30-day cycle unless it has been designated for reserve stocks.

3.1 Fuel Terminal Conceptual Modeling

The main activities associated with this system occur at the fuel terminals. Figure 2 illustrates a conceptual representation of a terminal. A terminal is a geographic location that is responsible for three main activities within the supply chain: receiving, storing, and transferring bulk fuel. Fuel terminals within the system allow for the receiving, storing, and issuing of fuel. Fuel terminals have different receipt capabilities and equipment for each type of fuel received. Fuel receipt capabilities consist of fuel piers or docks (for tanker ships or barges), pipeline manifolds, and tanker truck or rail tanker receipt points. The fuel terminals are arranged to receive, store, and issue fuel. Some terminals have manifold systems and tank designs that accommodate transitions to different products for tank usage. Other terminals have segregated fuel storage and manifold systems for each product. Similarly to receipt capabilities, fuel terminals have the capability to issue fuel into aircraft, ships, vehicles and refueling trucks. Fuel terminals may also transfer fuel between terminals by "issuing" to pipeline transfer pumps, fuel piers or docks, tanker truck and rail tanker car loading points. The issuing capability may be separate by product type or may have manifold systems that are designed to accommodate multi-product transfers (or receipts).

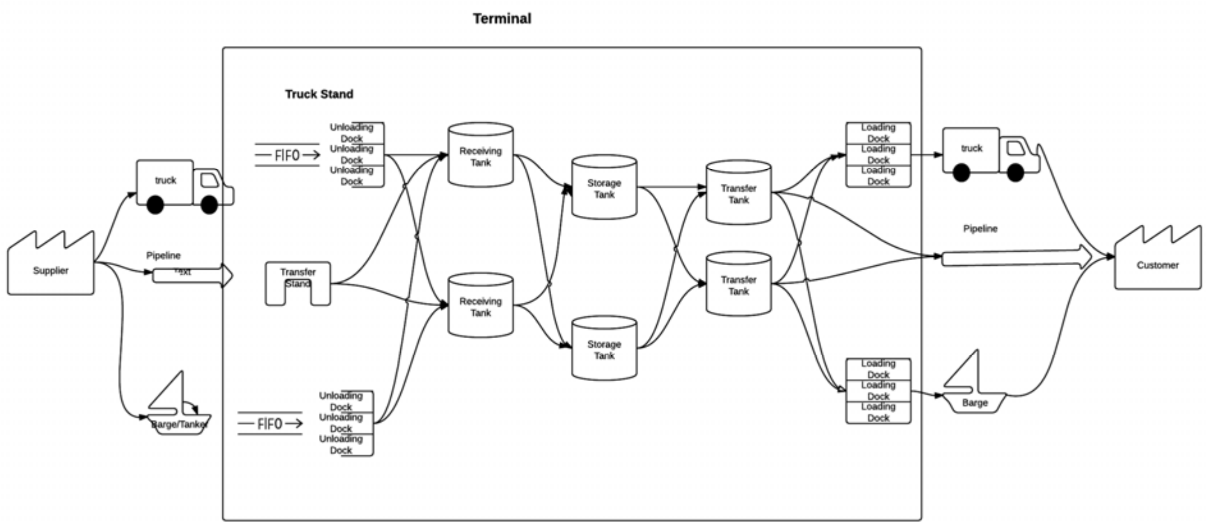

Figure 2: Conceptual representation of a terminal.

Terminals may receive bulk fuel by different modes, which include pipelines, tanker ships, barges, tanker rail cars, and tanker trucks from a supplier or other terminal. In order for the terminal to receive a particular mode of fuel transport, the terminal must have the equipment or facilities necessary to receive according to the particular mode. If the receiving equipment or facilities are available, the bulk fuel will be transferred into an available receiving tank (if available). During the receiving process, the fuel is checked for quality assurance to ensure that it meets the desired fuel specifications of the ordered product.

Terminals have specific modes of transport that they can handle. Tanker trucks require a truck stand. A terminal may have many truck stands in order to unload multiple tanker trucks at the same time. A truck stand permits the transfer of fuel to the receiving tank. The end of the pipeline has equipment that permits transfer of incoming pipeline batches to the receiving tank. If the receiving tank is not available, the pipeline transfer process cannot take place. Tanker ships and barges require a dock or berth position to hook up to equipment for transferring to the receiving tank. If there are more barges or tanker ships than berths, then the barge/tanker ship must wait. The berthing position permits the transfer of the fuel to the receiving tank. Fuel from the receiving tank may be transferred into longer-term storage tanks or may be changed over to transfer fuel to outgoing transport modes. The outgoing transport modes also vary by terminal.

There are capacity limits on unloading and loading fuel, both in the number of fuel transfer mechanisms and the rate at which fuel can be transferred. There are also capacity limits on fuel storage by commodity and location. The transfer mechanism requires that the equipment for transfer and the space needed for connecting to the transport mode be available. The fuel transfer time depends on the transfer rate plus setup and quality assurance times.

Each tank handles one type of fuel. Figure 3 shows a schematic of a petroleum fuel storage tank. The safe fill level is the capacity of the tank, which excludes unusable areas at the top for venting and the bottom sediment and settling. The tanks also holds reserve stock, which is for surge (sudden increases in) demand. The rest of the tank is for regular, running demand. There is some buffer (excess) capacity. The remainder corresponds to the maximum inventory level, which is set based on usage and demand. The control limit is the safety stock level, either the reorder point or the minimum allowable inventory. In essence, the inventory control for the fuel operates under a min/max policy that is set to ensure service levels while respecting tank usage and capacity constraints.

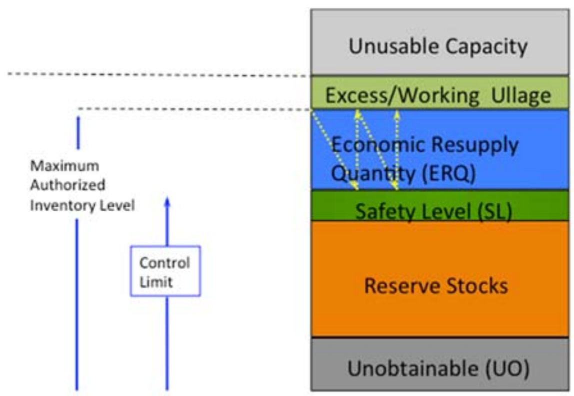

Figure 3: Conceptual schematic of a fuel tank.

3.2 Terminal Resource Conceptual Modeling

The complexity of modeling a terminal comes from the modeling of the resources. This section overviews the major resource types and discusses some of the modeling issues. For the purposes of this modeling, there are four major modes of transport: truck, barge/ship, rail and pipeline. Thus, at a terminal there must be resources that handle fuel from each of these modes if the terminal receives, issues, or transfers fuel by any of these modes. Because of this, every terminal has a set of resources that are used based on the type of fuel, the operation (issue/receipt), and complex resource interaction rules.

We conceptualize the terminal as having a boundary over which fuel is received or issued. At the highest level, we are interested in the capacity (or rate) at which fuel can cross the boundary by any of the modes. Thus, a resource is the mechanism by which the fuel crosses the boundary. At this level, we are assuming that fuel using a resource can only cross the boundary in one direction at a time, within the resource. Therefore, in the modeling of the resources, it may be necessary to understand if there are important limitations on the capacity of resources and whether or not the resources interact in ways that limit one another. The interactions between resources are primarily due to complex tankage and piping arrangements that are specific to each terminal. The following section discusses the representation of each of these elements.

3.2.1 Truck Racks, Docks, Rail Yards, and Pipelines

A truck rack is a set of locations that can hold trucks while loading or unloading fuel. A truck rack has a number of slots or truck stands. Each truck stand is taken by one vehicle while loading or unloading fuel. Essentially, the truck hooks up to a fuel transfer point similar to how one sees a fuel truck at a petrol station operate. A truck rack may be able to load or unload fuel at the same time depending on its design. In many cases, the truck rack is dedicated to one purpose: receiving (unloading fuel) or issuing (loading fuel). Some locations may have a multipurpose truck rack that does both loading and unloading. Depending on the design of the multi-purpose truck rack, it may accommodate simultaneous operation. Whether or not the truck rack can handle more than one type of fuel depends upon its design. Most often there are separate truck stands for each type of fuel. If a truck stand is dedicated to a particular fuel type, then it remains dedicated to that type of fuel and cannot be reconfigured to another fuel type without a significant capital allocation which is beyond the scope of this modeling effort.

Figure 4 presents a conceptual representation of a truck rack. Truck stands 1, 2, 3 of the truck rack are dedicated to product A, whereas truck stand 4 is dedicated to product B. We assume that the truck rack can issue and receive product A and B at the same time, via the truck stands dedicated to each product. However, truck stands 1, 2, 3 can only all be issuing or all be receiving because of the conceptual connection to product A. Similarly, truck stand 4 can only issue or receive product B but cannot perform both operations at the same time. Some possible operating configuration examples include: 1) the truck rack is dedicated to receiving fuel such that all truck stands can only receive fuel, 2) the truck rack is dedicated to issuing fuel such that all truck stands can only issue fuel, 3) the truck rack can issue and receive fuel such that some truck stands can only issue fuel and others can only receive fuel. An individual truck stand cannot issue and receive at the same time.

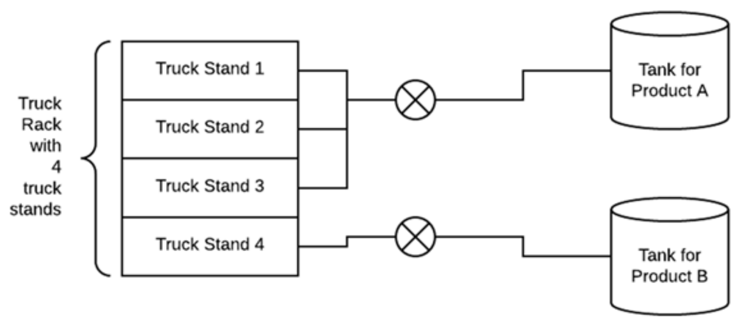

Figure 4: Truck rack conceptual illustration.

Rail yards and docks operate in a similar fashion as truck racks, with each having individual resource units that can process fuel. A dock is a set of locations that can hold ships or barges while loading or unloading fuel. A dock has a number of berths. Each berth is taken by only one vehicle while processing fuel. A berth is a single spot on the dock to accommodate a single ship or barge. There may also be complex rules related to which type of ship can have access to the dock while it is being used by other ships. A rail yard is a location that can hold rail tanker cars while loading or unloading fuel. Rail yards have physical constraints on the number of cars that can be processed. A rail yard has a number of fuel access points. Each access point accommodates a set of rail cars: multiple cars are processed simultaneously. The number of rail cars that can be processed simultaneously determines the normal shipment size that is sent to the rail yard. The rail yard is configured to process this batch of rail cars that are in the shipment. Shipment sizes are multiples of the quantity of cars that can be simultaneously processed.

The final fuel transport option is via pipeline. Commercial pipelines are shared amongst many different customers (not just DLA Energy). A pipeline connects a base terminal (first fuel terminal in pipeline system) to intermediate terminals in the pipeline system and ends at the head terminal. The pipeline is a system of interconnected pipes and pumping stations (normally at terminals) to facilitate the transfer of fuel in pipeline batches by product for multi-product pipelines. A pipeline transfers fuel to intermediate or head fuel terminals. The intermediate fuel terminals normally can receive and transfer fuel simultaneously. In a multi-product pipeline, fuel batches are in sequence, with only one fuel type at a time coming in from the pipeline into the receiving terminal.

Figure 5 illustrates a conceptualization of a pipeline at a terminal. Pipelines move *batches* of fuel, with some scheduled time between the batches of potentially different types of fuel. In a sense, the batch represents a load of fuel being conveyed (i.e., like a truck carrying a batch). In the figure, the terminal is able to receive both type A and B fuels, but cannot receive both fuels at the same time, since the batches are flowing sequentially through the pipeline. Similarly, if the fuel is being issued from the terminal via the pipeline, then only one type of fuel can be issued at a time. Users of the pipeline must wait until their batch of fuel is scheduled and maintain the required time between batch submissions on the pipeline.

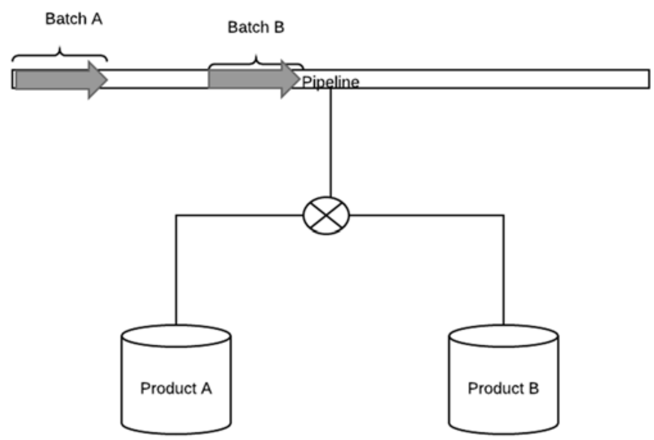

Figure 5: Pipeline conceptualization.

3.2.2 Modeling Resource Conflicts

As previously noted, resources can interact in complex ways due to tankage and piping considerations. This section overviews these interactions and describes the modeling issues that must be addressed. A terminal may have one or more of the various types of resources. For example, a terminal may have both truck racks and a dock. As such, there may be interactions between the types of resources that indicate that one type of resource may not be performing an operation concurrently with another resource. For example, there may be rules that state that if a truck rack is issuing fuel type A, then a dock cannot also be issuing fuel type A. The goal is to attempt to articulate these rules so that they can be noted and incorporated into the modeling. A requirement of this modeling is to support the representation of these rules as *data*, rather than as customized programming logic. In this manner, any terminal and its resources can be modeled based on stored rules, thereby allowing for generic modeling of terminals.

Since a tank holds only one type of fuel, we assume that a connection between the tank and a resource is dedicated to a single type of fuel. A fuel type (product) may have one or more connections associated with it. Connections limit the type of operation that can be performed. A single connection can only issue or receive fuel at any particular point in time; however, a connection cannot issue and receive at the same time. Thus, a connection can be in the following states: issuing-busy, receiving-busy, and idle.

Resources have active connections during the issuing or receiving of fuel. These connections constrain the operation of the resources. Resources can be dedicated to the issuing task or to the receiving task or be configured to do either task. If a resource is configured to handle a particular fuel type, then we assume that a connection between the resource and the fuel type exists. If a resource is configured to both issue and receive a type of fuel, then we assume that it cannot perform both tasks at the same time for that type of fuel. In other words, a unit of a resource cannot be both issuing and receiving fuel at the same time. Thus, we ignore this obvious connection conflict.

We model the association between resources, transport modes, and products via the concept of a connection. A connection represents the ability of a resource to issue or receive a particular type of fuel;

however, since resources can share connections, there may be interactions between resources that are not permitted. Resources are also dedicated to handling particular modes of transport. Thus, the ability of a resource to issue a particular fuel according to a particular transport option can be modeled as the following tuple *(resource identifier, transport option, product type, operation).* An instance of this tuple might be Connection 1 = (truck rack 16, 8K tanker truck, JAA jet fuel, issue), which means that truck rack 16 has a connection to issue JAA fuel via 8K tanker trucks. There may be another instance, such as, Connection 2 = (dock 13, 840K barges, JP5 fuel, receipt). If there is a conflict between these two connection assignments, this can be noted as Connection Conflict = (Connection 1, Connection 2), which indicates that truck rack 16 and dock 13 cannot both be issuing and receiving JAA and JP5 at the same time. Note that it may be possible that they could be issuing these fuels at the same time or receiving these fuels at the same time, but according to this conflict, they cannot be doing different operations (issuing, receiving) on different products (JAA, JP5) at the same time. This example should provide a basic illustration of the complex interaction rules that are needed to model resource interactions within a terminal. During the operation of the simulation model, the active connections must be maintained in order to determine whether a resource is permitted to start a processing activity.

4 NOTIONAL EXAMPLE AND ILLUSTRATIVE MODELING

This section presents a notional example to make some of the previously presented conceptual modeling more concrete. In addition, the simulation model translation of the conceptual model is briefly discussed to illustrate the capabilities of the simulation modeling library.

4.1 Overview of Simulation Modeling Constructs

To represent a bulk petroleum supply chain, a database was constructed to represent external suppliers, contracts, terminals, transit times by origin/destination/mode, resources, resource issuing and receipt time by mode and product, resource connection assignments and conflicts, product types, inventory control parameters for each product at each terminal, and demand characteristics. This paper does not detail the requirements and specifications of this database. However, the database provides a specification of the supply chain that is to be simulated and represents a method to persist the simulation model structure and to automatically generate the simulation model from data. Thus, simulation models of bulk petroleum supply chains can be configured and executed based only on data. The simulation library also allows for constructing the model directly from Java code. Thus, a small example, such as shown in the Figure 7, can be readily written by instantiating library objects that represent the elements of the supply chain.

The bulk petroleum supply chain simulation library (BPSCS) is based on the JSL (Rossetti 2008) and the lessons and ideas embodied within Rossetti et al. (2008) and Rossetti and Chen (2012). The BPSCS library encompasses 35 classes and 10 interfaces and is supported by the aforementioned database. While space does not permit the discussion of the full library, a brief overview of the major classes is presented. The major classes of interest are Network, Terminal, TerminalResource, and TimeBasedCarrier.

The Network holds all the elements of the supply chain including the products, transportation types, terminals, external suppliers, and transportation carriers. The network is essentially a container class that facilitates the construction of objects within the network and some of their relationships. The next most important class is the Terminal class. The Terminal class implements the ideas described within Section 3. Instances of Terminal represent customers and suppliers within the network that process fuel (receive and send shipments) and respond to customer demand (receive demand requirements). Every terminal can have one or more suppliers and supply one or more customers. Thus, this is not a arborescent supply chain.

Terminals hold the inventory for products (fuel) and the resources necessary to receive and issue fuel. A TerminalResource is a generalization of the concepts discussed in Section 3.2 and can represent truck racks, docks, rail yards, and pipeline headers. Instances of TerminalResource hold queues and resources for processing incoming and outbound shipments. Both terminals and terminal resources can become unavailable due to disruption events (e.g., hurricane flooding). A TimeBasedCarrier represents the time that it takes to move products between two locations. Instances of TimeBasedCarrier are held within a class (NetworkOriginDestinationTimeBasedCarrier) that permits the transport time to consider the origin, destination, and transport mode associated with the transport. The following illustrates how to use these classes to construct a simple simulation model "by-hand" instead of from a database representation.

```
Simulation simulation = new Simulation("WSC Example");
Network network = buildNetwork(simulation.getModel());
simulation.setNumberOfReplications(20);
simulation.setLengthOfReplication(90);//days
simulation.run();
out.println(simulation.getHalfWidthSummaryReport());
```

Figure 6: Overall model construction code.

Figure 6 illustrates the building of the overall simulation model. Using standard JSL constructs, line 1 constructs the simulation and line 2 calls a method to construct the entire supply chain network. The rest of the code simply sets up the simulation run, executes the simulation, and prints out standard results. Figure 7 illustrates the definition of a network carrier for providing transportation between origin and destination pairs. The carrier defines these times as dependent on the mode, origin, and destination (the first three arguments of the method call in line 4 of Figure 7). Figure 7 also illustrates the construction of one terminal (Houston) and a terminal resource. The library utilizes the builder coding pattern to define the TerminalResource. Note that statement 5 presents defining issue times, which depend on the pre-operation times (setup), post-operation time, and the pumping rate via the three provided parameters. The construction of objects such as those illustrated here constitute the method for building instances of supply chains via the BPSCS library. Future papers will present further details of the library.

```
NetworkTimeBasedCarrier carrier = new NetworkTimeBasedCarrier(network);
 network.setShipmentCarrier(carrier);
carrier.addTransport(pipelineBatch, houston, baltimore, 24);
carrier.addTransport(tankerTruck8K, yorktown, fort, 1);
Terminal houston = network.addTerminal("Houston");
TerminalResource yorktownTruckRack = TerminalResource.builder(yorktown)
.name(makeResourceName(yorktown, "Truck Rack")).capacity(2).issues(JAA,
tankerTruck8K).issues(JAA, tankerTruck8K).issueOperation(tankerTruck8K, new
Uniform(40, 60), new Uniform(20, 30), new Constant(400)). build();
```

Figure 7: Instantiating library elements.

As one might expect, a supply chain simulation, such as described here, will produce a tremendous amount of statistical output. The following are *some* of the key performance measures (in all cases statistical measures of the variables are captured). For every terminal and every resource within the network, the queuing and resource statistics are captured. The number of shipments requiring vehicles and the waiting time of the shipments are captured as well as customer service measures, such as time to delivery. All the inventory performance measures discussed in Rossetti et al. (2008) are also captured. All captured statistical measures are written and stored in a database.

4.2 Notional Example

Figure 8 presents the terminals and connections within the notional example. This is a simplified representation of part of the DLA Energy East supply chain that is part of DLA Energy's America's East region that has been limited for this paper. The boxes within the figure represent either terminals or external suppliers. The smaller boxes within the terminals represent resources for the transportation options (pipeline, barge, rail, and truck). The example contains one external supplier (SDP), three main terminals (Houston, Baltimore, Yorktown), and four terminals/end users (Jacksonville, Port Mahon, AFB, Fort). The example has been limited to include pipeline, barge, and tanker trucks.

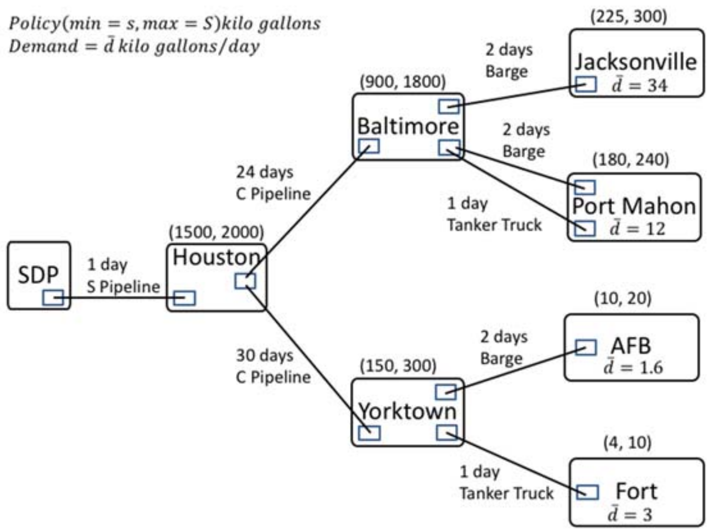

Figure 8: DLA Energy East notional example

Houston is the main starting terminal of the network. Fuel type JAA is delivered via pipeline from SDP. Houston supplies Baltimore and Yorktown with JAA via pipeline. Baltimore issues fuel primarily by barge to Port Mahon via the dock, but it also has a backup truck stand. Baltimore issues fuel to Jacksonville via barge. Yorktown issues fuel via barge to an air force base (AFB) and to an army base (Fort) via tanker truck. The mean travel times are indicated in days in the diagram. Figure 8 indicates the inventory policies for each location in thousands of gallons as well as the mean demand per day, which is assumed to be a Poisson process.

One of the uses for the library is for contingency analysis. For instance, suppose a category 4 hurricane makes landfall in the east coast near Baltimore. During this time, it is expected that barge processing will be disrupted due to flooding and storm surge. Suppose the storm lasts for two days and barge processing is disrupted for 14 days, because resources used to process barges at Baltimore, Yorktown, Port Mahon, and AFB become unavailable because of flooding and subsequent clean up. This roughly approximates the effects on Houston resources because of Hurricane Harvey in the summer of 2017.

For the results in Table 1, the model was executed for 20 replications with a warmup period of 100 days. The hurricane event was scheduled for 30 days after the warmup with the disruption lasting 14 days. The planning horizon for the simulation is 60 days. The half-width results are based on 95% confidence levels. Table 1 presents results for selected performance measures of the AFB location based on running the model with and without the hurricane in order to illustrate the type of analysis that can be performed. As can be noted in Table 1, the AFB location has an overall reduction of on-hand inventory during the planning period due to the hurricane. While the ready rate (percentage of time with stock on hand) is still 1.0, we see that the probability of being able to fill the demand directly from stock on hand (FirstFillRate) is reduced from 0.76 to 0.43. While the amount ordered from AFB remains the same, the total number of receipts and amount received is substantially decreased due to the hurricane. Finally, in this instance the control limit for JAA is 10,000 gallons. New metrics created for monitoring disruption events monitor the distance below the control limit and the time spent below the control limit. For DLA, maintaining the control limit is critical for not dipping into war reserves. As noted in Table 1, the percentage of time under the control limit increases from 0.57 to 0.78 over the planning horizon.

Table 1: Selected performance metrics for notional example.

	Without Hurricane		With Hurricane	
Performance Measure	**avg**	**hw**	**avg**	**hw**
AFB:JAA:OnHand	8503.78	948.44	5162.89	488.38
AFB:JAA:LResponse:DistBelowLimit:10000.0	4664.81	137.64	4903.08	150.49
AFB:JAA:LResponse:MaxDistBelowLimit:10000.0	8826.95	280.20	8617.50	262.83
AFB:JAA:LResponse:PctTimeBelow:10000.0	0.57	0.07	0.78	0.03
AFB:JAA:LResponse:MaxTimeBelowLimit:10000.0	3.92	0.90	30.88	0.85
AFB:JAA:ReadyRate	1.00	0.00	1.00	0.00
AFB:JAA:AmtBackOrdered	1148.47	970.11	21582.70	4215.95
AFB:JAA:AmtOnOrder	8101.74	1925.11	31876.84	4579.68
AFB:JAA:FirstFillRate	0.76	0.09	0.43	0.06
AFB:JAA:NumOrdersPlaced	15.30	1.23	15.30	1.23
AFB:JAA:TotalAmtOrdered	183495.50	14635.42	183495.50	14635.42
AFB:JAA:TotalAmtReplenished	180509.40	13230.48	90578.55	7572.53
AFB:JAA:TotalNumReplishmentsRecieved	15.05	1.12	7.55	0.63
AFB:JAA:TotalAmountFilled	182526.20	13718.02	97605.00	6567.64

5 FUTURE WORK

This paper describes the conceptual modeling of bulk petroleum supply chains for the DLA. The primary purpose of the modeling is to understand the capacity of network components under contingency planning scenarios such as increased surge demand and disruption events. Future work will explore the use of simulation for defining network resilience and for finding alternatives to use to mitigate the effect of network disruption. While many definitions of resilience have been proposed, we adopt the following definition by Vugrin et al. (2010): “Given the occurrence of a particular disruptive event (or set of events), the resilience of a system to that event (or events) is that system's ability to reduce efficiently both the magnitude and duration of deviation from targeted system performance levels.” Acquisition processes have tended to ignore issues related to resilience, because acquisition processes focus on finding the lowest cost solutions that meet requirements that have historically not included resilience as part of the decision making context. Future work will explore how to incorporate resilience planning within this complex decision making context using newly developed metrics for monitoring resilience within supply chain simulations.

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