

**Simulation Modeling of Domestic and International  
Intermodal Supply Paths**

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## ABSTRACT

The supply of material to a manufacturing facility obviously has a major impact on enterprise performance, whether measured in terms of cost, timeliness, quality, etc. Most material that is input to a manufacturing process is transported to the manufacturing facility via multiple modes of transportation, i.e., it involves intermodal transportation. Since the material must be acquired from outside of the manufacturing site, sourcing decisions have significant impact on overall enterprise performance. Critical elements of those sourcing decisions include specifying from where to acquire the material, in what quantity, etc. It may also involve deciding the modes that should be used to transport the material from the source to the manufacturer. Even if specifying the mode is not part of the decision process, it is a significant driver in terms of cost, reliability, timeliness, etc. These issues pertain to domestic supply, but more importantly to international supply.

The sourcing decision is complex since it involves a large number of factors and considerations, as well as interdependencies between the factors, and considerable variability and uncertainty. This is especially true when considering international sourcing options, but is important in assessing alternative domestic intermodal paths as well.

This project provides the capability, through a software toolset, to deal with these issues. Simulation modeling and analysis is commonly applied to complex problems similar to those in the sourcing decision. Simulation provides the means to perform sophisticated what-if analyses on complex problems, such as assessing alternative intermodal supply paths. The toolset provides a means to quickly develop simulation models of both domestic and international supply chains. The project also provides a case study that illustrates how the toolset can be applied in a real setting.



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## INTRODUCTION

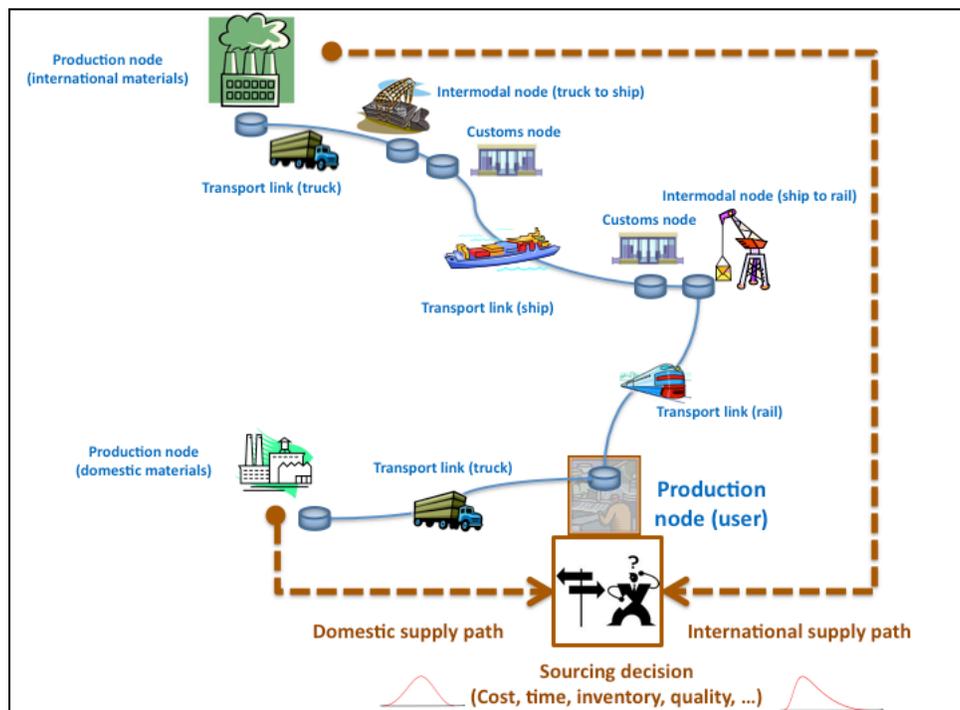
Organizations can select materials from a variety of providers or sources; these sources can be both domestic and international. As such, the goods use multiple modes of transportation to get from supplier to user and go through a number of transportation mode transfers. Therefore, the transportation from supplier to user is intermodal and involves the transfer of goods between various modes of transportation – rail, truck, and ocean carrier. Alternative intermodal transportation paths affect cost, timeliness of production, quality, batch size, inventory, etc. Therefore, sourcing decisions are a critical part of the acquisition process and in most industries is a major driver of manufacturing and product performance. Critical elements of the sourcing decisions include specifying from where to acquire the material, in what quantity, etc. It may also involve deciding the modes that should be used to get the material from the source to the manufacturer. The importance of the sourcing decision, as noted in Eksioglu, et al. (2010), “(p)roduct outsourcing is recognized as a way to gain the flexibility necessary for competitive advantage.”

Simulation is applied to supply chain design and management at a variety of levels. Good overviews of transportation logistics and global supply chain design are described in Goldsman, et al. (2003) and in Meixell and Gareya (2005), respectively. Detailed discrete-event simulation models have been developed to represent the operations of key elements in the supply chain. For example, Liu and Takakuwa (2011) modeled the activities in a Japanese container terminal in order to analyze bottlenecks and improve performance. Our approach represents such elements at a much higher level. Of course, these detailed models provide a good means for abstracting to a higher level and identifying key performance drivers. We see these detailed models as complementary to what we propose, not contradictory.

Eksioglu, et al. (2010) apply simulation to assess supply chain performance in the furniture industry. They provide a good overview of the issues and clearly demonstrate the importance of applying simulation to analyzing the impact of outsourcing on supply chain performance. Our approach builds upon their work and extends the capabilities of their models in several important ways. Since we develop general objects that represent key intermodal supply chain transportation elements, those objects could be applied to any industry. Our object-oriented architecture and designed data and user interfaces enable users to quickly construct simulation models of their supply chains.

This project provides a software toolset that is capable of analyzing and assessing alternative domestic and international intermodal supply chain performance. The project develops a library of generalized intermodal transportation-related objects that can quickly be configured to

represent specific intermodal routes or paths. That is, the simulation models are constructed through the assembly of standard components, developed as part of this research project, which represent and simulate common transportation elements in a supply chain. As shown in shown Figure 1, a simulation model represents a set of intermodal transportation *paths* between supplier and consumer (domestic manufacturer). The paths will be composed of a series of intermodal *nodes* (e.g. container port, rail yard) and *links* (e.g., roadways, rail lines, shipping lanes). These general nodes and links contain basic operational logic and data values for properties that describe the operation and performance of the specific element. Once populated with the requisite parameter values, the nodes and links provide a high-level representation of the functionality of part of a specific intermodal path. In addition to developing the generic nodes and links, the project also provides the means to assemble the nodes and links into paths. Once the paths are assembled they can be simulated and used to assess lead times, lead time distributions, costs, etc. Since simulation models include random variables, part of the output are measures of variability and risk.



**Figure 1: Examples of high-level intermodal paths - node and link models combined to form a domestic and international supply path**

One key aspect of this research project is to determine how detailed the node and link elements need to be in order to provide high-level estimates of cost, risk, lead time, etc. While the nodes and links could represent detailed operations and traffic flows, that is beyond the scope of this project. Early on in the project, in the Investigation Phase, domain experts in industry and the

literature will be used to identify and define the high-level performance drivers of the different types of intermodal nodes and links. The literature review will consist of academic journals, trade journals, and research reports. Industry engagements will involve in-depth discussions with domain experts, primarily in the furniture and automotive industries, to identify and define the key intermodal transportation issues, basic operational aspects of the elements, data requirements and sources, performance measures, etc. The partners in this project – MSU’s Franklin Furniture Institute, CAVS Extension, and Department of Industrial and Systems Engineering – all have strong ties to industry. The industry engagements will be set up through these contacts. As shown in Section 4, we have the support of three prominent companies, Nissan in the automotive industry and Bauhaus and FlexSteel in the furniture industry.

Existing detailed models may be used to help define the high-level models by supporting the development of parametric type representations of the node and link operations and/or to help identify key process drivers, those that have the most impact on node and link performance. The project will also provide input specifications for the node and link objects so that existing detailed models can provide input to the high-level simulation.

Another key aspect of the Investigation Phase is the definition of primary use cases for the toolset, i.e. definition of how the tools will be used, by whom, the type of data to be provided, and the types of output expected. The use cases and literature review will directly support the second phase, System Design. This phase will involve development of the overall architecture and framework, conceptual design for the generic intermodal nodes and links, specification for the means to assemble the nodes and links into paths, preliminary definition of output requirements, and preliminary definition of the input data structures. The toolset will be developed primarily using *Flexsim* simulation software. As shown in the letter of support in Section 4, Flexsim Software Products, Inc. is a partner in the project. They will provide design and development support, as well as providing *Flexsim* and *Flexsim CT* (now Moffatt & Nichol’s *FlexTerm*) software licenses to project team members.

Once designed, the generic node and link elements and assembly mechanism will be developed and tested during the System development Phase. In this phase, at least one prototype review will be conducted with industry to gain feedback on the functionality and usability of the toolset. Another opportunity to gain feedback on the approach is during the NCITEC conference at MSU in Spring 2013. A paper based on the project’s research outcomes to date will be presented at the conference. Based on feedback, the design will be modified and development and testing will continue until the toolset is released at the conclusion of the project, in December 2014. Another research paper will be prepared for submission to the 2013 Winter Simulation Conference; the paper needs to be completed by April 2013 and will be delivered in December 2013.

To help with dissemination and outreach, one case study will be developed using the toolset. The case study will provide a detailed assessment of at least one domestic supply path and one international supply path. It will also provide feedback on future enhancements and developments.

The supply of material to a manufacturing facility obviously has a major impact on enterprise performance, whether measured in terms of cost, timeliness, quality, etc. Most material that is input to a manufacturing process is transported to the manufacturing facility via multiple modes of transportation, i.e., it involves intermodal transportation. Since the material must be acquired from outside of the manufacturing site, sourcing decisions have significant impact on overall enterprise performance. Critical elements of those sourcing decisions include specifying from where to acquire the material, in what quantity, etc. It may also involve deciding the modes that should be used to transport the material from the source to the manufacturer. Even if specifying the mode is not part of the decision process, it is a significant driver in terms of cost, reliability, timeliness, etc. These issues pertain to domestic supply, but more importantly to international supply.

The sourcing decision is complex since it involves a large number of factors and considerations, as well as interdependencies between the factors, and considerable variability and uncertainty. This is especially true when considering international sourcing options, but is important in assessing alternative domestic intermodal paths as well.

This project provides the capability, through a software toolset, to deal with these issues. Simulation modeling and analysis is commonly applied to complex problems similar to those in the sourcing decision. Simulation provides the means to perform sophisticated what-if analyses on complex problems, such as assessing alternative intermodal supply paths. The toolset provides a means to quickly develop simulation models of both domestic and international supply chains. The project also provides a case study that illustrates how the toolset can be applied in a real setting.

The simulation models represent intermodal transportation *paths* between supplier and consumer (domestic manufacturer). The paths will be composed of a series of intermodal *nodes* (e.g. container port, rail yard) and *links* (e.g., roadways, rail lines, shipping lanes). These general nodes and links will contain basic operational logic and data values for properties that describe the operation and performance of the specific element. The project will also provide the means to assemble the nodes and links into paths. Once the paths are assembled they can be simulated and used to assess expected lead times and costs, as well as the distributions of lead time and cost in order to assess risk and uncertainty and thus better understand the cost and benefit tradeoffs

involved in making the sourcing decision. The toolset could also be used to assess the competitiveness and needs of current and future intermodal transportation systems, especially in terms of timeliness of delivery.

## **OBJECTIVE**

The objective of this research is to provide a means for those making sourcing decisions for inputs to a manufacturing process to assess the impact on performance (e.g. lead time, variation in lead time) of alternative paths of travel between supplier and user.

## **SCOPE**

One issue that has to be dealt with in every modeling project is how detailed should the model be. Of course, in general it should only be as detailed as needed to answer the questions being posed. In this case, our concern was how much of the internal operations of the logistics nodes (ports, factories, terminals, etc.) need to be considered and represented in the model. Our goal was to make those model components as simple as possible. Based on our discussions with industry, it became apparent that minimal internal detail was needed. For example, in the case of ports, we can model at a high level because items flow from arrival to exit quite quickly, at least relative to the transportation time and total lead time. The quick time through that part of the system is evidenced by the low inventory that existed at the facilities we visited.

## **METHODOLOGY**

### **Background**

In order to obtain and maintain competitive advantage, US firms receive raw materials and components from all over the world. For example, products may be developed in Europe and the USA, manufactured in Asia and Latin America, and sold worldwide (Burnson, 1999). These operations require management of logistics processes that form critical loops of materials, information and cash. Because of global sourcing, total lead time and total logistics cost have become key performance measures. These measures include: transportation, warehousing, order processing/customer service, administration, and inventory holding (e.g. Lambert et al., 1998; Saccomano, 1999). In order to move materials or products through a global supply chain, e.g. from the Far East to North America or Europe, multiple handoffs are required (Russell and

Saldanha, 2003). Among these handoffs are varying modes of transportation. The term “intermodal” is used to describe “the transfer of products involving multiple modes of transportation – truck, railroad or ocean carrier” (IANA, 2010). For example, items shipped in containers by ocean carrier must be transferred to rail or truck usually several times.

In intermodal global supply chains the basic unit of transport is the container. Containers, introduced in the 1950s, are large boxes that contain goods for transport from one destination to another. The dimensions of containers have been standardized. The term twenty-foot-equivalent-unit (TEU) is used to refer to one container with a length of twenty feet. A container of 40 feet is expressed by 2 TEU. Several transportation systems are used to transport containers from one destination to another – ships, trucks, and trains/rail. To transship containers from one mode of transportation to another, ports and terminals are used. For example, a container terminal at a port transfers containers between ships and rail or truck. Since the capacities of ships have increased to thousands of TEUs and the need to reduce inventory, intermodal facilities have become very efficient in processing containers, aided by sophisticated information technology and automated control technology.

### **General Approach**

As described in the scope section, one of the first tasks of the projects was to discuss with industry how supply paths work in the furniture and automotive industries, as well as visit some of the facilities (factories, terminals and ports). Based on those discussions and visits, it became apparent that the logistics nodes could be represented at a high level.

Concurrently with the industry research, we built conceptual and programmed models of some of the logistics nodes. During this effort, it became apparent that in order to provide a very granular model, much detailed data about the node would be required. This data would not only include detailed process information, such as task times at each step and resource capabilities and capacity, but current system status when a shipment arrives at the facility, such as number and type of other items in the system, past and future loadings on the transportation unit (e.g. container ship), etc. For the type of analyses we envision to be conducted with the system being developed – relatively quick tradeoffs between alternative supplier locations and transportation means – obtaining this type of information is not feasible. However, we do provide a data specification so that if someone has a detailed simulation model of a logistics node (factory, port, etc.) then it can be used to drive the system developed in this research.

In conjunction with the exploration of the level of detail needed in the models, the research also looked for commonality among the logistics elements in order to simplify development and use.

It was found that the facilities for handling of the three types of transportation – ports, rail yards, and truck terminals can be represented as one general object, referred to as a transportation hub. Similarly, supplier and plant (customer) manufacturing facilities can be represented as one common object, referred to as a factory. The three means of transport – road, rail, and sea – can be represented as one common object. Each of these basic objects are described in the sections below. Prior to describing each type of basic object, the overall system is defined.

### Overall System

An intermodal supply path is composed of a series of intermodal nodes (e.g. factories, ports, and rail yards) and links (e.g. railways and roads). The links are transportation modes that link nodes. An example supply path is provided in **Error! Reference source not found.**; it shows the transport of an item from a supplier to an end user via rail, ship, and truck links. In this case, an item travels by rail from the supplier to a rail yard, is transferred to a truck for travel on a road, is transferred to a ship at a port where it travels by sea to another port, is transferred to a truck for road travel until it reaches the plant/consumer.

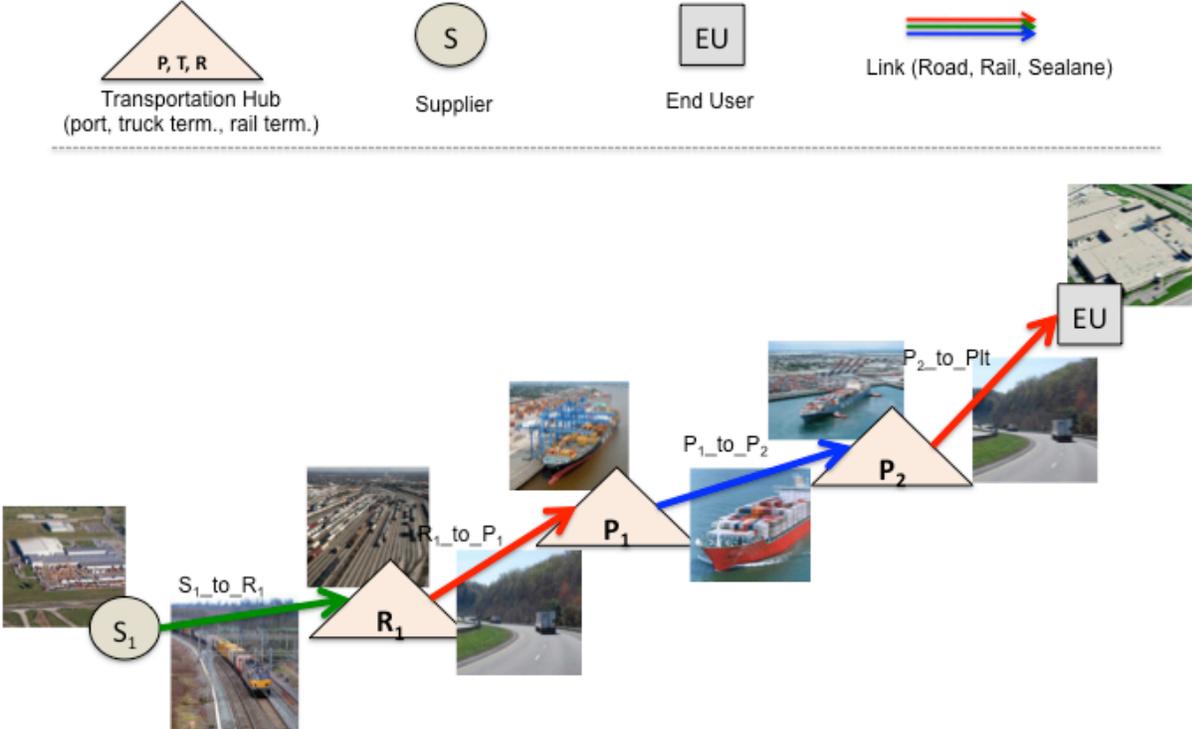


Figure 2: Example intermodal supply path

We refer to a supplier as a facility that provides an input to a facility that consumes the input (end user). While suppliers and end users are both plants, or manufacturing facilities, and there is a lot of operational commonality between them, we consider them separate objects. As will be explained below, suppliers are simpler versions the end-user object. The end-user object is the focus of the analyses; i.e., the simulation model is used to measure its performance in terms of alternative supply paths or different arrangements of suppliers and links.

### **Supplier-plant object**

As shown in Figure 3, in the supplier-plant object is driven by its customer, which is the end-user object. The `sc_Supplier` object receives orders and creates the number of items required to fill the order quantity. Each item created by the `sc_Supplier` object represents a minimum order quantity that is entered by the user in the supplier GUI. These items are then sent to a queue to await processing. Processing time, represented for example as `pr_Plant_26` in Figure 4, is the product's lead time multiplied by the minimum order quantity. These values are provided by the user via the supplier GUI. Once the items are processed, they are combined with other objects, based on the container quantity, and then are merged with a truck for transport. As can be seen from Figure 3, the logic in the supplier plant object is a subset of that contained in the end-user plant object.

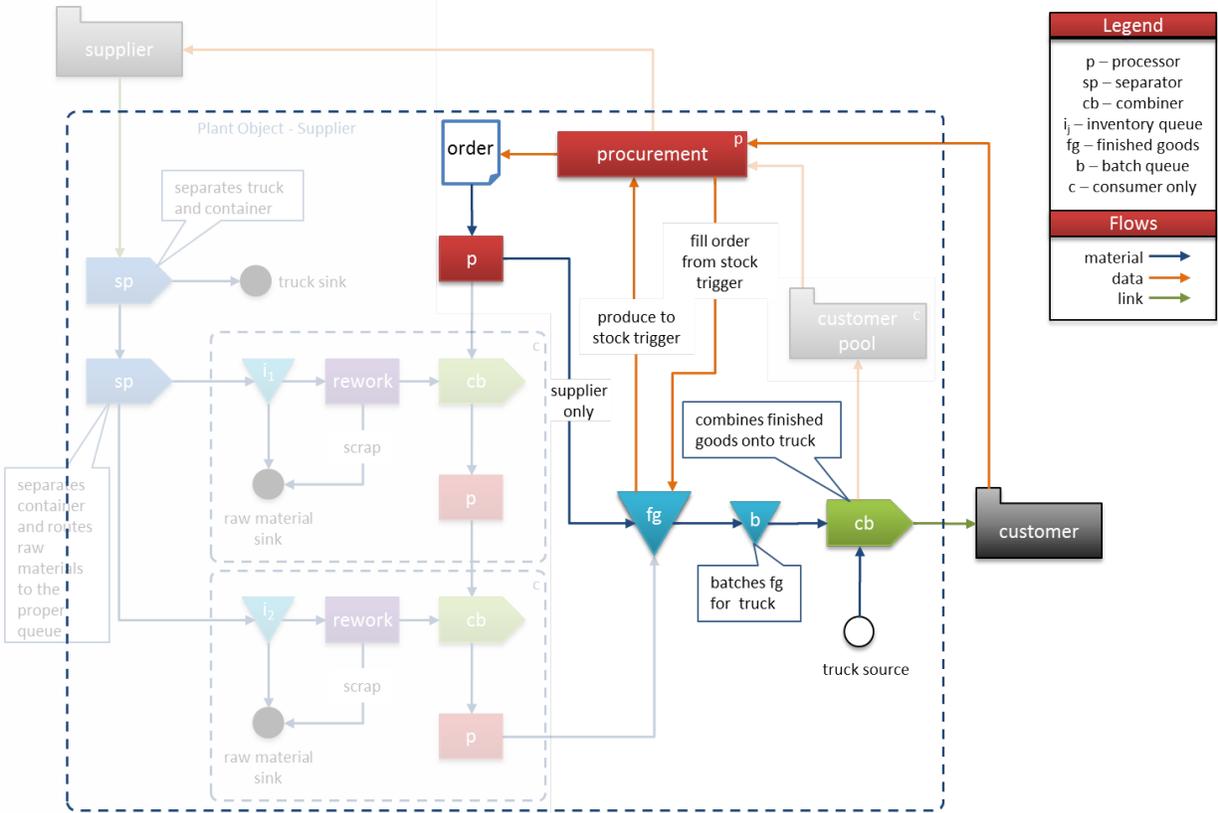


Figure 3: Supplier-plant object architecture

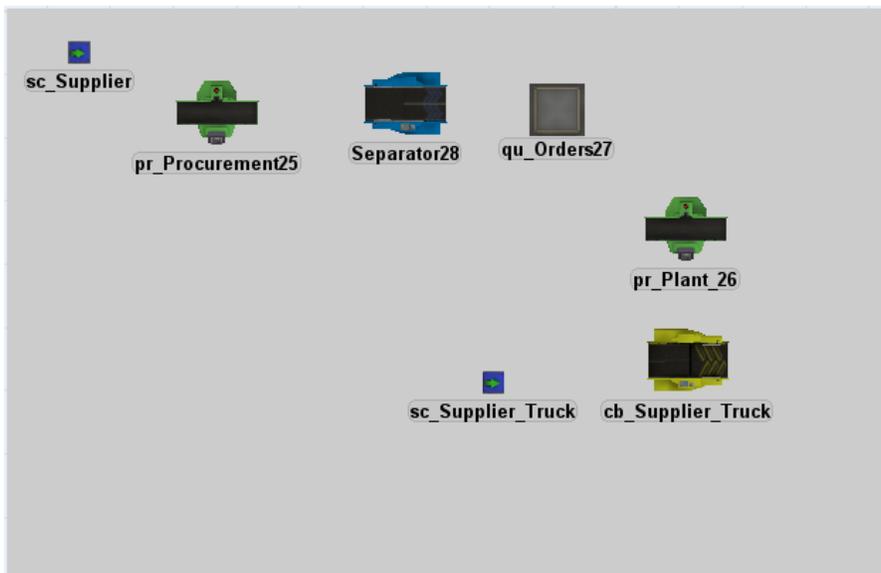


Figure 4: FlexSim representation of the supplier-plant object

As shown in Figure 5, the supplier-plant object contains a GUI that allows users to set and view important attributes of a supplier. The attributes include supplier location, “Min Order ty” (the

minimum number to be ordered from a supplier), and “Product Lead Time” (process time per part at the supplier).

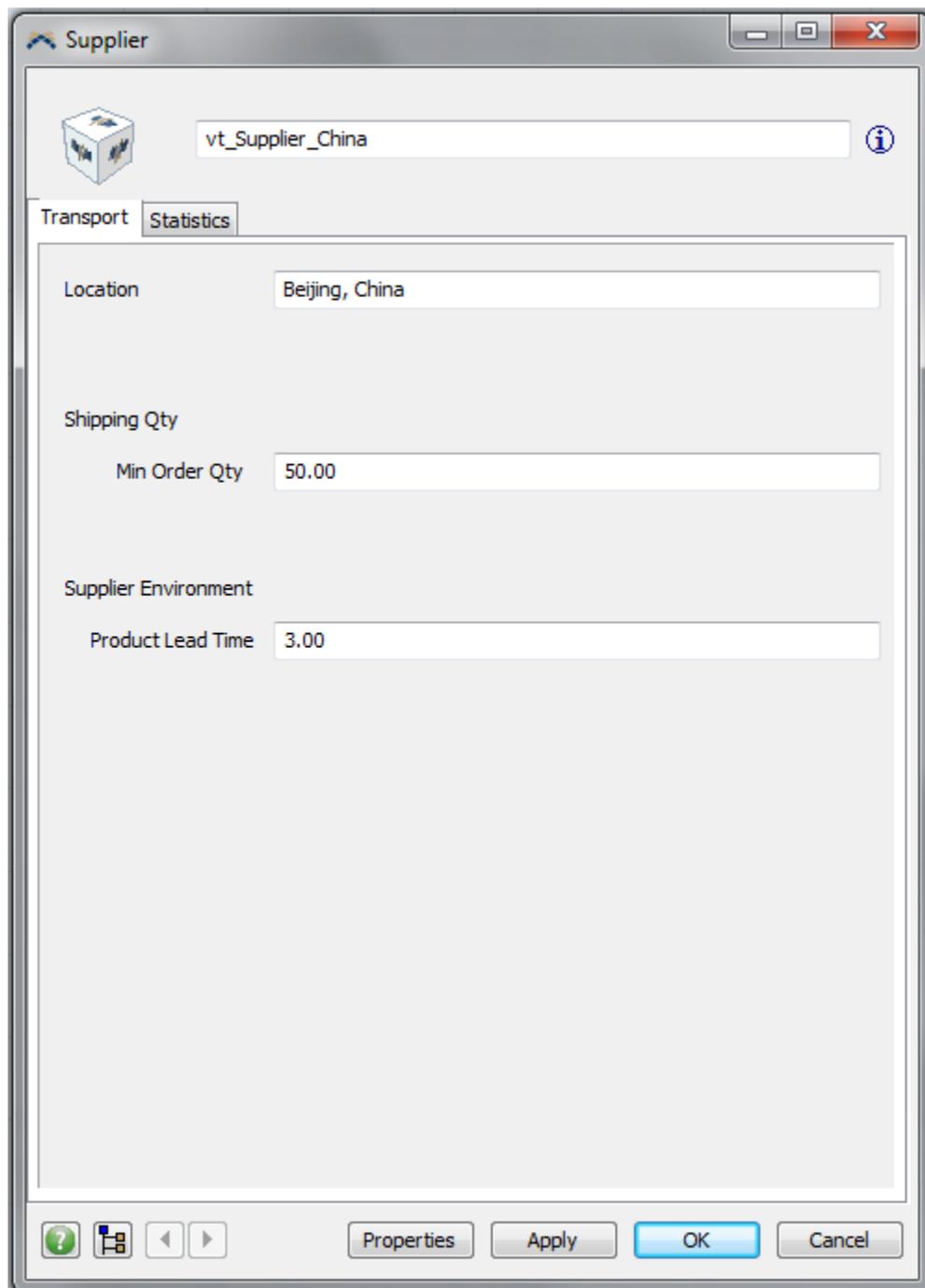


Figure 5: Supplier-plant object GUI

## End-user-plant object

As shown in Figure 6, the end-user-plant object is driven by a consumer pool, a virtual market that this object must satisfy. An example of a consumer pool is `sc_Customer` in Figure 7. The consumer pool calculates the order frequency based on the value entered in the end-user GUI as average sales per day.

It is assumed that the end-user-plant object produces to order. Production orders are generated for the end-user plant's single production line and supply orders are placed with suppliers (supplier-plant objects) as needed. Once a supplier order has been generated, the procurement object, for example `pr_Procurement` in Figure 7, determines if additional supplies are needed to fulfill the new order. The calculation is based on the amount of material on hand in the end-user plant, in transit from a supplier, and being produced at a supplier's plant. The requested supplies are received via transport into an object that separates the container(s) loads of material from the mode of transportation. Each container load is then split into the basic unit of material considered for production. The material is routed to the appropriate production input queue within the end-user plant to await use.

The end-user object's production line processes orders from the consumer pool as long as it has the needed materials. The end-user production process begins with a general process step that represents the time required to produce a product up to the point where the first key material is required. This time is represented as  $t_1$  in the sample timeline in Figure 8. A general process is represented by `pr_Plant_1` in Figure 7 and the processing time is based on the information provided by the user in the end-user GUI -- 1<sup>st</sup> Process Time and the order quantity.

Each production input queue and their corresponding processing task are a building block. For example,  $t_2$  in the sample timeline in Figure 8. These blocks can be combined to represent a complex production line. The number of blocks depends on how many processes are being analyzed in the end-user plant. These building blocks function as follows:

1. Materials from within each production input queue are transferred either to a rework processor or to a staging area for the production line based on the percentage of rework entered by the user in the end-user plant GUI for the particular process step. The rework processor represents incoming materials that are damaged, out of specification or the wrong product. If the material can be repaired it is delayed based on a rework time entered by the user and then sent on to the production line; otherwise, it is scrapped.
2. The production line in each building block is comprised of a combiner and a processor. The combiner represents the action of merging material with the base product including its process time. The processor represents the group of processes after the merge until then next incoming material is considered.

- The final product is sent to a finished good queue where it waits until the container batch size is satisfied.
- Once a container is full, it is transported as soon as a truck becomes available to the customer pool.

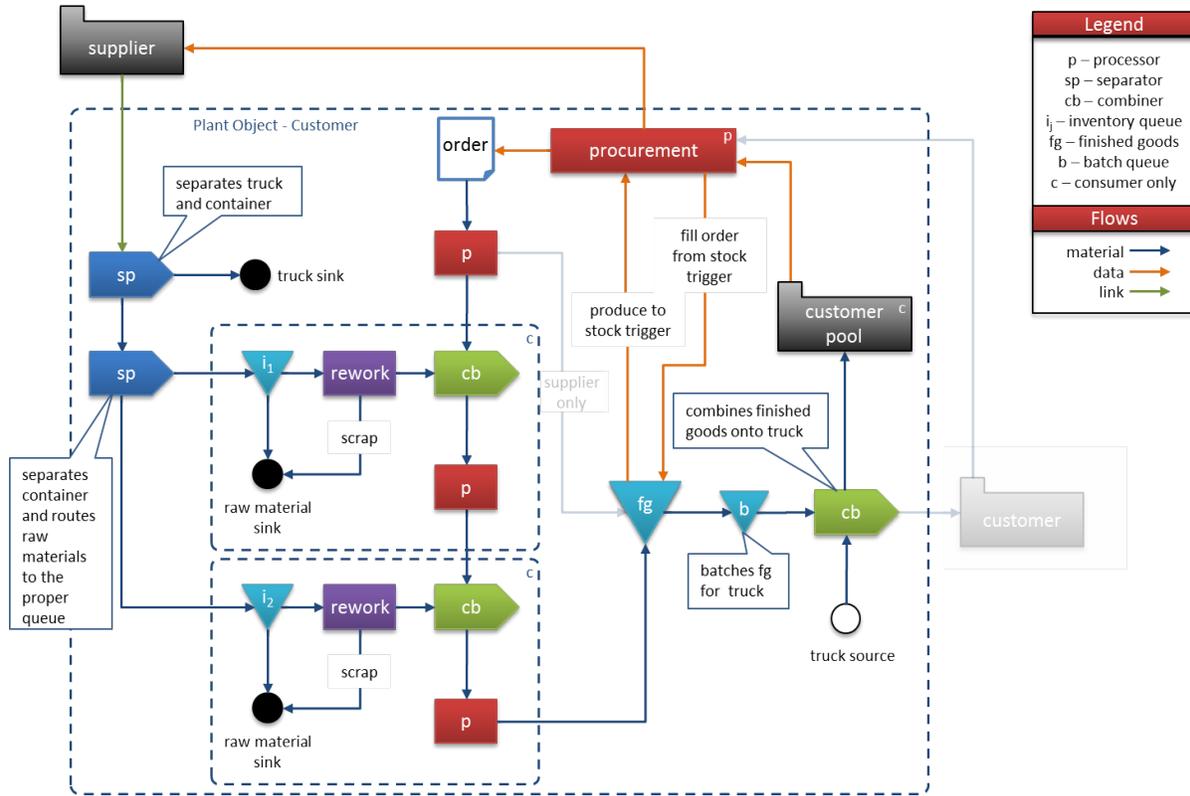


Figure 6: End-user-plant object architecture

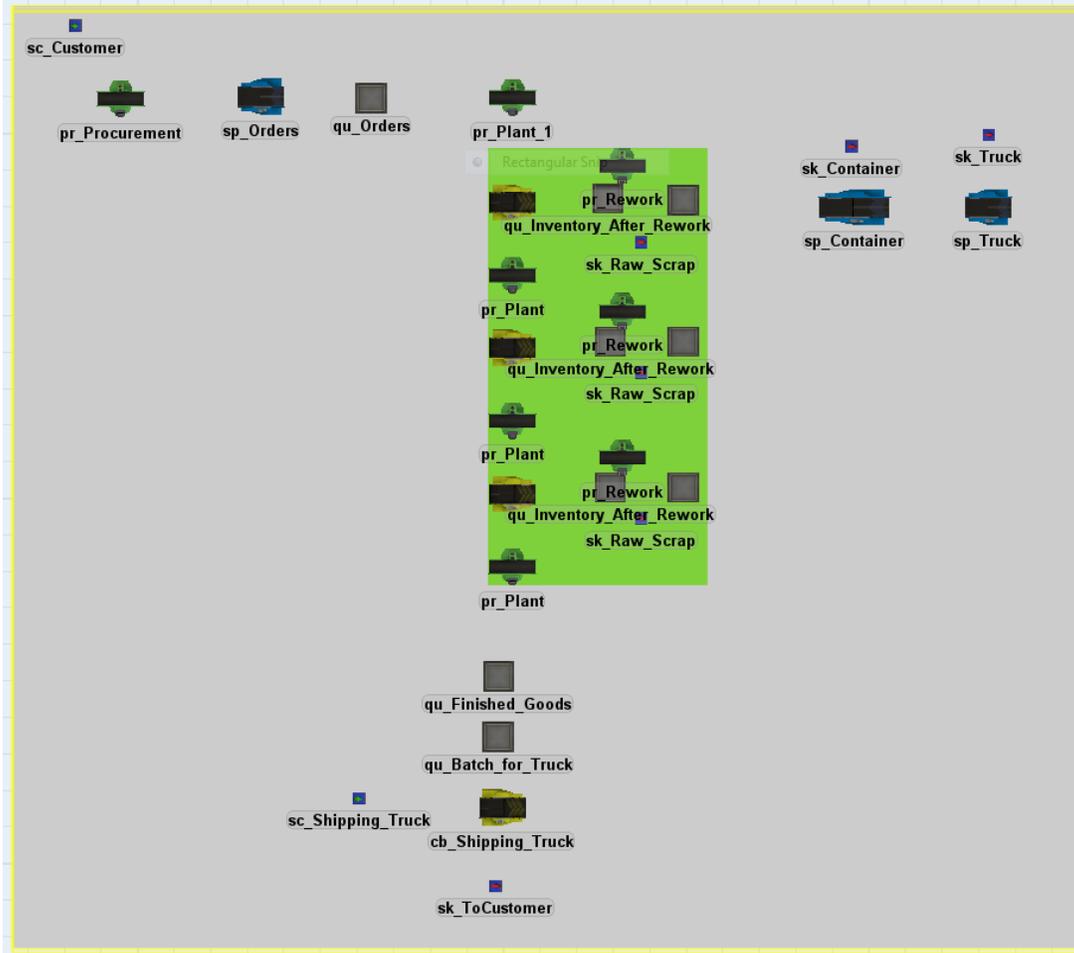


Figure 7: FlexSim representation of an end-user-plant object

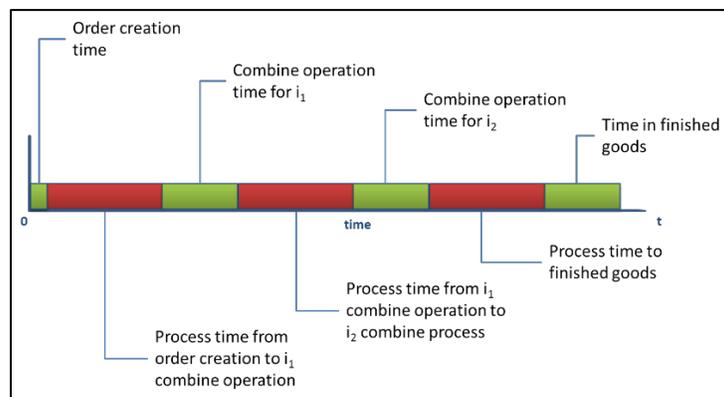


Figure 8: Example process timeline for the end-user plant object

As shown in Figure 9, the GUI for the end-user-plant object allows users to set and view important attributes of the object. The attributes include the location of the plant, “Avg. Sales per Day”, and “Shipping Qty” including the minimum amount that can be ordered at a time and

the amount of product that can be shipped in a container (both of which are for information and cannot be changed from this GUI).

The “Plant Environment” section allows users to set information about the process steps for the plant, such as “1st Process Time” (the time per part required to produce the product up to the point where the first material is required), “Scrap %” (overall scrap percentage for the plant), and “# Process steps” (number of steps in the process that require the material).

The number of process steps sets up a table with one row for each process step. For each step users provide the process time per part, time required to rework material, percentage of material that needs rework, number of units of material required at this process step, storage capacity of the area, and the process time per part for the subsequent process (until the next material is required).

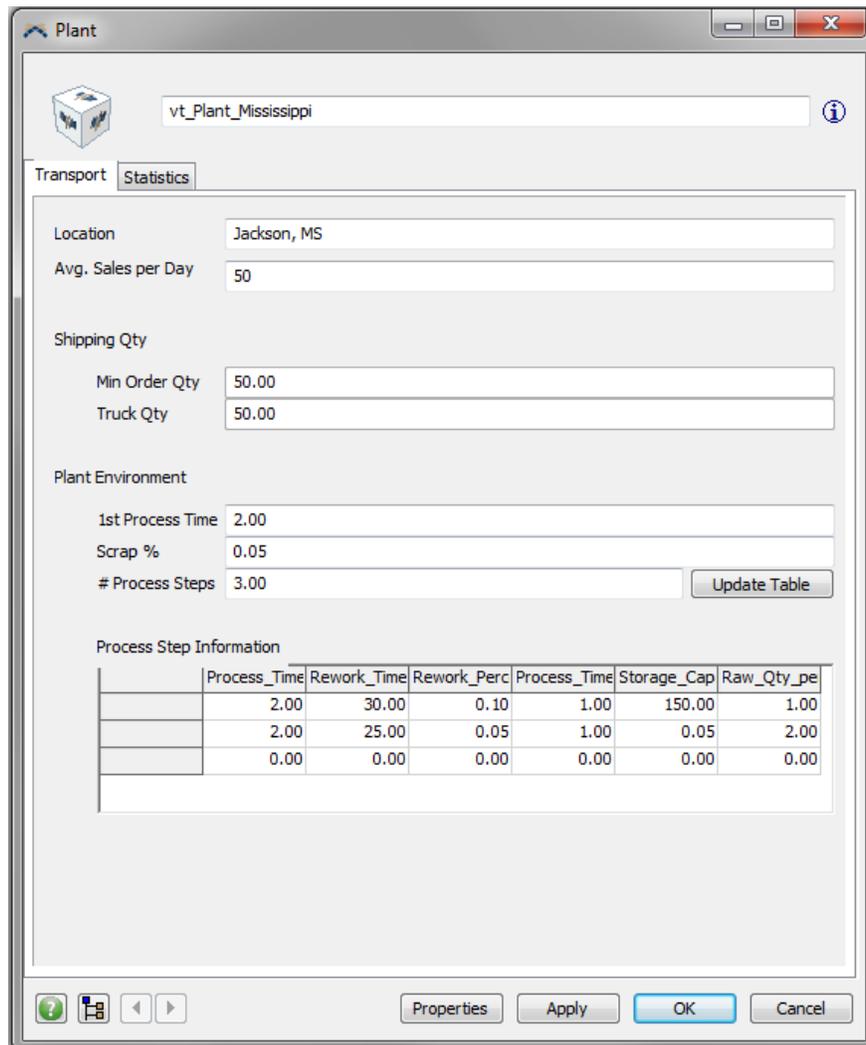


Figure 9: End-user-plant GUI

## Transportation hub object

A transportation hub represents a facility that is responsible for the processing of containers and the transfer of containers to various modes of transportation (ship, rail and truck). As shown in Figure 10, the basic architectural concept for a generic transportation hub is centered on a central container queue with components representing ship, rail and truck handling pushing and pulling from this queue.

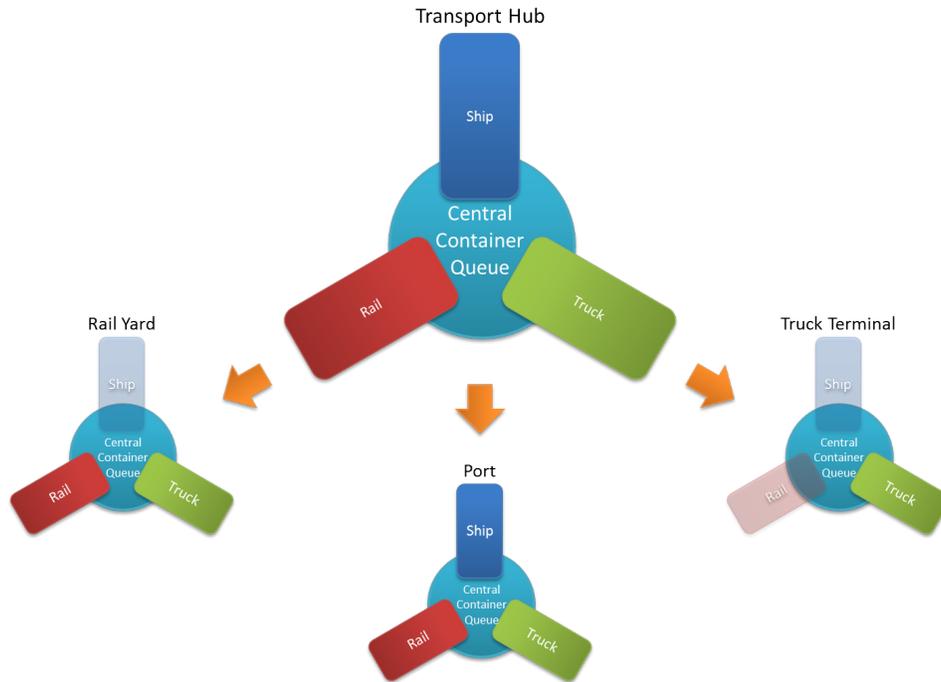


Figure 10: Transportation hub object architectural concept

The detailed architecture of the generic transportation hub is shown in Figure 11. The flow for each mode of transportation is similar. For example, trucks arrive to the system via two inputs: an internal truck source that generates trucks and any roadway transportation links connected to the transportation hub. All trucks enter a truck queue to wait for processing. If a truck needs to be unloaded, it goes to a separator/processor object to have the container unloaded. That container then is put into the outgoing area of the central container queue. Once a truck is available to be loaded it moves to a combiner/processor object and begins loading a new container from the incoming area of the central container queue. Once loaded, the truck exits the transportation hub by being transferred to a transportation link.

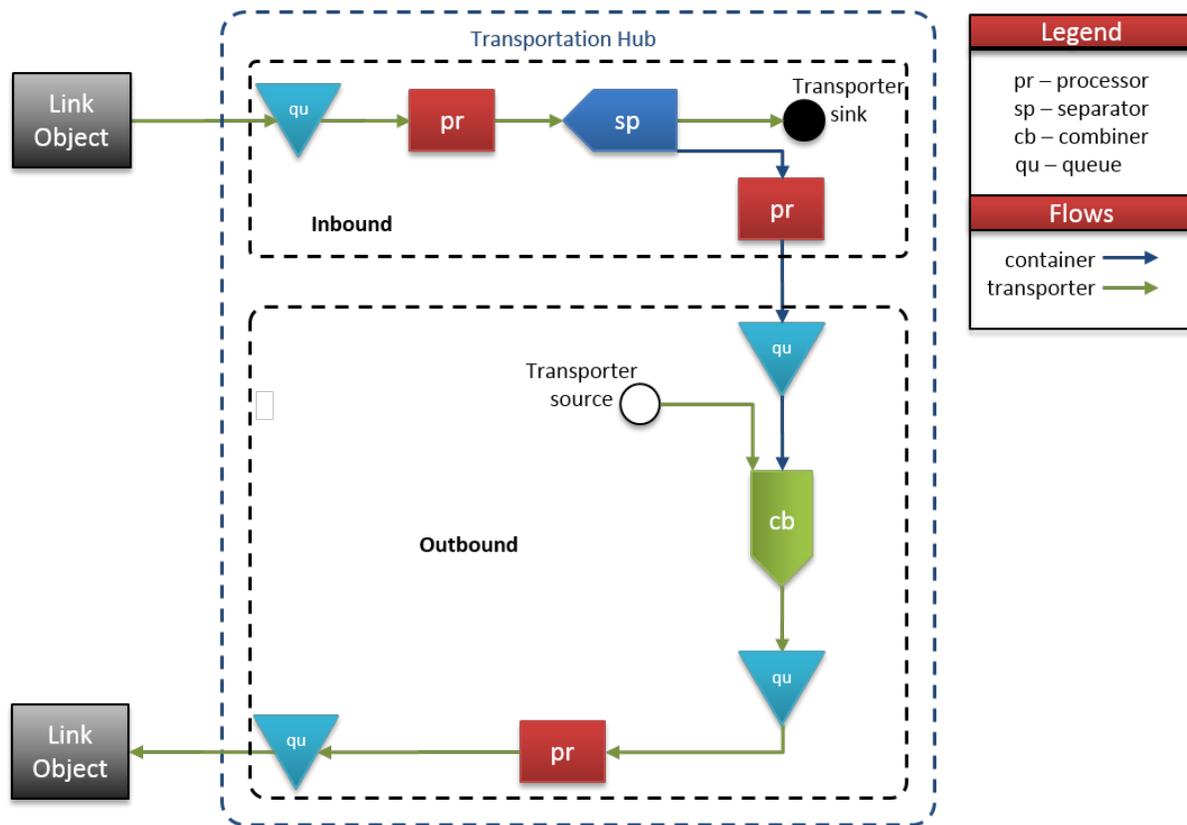


Figure 11: Transportation hub object architecture

The rail and ship components work in a similar fashion with a few slight differences. The first major difference is that both the rail and ship transporters carry multiple containers; therefore, multiple containers are pulled off in the separator/processor object before being sent to the central container queue. The number of containers pulled off is determined by the train's or ship's unload quantity attribute.

The key attributes of the transportation-hub object are: the type of entity being represented (port or rail yard or truck terminal), number of key locations for each mode of transportation (e.g.

berths), location (address or GPS coordinates), interarrival time for each mode of transportation, container load and unload times for each mode, capacity of central container queue.

### **Implementation of transportation hub in *Flexsim***

The basic *FlexSim* modeling components of the transportation hub are shown graphically in Figure 12 and in list format, in term of the *FlexSim*'s tree structure, in Figure 13. The basic flow through the transportation hub object, in *FlexSim* terms, is as follows. Three types of transporters can enter the hub: trucks, trains, and ships. These transporters enter via a link object which acts as a pathway to the hub (ex. road, rail, water). Transporters first move into *qu\_Inbound* and then proceed into *pr\_Inbound\_Unload.* , which has a maximum content that is defined by “Num Locations” in the object GUI. Process times are determined by the quantity of containers being unloaded and the “Unload Time.” The transporter then moves into *sp\_Unpack\_Transport*, which simply separates out the transporter's entire contents into individual containers (with process time = 0). The transporter then exits the model through *sk\_Transporters*. The containers continue to *pr\_Dwell\_Time* where they delayed based on the user input “Hub Dwell Time.” This considers congestion and delay time in the hub. Subsequently, containers move into *qu\_Product\_To\_Combine* to wait for a transporter to become available.

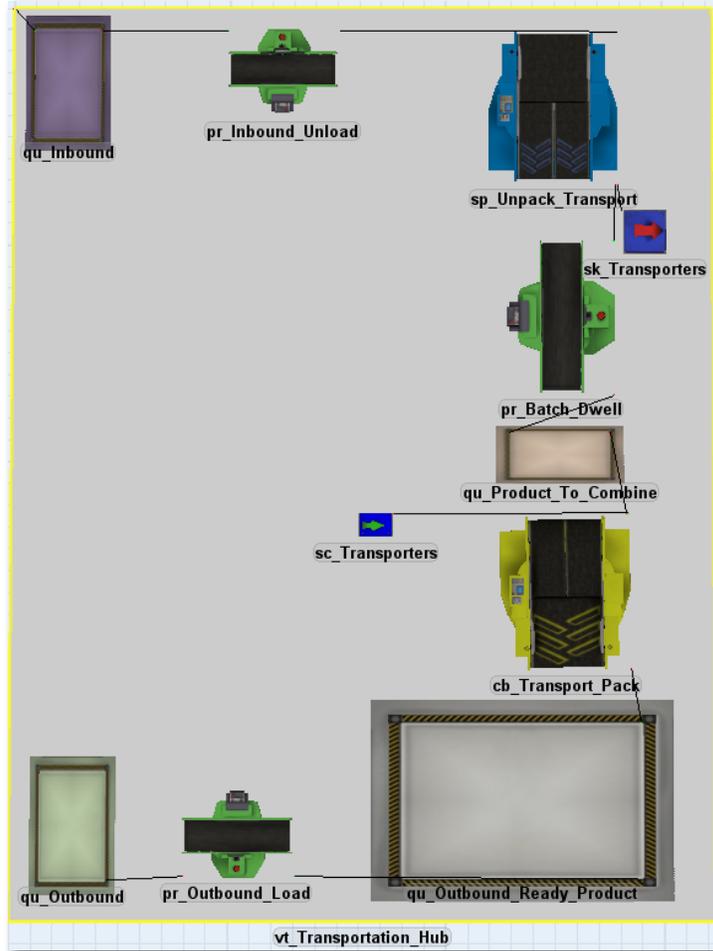


Figure 12. Transportation-hub object represented in *Flexsim*

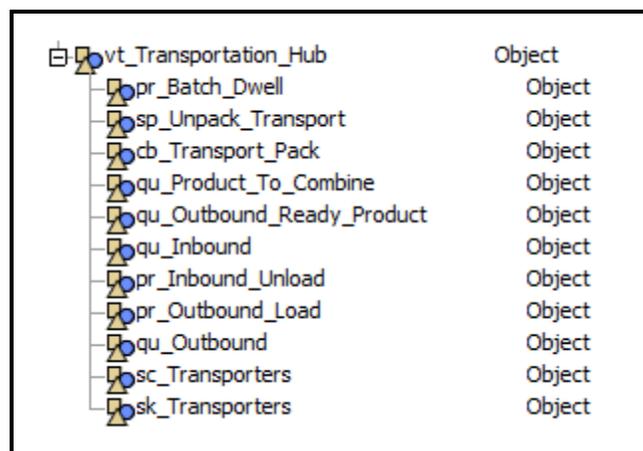


Figure 13 FlexSim tree structure for transportation hub object

The *sc\_Transporters* component generates transporters based on the user's input for "Interarrival Time" in the GUI. Transporter enter *cb\_Transport\_Pack* and get combined with containers waiting in *qu\_Product\_To\_Combine* based on a quantity dependent on transporter type (process time is 0). Packed transporters move to *qu\_Outbound\_Ready* where they wait to move into *pr\_Outbound\_Load*, which has a maximum content based on the user's input for "Num Locations." The process time is dependent on the quantity of containers being loaded and the user-specified "Load Time." After being processed, the loaded transporter moves into *qu\_Outbound* and exits via the output link object. The FlexSim objects included in the transportation hub object are summarized in Figure 13.

In order to connect the transportation hub to other objects, an "A" connection is made from a link object to the hub's container object ("vt\_Transportation\_Hub"); this enables transporters to enter the hub. In addition, an "A" connection is made from the hub's container object ("vt\_Transportation\_Hub") to another link object for transporters to exit the hub. Once the connections have been made, the model needs to be reset so that the hub can set itself up based on the type of links that are connected to it. The link object needs to have the number label, "Type", on it's container object (Type = 1 = Road; Type = 2 = Rail; Type = 3 = Water).

The GUI can be found in Figure 14. The descriptions of the fields are as follows:

Location – The geographical location of the transportation hub

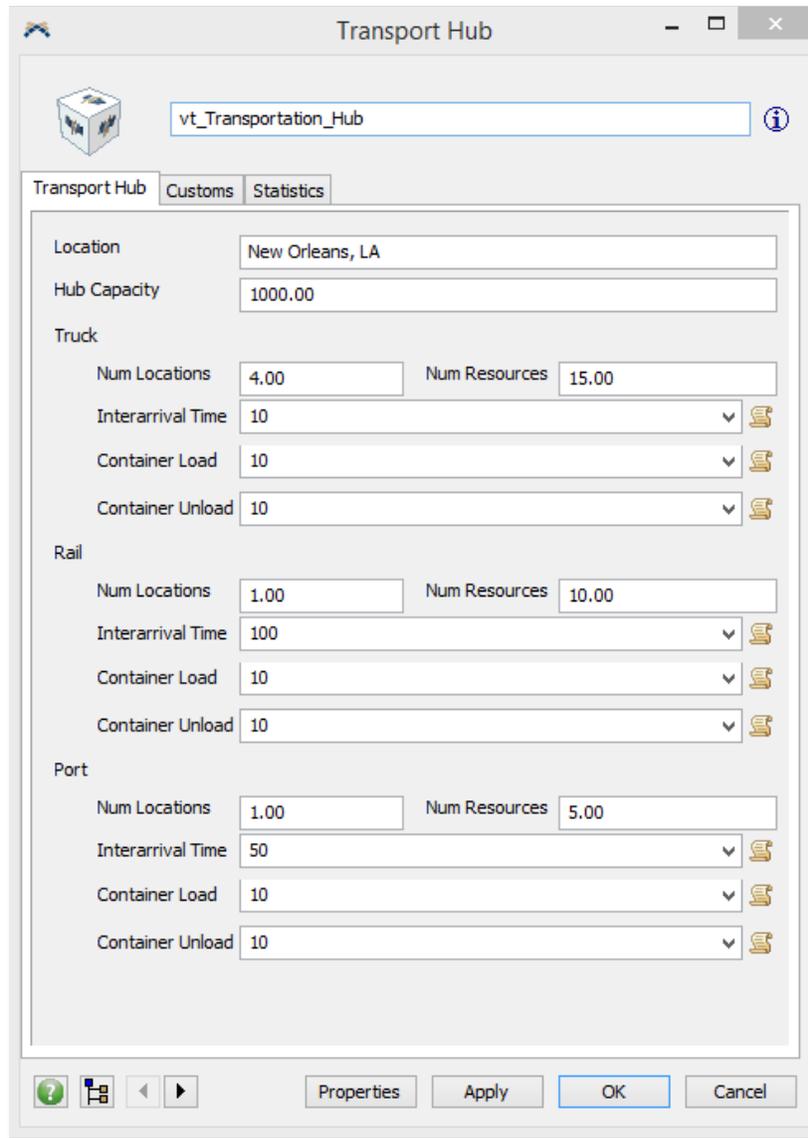
Hub Capacity – The maximum number of containers that the hub can hold at any given time

Truck/Rail/Port Num Locations – Number of unload/load locations that can be processed in parallel

Truck/Rail/Port Interarrival Time – The interarrival time for transporters into the hub

Truck/Rail/Port Container Load – The time required to load an individual container onto a transporter

Truck/Rail/Port Container Unload – The time required to unload an individual container onto a transporter



**Figure 14. Graphical User Interface for the transportation hub.**

## Transportation link

Transportation links define a path from one location to another, e.g. from a supplier-plant object to an end-user-plant object. These links represent rail lines, roadways, or sea lanes. Transportation links determine how long it will take for a mode of transportation to move items from one location to another.

### Link object operation

The link object is a processor object with custom code to provide its capability. It may be connected to any two objects, one that is the origin of the items that flow through the link and one that is the destination. As shown in Figure 15, the link object is connected to an origin, `sc_Any-NYC`, and a destination, `sk_Any-DFW`. Again, the connections can be to any type of object.

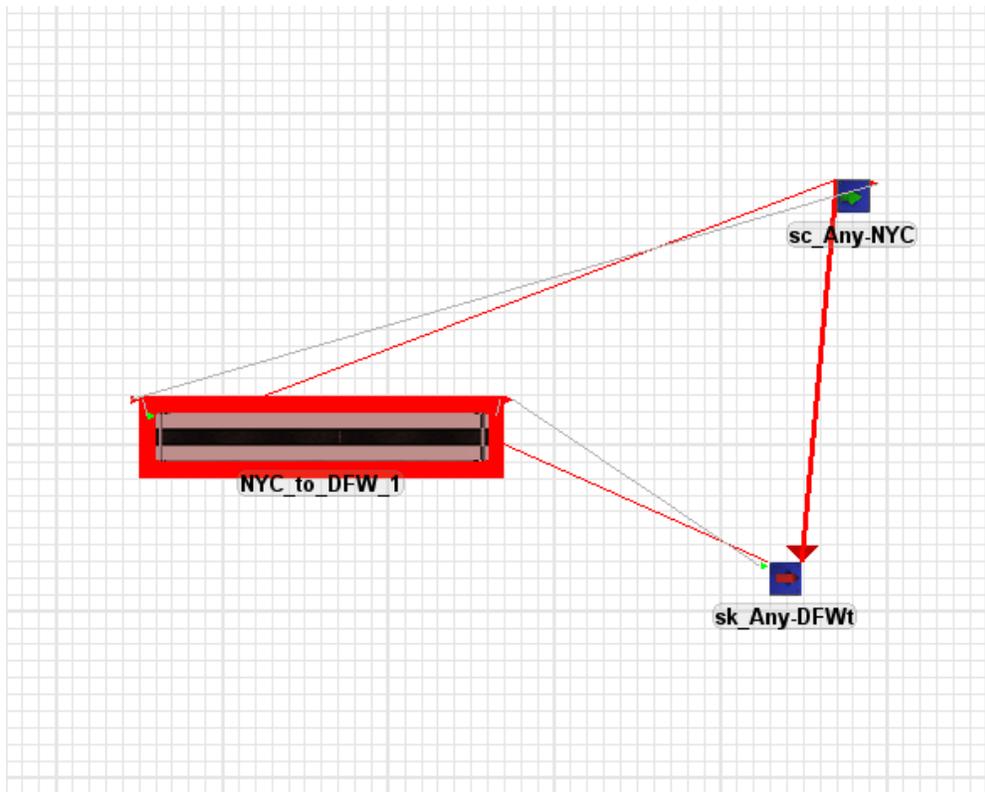
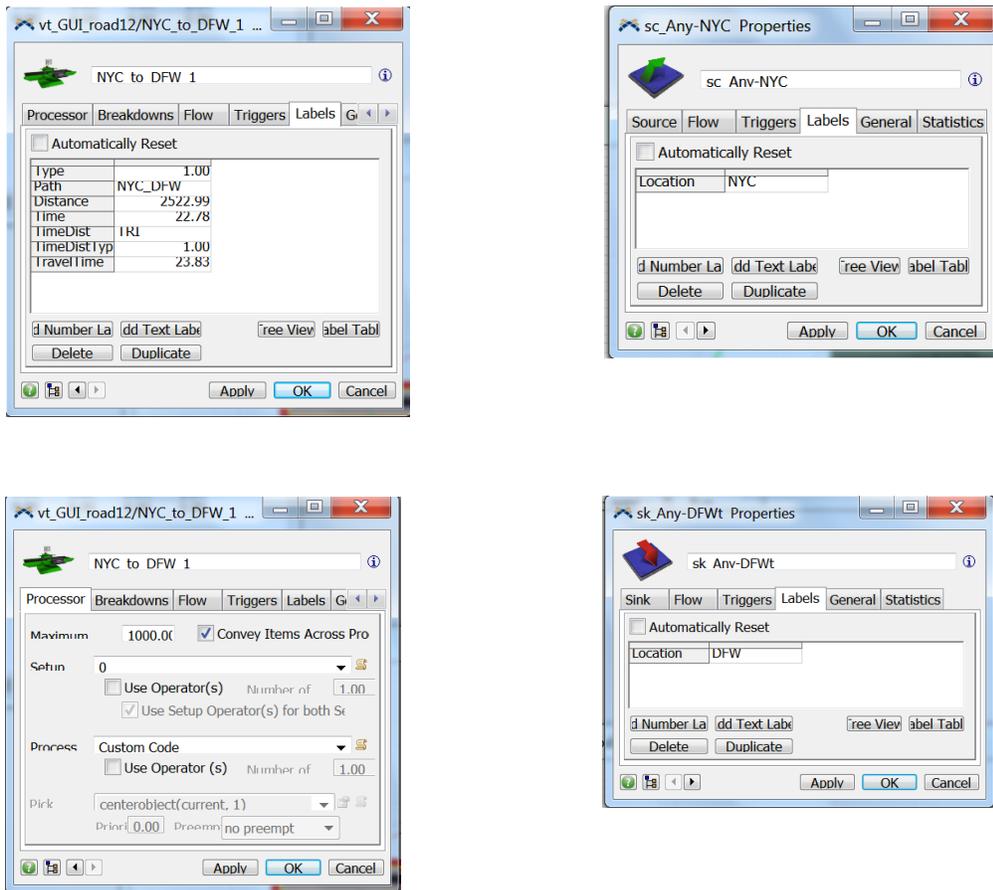


Figure 15 Transportation link object

The source and destination objects each have a label named Location; their values are the name destination, e.g. NYC, DFW. The link object automatically uses the label values to create its name. The name is the concatenation of the two label names separated by `_to_` and a sequential number at the end; in this case, `NYC_to_DFW_1`. Each object needs to have a unique name. If for example there is another link between NYC and DFW, say a rail line, then that link would be named `NYC_to_DFW_2`. The labels on the object in the example are shown in the right-hand portion of Figure 16.



**Figure 16 Object properties related to link object**

When a link is created between two objects, the link object automatically populates some of its label values, including Type (road, rail, sea) and Path (concatenation of the two location names that the link connects). It also populates the Distance and Time between the two locations. These values are obtained from a path table, like the example shown in the top- portion of Figure 17. The table contains the distance and travel time between two locations. The time and distance

information is obtained from various sources, e.g. Google Maps, and are explained later in this section. The link object also contains two labels that refer to the probability distribution that is used to set the actual travel time. The time obtained from the path table is assumed to be a mean time.

As discussed further in the next section, the distribution of travel times is assumed to be triangular. The triangular distribution requires three parameters, minimum, maximum, and most likely. Distributions with similar characteristics, such as same skewness and same degree of variability (coefficient of variation), can be represented as standard or normalized distributions. The standardized distributions can be transformed to a specific distribution by multiplying each parameter by the desired mean. Different families of triangular distributions can be included in a Distribution table, like the example in the bottom portion of Figure 17. Each standardized set of parameters are associated with a distribution Type.

Whenever a shipment moves through the link object it executes the code in the Process trigger (an example is shown in the lower left interface in Figure 16). The specific travel time is a random sample from a triangular distribution that has the parameters given by the Type label on the link object (refers to the Type in the distribution table) and the mean given as the label value Time on the link object. The resulting sampled time is used to delay the shipment in the link object simulating the transportation time; the value is also noted as a label on the link object named TravelTime (23.83 in Figure 16).

Global Table - gt\_Path

Row: 11.00 Column: 6.00 Clear on f

Origin	Destinat	Trip	Distance	Time (hrs)	
GTR	NYC	GTR_NYC	1754.14	16.18	0
BOS	DFW	BOS_DFW	2871.69	26.15	0
CDG	MUC	CDG_MUC	857.77	7.70	0
BOS	SAN	BOS_SAN	4905.18	43.71	0
NYC	DFW	NYC_DFW	2522.99	22.78	0
DFW	NYC	DFW_NYC	2525.72	22.82	0
SAN	NYC	SAN_NYC	4448.59	40.57	0
GTR	SAN	GTR_SAN	3076.19	26.86	0
NYC	GTR	NYC_GTR	1751.79	16.18	0
PDX	SAN	PDX_SAN	1767.30	16.34	0
DFW	PDX	DFW_PDX	3276.85	29.89	0

Close

Global Table - gt\_Distributions

Row: 3.00 Column: 5.00 Clear on f

Dist	Type	Min	MostLike	Max
IRI	1.00	0.85	0.90	1.25
IRI	2.00	0.80	0.85	1.35
IRI	0.00	0.00	0.00	0.00

Close

Figure 17 Path and distribution property tables

## Data for link object

Each link object obtains its time and distance properties from a global table that is defined within *FlexSim*. The table contains time and distance values between any two locations; it also depends on the mode of transportation used between the locations. The table is populated either manually or from an external source. The external source can be a simple *MSExcel* file or an online provider (e.g. Google Maps).

Part of the project involved investigating means to obtain time and distance information from online services. Internet research identified the following as primary map information service providers: Google Maps, Yahoo! Maps, and MapQuest. Based on online reviews and evaluation of the options, we selected Google Maps and its API. Information for *FlexSim*'s global table is obtained from Google Maps via a *MSExcel* spreadsheet and VBA interface. The interface and example data table are provided in Figure 18.

Origin	Destination	Trip	Distance (km)	Time (hrs)	Timestamp
GTR	NYC	GTR_NYC	1754.14	16.18	10/13/2013
BOS	DFW	BOS_DFW	2871.69	26.15	10/14/2013
CDG	MUC	CDG_MUC	857.77	7.7	10/14/2013
BOS	SAN	BOS_SAN	4905.18	43.71	10/14/2013
NYC	DFW	NYC_DFW	2522.99	22.78	10/14/2013
DFW	NYC	DFW_NYC	2525.72	22.82	10/14/2013
SAN	NYC	SAN_NYC	4448.59	40.57	10/14/2013
GTR	SAN	GTR_SAN	3076.19	26.86	10/14/2013
NYC	GTR	NYC_GTR	1751.79	16.18	10/14/2013
PDX	SAN	PDX_SAN	1767.3	16.34	10/14/2013
DFW	PDX	DFW_PDX	3276.85	29.89	10/14/2013
NYC	PDX	NYC_PDX	4663.08	41.97	10/23/2013
SAN	DFW	SAN_DFW	2178.85	18.74	10/23/2013
ATL	BOS	ATL_BOS	1751.07	16.44	10/23/2013
MUC	CDG	MUC_CDG	857.7	7.65	10/23/2013

**Figure 18 Interface to obtain data from Google Maps**

In the example in Figure 18, we use airport codes to represent locations. We considered a variety of formats and decided the 3-letter airport is the best option. A full address could be entered and submitted to Google Maps, but it would be easy to get multiple entries for the same location due to different spellings and punctuations. Also, since the tool is meant for high-level analyses the additional granularity offered by a full address is not very important. Another option considered is zip codes but for a worldwide model, postal code formats differ. In order to facilitate locating

an airport code near to a location, we have provided in the VBA tool a list of nearly 5,000 airport codes worldwide.

It was found that it is possible to access Google Maps API directly from within *FlexSim* through application commands. However, imbedding the external link to the web within the path analysis tool would require additional interfaces and checks within the tool. It may also require file parsing to extract the needed information. These additional developments could be considered as part of a future research task that defines the requirements and assesses the benefits of adding that capability.

### **Accounting for variability**

A key concern in assessing the performance of alternative supply paths is the risk of not receiving goods when expected. Oftentimes the issue is the risk of lateness, but receiving goods too early can also be a concern since there may not be temporary storage space or there is increased risk of damage. Therefore, to assess risk, variability must be introduced into the models and analyses. This is done by specifying probability distributions for process times, transportation times, etc. This is a basic component of any simulation model – specification of the applicable probability distributions.

One common problem in any simulation modeling activity is decide the appropriate distribution and accompanying parameters to use. If data are available, say on individual process times, then the data are statistically fit or compared to theoretical distributions and the “best” distribution is selected. There is much literature on how make these decisions and discussion of those is beyond the scope of this project. However, in many cases, detailed data are not available or collecting the data are too time consuming or costly. In that case, general families of distributions are used along with engineering judgment.

The most common family of distributions used in simulation projects to represent probabilistic processes, in the absence of data, is the triangular. The distribution is popular since it can take on a variety of shapes and requires three easy-to-estimate location parameters – minimum, maximum, and most likely values. As part of this research a means was provided to incorporate the first three moments of the distribution into the estimation process. With our approach the distribution can be specified with any combination of the three location parameters and three moments. We also provide a methodology to use a percentile estimate rather than an extreme-point estimate; e.g. a domain expert may feel more comfortable providing a 95th percentile value

than the absolute maximum value. These contributions enable simulation modelers to more effectively use the already popular triangular distribution to represent system characteristics.

The approach is especially useful when trying to understand the effects on system performance of shifts in location or variability in some of the random variables in the system. For example, to find the effect of changes in variability of a process on cycle time it is desirable to keep the mean and level of skewness constant while only changing the level of variability from scenario to scenario. In this case, the standard triangular information or location parameters are not especially useful. The problem needs to be framed in terms of the three moments of the distribution and not the three location parameters. Of course, the distribution eventually needs to be specified in terms of the three location parameters so it can be incorporated into a simulation model and be executed using simulation software. The approach provides the means to do this.

The full methodology is explained in (Jannat & Greenwood, 2014), along with illustrative examples. A summary is provided here.

The three moments of the triangular distribution – mean  $\mu$ , standard deviation  $\sigma$ , and skewness  $S_k$  -- in terms of the location parameters ( $a$  = minimum,  $b$  = maximum,  $m$  = most likely) are:

$$\mu = \frac{(a + b + m)}{3}$$

$$\sigma = \frac{(a^2 + b^2 + m^2 - ab - am - bm)}{18}$$

$$S_k = \frac{\sqrt{2}(a + b - 2m)(2a - b - m)(a - 2b + m)}{5(a^2 + b^2 + m^2 - ab - am - bm)^{3/2}}$$

Once three of the six location and moment parameters values are specified, the three equations above are solved simultaneously for the desired value of the three remaining variables. Of course, the solution of these simultaneous nonlinear equations is not trivial, but can be obtained through the use of such commercial software as Wolfram's *Mathematica* 8.0. So that modelers do not have to solve these equations each time they want to use the triangular distribution with non-standard information, we provide a standardized table, analogous to the standard normal table, to facilitate the estimation of the required parameters.

The standardized table is presented as Table 1. It provides values for location parameters  $a$ ,  $b$ , and  $m$  in terms of a standardized mean, i.e.  $\mu = 1$ , and varying levels of variability and skewness. The row values in the table are for the coefficient of variation,  $C_v = \sigma/\mu$ , which varies from 0.1 to 1.5. The column values in the table are for levels of skewness,  $S_k$ , which

varies from -0.5656 (the minimum skewness possible in a triangular distribution) to 0.5656 (the maximum skewness possible in a triangular distribution). The tables are available in MSExcel format at <https://sites.google.com/site/jannatgreenwood/reearch/triangular-parameters-table>.

**Table 1 Standard values for the minimum (*a*), maximum (*b*) and most likely (*m*) when  $\mu = 1$**

Triangular parameter value, minimum ( <i>a</i> )													
$C_v \backslash S_k$	-0.5656	-0.5	-0.4	-0.3	-0.2	-0.1	0	0.1	0.2	0.3	0.4	0.5	0.5656
0.1	0.7172	0.7209	0.7268	0.7331	0.7398	0.7471	0.7551	0.7639	0.7738	0.7855	0.8000	0.8209	0.8572
0.2	0.4343	0.4417	0.4536	0.4662	0.4797	0.4942	0.5101	0.5277	0.5476	0.5710	0.6000	0.6417	0.7143
0.3	0.1515	0.1626	0.1804	0.1993	0.2195	0.2413	0.2652	0.2916	0.3215	0.3565	0.4000	0.4626	0.5715
0.4	-0.1314	-0.1165	-0.0928	-0.0676	-0.0407	-0.0116	0.0202	0.0554	0.0953	0.1420	0.2000	0.2835	0.4286
0.5	-0.4142	-0.3956	-0.3660	-0.3345	-0.3008	-0.2645	-0.2248	-0.1807	-0.1309	-0.0726	0.0000	0.1044	0.2858
0.6	-0.6970	-0.6748	-0.6392	-0.6014	-0.5610	-0.5174	-0.4697	-0.4169	-0.3571	-0.2871	-0.2000	-0.0748	0.1430
0.7	-0.9799	-0.9539	-0.9124	-0.8684	-0.8212	-0.7702	-0.7146	-0.6530	-0.5833	-0.5016	-0.4000	-0.2539	0.0001
0.8	-1.2627	-1.2330	-1.1856	-1.1353	-1.0813	-1.0231	-0.9596	-0.8892	-0.8094	-0.7161	-0.6000	-0.4330	-0.1427
0.9	-1.5455	-1.5122	-1.4589	-1.4022	-1.3415	-1.2760	-1.2045	-1.1253	-1.0356	-0.9306	-0.8000	-0.6122	-0.2855
1	-1.8284	-1.7913	-1.7321	-1.6691	-1.6017	-1.5289	-1.4495	-1.3615	-1.2618	-1.1451	-1.0000	-0.7913	-0.4284
1.25	-2.5355	-2.4891	-2.4151	-2.3364	-2.2521	-2.1612	-2.0619	-1.9518	-1.8272	-1.6814	-1.5000	-1.2391	-0.7855
1.5	-3.2426	-3.1869	-3.0981	-3.0036	-2.9025	-2.7934	-2.6742	-2.5422	-2.3927	-2.2177	-2.0000	-1.6869	-1.1426

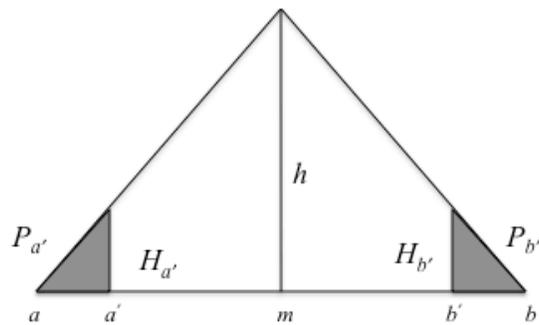
  

Triangular parameter value, maximum ( <i>b</i> )													
$C_v \backslash S_k$	-0.5656	-0.5	-0.4	-0.3	-0.2	-0.1	0	0.1	0.2	0.3	0.4	0.5	0.5656
0.1	1.1428	1.1791	1.2000	1.2145	1.2262	1.2362	1.2450	1.2529	1.2602	1.2669	1.2732	1.2791	1.2828
0.2	1.2857	1.3583	1.4000	1.4290	1.4524	1.4723	1.4899	1.5058	1.5203	1.5338	1.5464	1.5583	1.5657
0.3	1.4285	1.5374	1.6000	1.6435	1.6785	1.7084	1.7349	1.7587	1.7805	1.8007	1.8196	1.8374	1.8485
0.4	1.5714	1.7165	1.8000	1.8580	1.9047	1.9446	1.9798	2.0116	2.0407	2.0676	2.0928	2.1165	2.1314
0.5	1.7142	1.8956	2.0000	2.0726	2.1309	2.1807	2.2247	2.2645	2.3008	2.3345	2.3660	2.3956	2.4142
0.6	1.8570	2.0748	2.2000	2.2871	2.3571	2.4169	2.4697	2.5174	2.5610	2.6015	2.6392	2.6748	2.6970
0.7	1.9999	2.2539	2.4000	2.5016	2.5833	2.6530	2.7146	2.7702	2.8212	2.8684	2.9124	2.9539	2.9799
0.8	2.1427	2.4330	2.6000	2.7161	2.8094	2.8892	2.9596	3.0231	3.0813	3.1353	3.1856	3.2330	3.2627
0.9	2.2855	2.6122	2.8000	2.9306	3.0356	3.1253	3.2045	3.2760	3.3415	3.4022	3.4589	3.5122	3.5455
1	2.4284	2.7913	3.0000	3.1451	3.2618	3.3615	3.4495	3.5289	3.6017	3.6691	3.7321	3.7913	3.8284
1.25	2.7855	3.2391	3.5000	3.6814	3.8273	3.9518	4.0619	4.1612	4.2521	4.3364	4.4151	4.4891	4.5355
1.5	3.1426	3.6869	4.0000	4.2177	4.3927	4.5422	4.6742	4.7934	4.9025	5.0036	5.0981	5.1869	5.2426

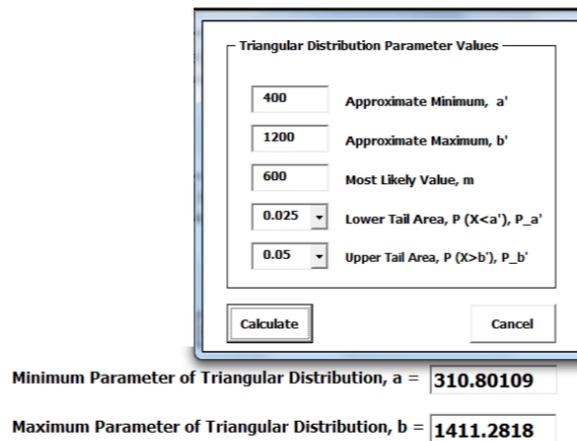
Triangular parameter value, most likely ( <i>m</i> )													
$C_v \backslash S_k$	-0.5656	-0.5	-0.4	-0.3	-0.2	-0.1	0	0.1	0.2	0.3	0.4	0.5	0.5656
0.1	1.1400	1.1000	1.0732	1.0524	1.0340	1.0167	1.0000	0.9833	0.9660	0.9476	0.9268	0.9000	0.8600
0.2	1.2800	1.2000	1.1464	1.1048	1.0680	1.0335	1.0000	0.9665	0.9320	0.8952	0.8536	0.8000	0.7200
0.3	1.4200	1.3000	1.2196	1.1572	1.1020	1.0502	1.0000	0.9498	0.8980	0.8428	0.7804	0.8000	0.5800
0.4	1.5600	1.4000	1.2928	1.2096	1.1360	1.0670	1.0000	0.9330	0.8640	0.7904	0.7072	0.6000	0.4400
0.5	1.7000	1.5000	1.3660	1.2620	1.1699	1.0837	1.0000	0.9163	0.8301	0.7380	0.6340	0.5000	0.3000
0.6	1.8400	1.6000	1.4392	1.3144	1.2039	1.1005	1.0000	0.8995	0.7961	0.6856	0.5608	0.4000	0.1600
0.7	1.9800	1.7000	1.5124	1.3668	1.2379	1.1172	1.0000	0.8828	0.7621	0.6332	0.4876	0.3000	0.0200
0.8	2.1200	1.8000	1.5856	1.4192	1.2719	1.1340	1.0000	0.8660	0.7281	0.5808	0.4144	0.2000	-0.1200
0.9	2.2600	1.9000	1.6589	1.4716	1.3059	1.1507	1.0000	0.8493	0.6941	0.5284	0.3412	0.1000	-0.2600
1	2.4000	2.0000	1.7321	1.5240	1.3399	1.1675	1.0000	0.8326	0.6601	0.4760	0.2679	0.0000	-0.4000
1.25	2.7500	2.2500	1.9151	1.6550	1.4249	1.2093	1.0000	0.7907	0.5752	0.3450	0.0849	-0.2500	-0.7500
1.5	3.1000	2.5000	2.0981	1.7860	1.5098	1.2512	1.0000	0.7488	0.4902	0.2140	-0.0981	-0.5000	-1.1000

Domain experts oftentimes have problems estimating extreme values of a triangular distribution,  $a$  and  $b$ . They may over or underestimate the absolute maximum or minimum value and thus bias the simulation analysis. In many cases, those knowledgeable about the process are more comfortable estimating percentiles, such as the 5th and 95th. For example, they may be able to provide an estimated near-low value,  $a'$ , recognizing that there is a 5% chance of a value falling below that value. The 5% estimate is assumed to imply the  $P(x < a') = 0.05$ . The same is considered at the upper end of the distribution; i.e.,  $b'$  and  $P(x > b')$ . Figure 19 shows the location parameters of the triangular distribution –  $a$ ,  $b$ , and  $m$  – as well as  $a'$ , the estimated near minimum value, and  $b'$ , the estimated near maximum value of the distribution. The tail probability areas are also shown as  $P_{a'} = P(x < a')$  and  $P_{b'} = P(x > b')$ ; i.e., an estimated fraction of the distribution values that lie beyond the estimated near extremes.



**Figure 19 Triangular distribution with extreme tail areas denoted**

So that modelers do not have to solve the non-linear simultaneous equations each time they want to use the triangular distribution, we developed standardized tables, similar to those above, to facilitate the estimation process. However, these tables are much larger. In order to obtain reasonable coverage in our tables,  $P_{a'}$  and  $P_{b'}$  both vary from 0.025 to 0.475 with an increment of 0.025 and  $m$  varies from 0.05 to 0.95 with an increment of 0.05, resulting in 6,859 cells. A simple *Visual Basic* (VB) interface is used to navigate the cells, as shown in Figure 20 – the user enters  $a'$  and  $P_{a'}$ ,  $b'$  and  $P_{b'}$ , and  $m$ ; the system provides  $a$  and  $b$ . The tables and VB interface are available at: <https://sites.google.com/site/jannatgreenwood/research/triangular-excel-tool>.



**Figure 20 MS Excel tool for estimating  $a$  and  $b$  from near-extreme estimates**

As an alternative for using *MS Excel*, we provide two simplified tables, Table 2 and Table 3, that can be used to estimate  $a$  and  $b$  based on commonly used values of  $P_{a'}$ , and  $P_{b'}$ , 0.005, 0.025, 0.050, and 0.100. The tables are standardized in terms of  $a' = 0$ ,  $b' = 1$  and consider  $m$  at three levels - 0.25, 0.50, and 0.75. The row values in each table are for  $P_{a'}$ , varying from 0.005 to 0.1. The column values in each table are for  $P_{b'}$ , also varying from 0.005 to 0.1. The tables provide a standard minimum parameter,  $\hat{a}$  and a standard maximum parameter,  $\hat{b}$ . [1]

**Table 2 Standard values for the distribution minimum (a) when  $a' = 0$  and  $b' = 1$**

$m$	$P_{a'}$ \ $P_{b'}$	0.005	0.025	0.050	0.100
0.25	0.005	-0.04008	-0.04200	-0.04368	-0.04649
	0.025	-0.10141	-0.10678	-0.11150	-0.11950
	0.050	-0.15846	-0.16749	-0.17548	-0.18917
	0.100	-0.26132	-0.27788	-0.29270	-0.31848
0.50	0.005	-0.05556	-0.05775	-0.05968	-0.06295
	0.025	-0.13812	-0.14400	-0.14922	-0.15815
	0.050	-0.21301	-0.22264	-0.23124	-0.24610
	0.100	-0.34489	-0.36199	-0.37743	-0.40451
0.75	0.005	-0.06727	-0.06925	-0.07105	-0.07419
	0.025	-0.16638	-0.17163	-0.17643	-0.18490
	0.050	-0.25559	-0.26410	-0.27196	-0.28596
	0.100	-0.41152	-0.42647	-0.44045	-0.46574

**Table 3 Standard values for the distribution minimum (b) when  $a' = 0$  and  $b' = 1$**

$m$	$P_{a'}$ \ $P_{b'}$	0.005	0.025	0.050	0.100
0.25	0.005	1.06727	1.16639	1.25559	1.41152
	0.025	1.06925	1.17163	1.26410	1.42648
	0.050	1.07104	1.17643	1.27196	1.44045
	0.100	1.07419	1.18490	1.28596	1.46574
0.50	0.005	1.05556	1.13812	1.21301	1.34488
	0.025	1.05775	1.14400	1.22264	1.36198
	0.050	1.05968	1.14922	1.23124	1.37743
	0.100	1.06295	1.15815	1.24610	1.40451
0.75	0.005	1.04008	1.10141	1.15846	1.26132
	0.025	1.04200	1.10678	1.16749	1.27788
	0.050	1.04368	1.11149	1.17548	1.29270
	0.100	1.04649	1.11950	1.18917	1.31848

### Case example

In order to illustrate the use of the tool, it is applied to an actual industry example. The example involves the acquisition of transmission for use in an automotive assembly plant. Information

and data are representative but have been modified so as to not violate non-disclosure agreements and reveal proprietary information.

The case study utilizes the simulation toolset described previously, to evaluate a sourcing decision to determine the best supplier to obtain transmissions from for an automotive assembly plant. Two potential suppliers include one located in Japan and another located in Tennessee. The automotive assembly plant is located in Mississippi. Using the simulation toolset, each supply chain is rapidly developed and evaluated in the *FlexSim* simulation software. Then key performance measure are captured and analyzed.

The supply chain from Japan to Mississippi includes the supplier, the intermodal transportation network and the automotive assembly plant. The transportation network includes roadways, rail and sea transportation and transportation hubs (e.g. ports and rail yards). The Tennessee supply chain is much simpler and only includes the supplier, a roadway and the automotive assembly plant. Data was provided for each piece of these supply networks from the automotive assembly plant, ports, and the internet (specifically distance information for roadways).

The simulation toolset includes components that represent the key components of the supply chains such as the supplier plant, transportation hubs, roadways, rail ways, and sea, and consumer plants. This components were rapidly configured for both scenarios, data was applied, and the simulation analysis was performed at varying levels of risk – low, medium and high. The results show a difference in how the two supply chains impact the automotive assembly plant’s operational performance which leads to a more informed decision concerning sourcing.

## **DISCUSSION OF RESULTS**

Results from the project are discussed in terms of the following: modeling level of detail, modeling toolset, and case study; each topic is described a separate section below.

### **Modeling level**

The project team visited a number of sites (e.g. FlexSteel Products, Nissan North America, Port of New Orleans including rail yard, Port of Mobile including truck terminal) and engaged in discussions with subject-matter experts at the sites to understand the ordering and transportation processes involved in domestic and international supply paths. The transportation hubs that were

visited indicated containers move quickly through their facilities; containers do not remain in inventory in the facilities very long.

### **Simulation modeling toolset**

A main deliverable for this project is a simulation modeling and analysis toolset for assessing supply path options. The tool was effectively developed in a state-of-the-art simulation environment – *FlexSim*.

### **Case study**

The case study revealed that the sourcing problem could be rapidly modeled and analyzed using the simulation toolset. Some future work is still needed to enhance the toolset to make it more flexible and additional cases need to be evaluated to ensure the toolset can handle any special supply chain requirements.

## **CONCLUSIONS**

This project provides a solid foundation for a high-level toolset to analyze alternative supply paths. It demonstrates the feasibility of the approach and utilizes *FlexSim*'s state-of-the-art simulation technology. FlexSim provides a powerful, yet easy to use, development and analysis environment. The open architecture enables full visibility and access to powerful development tools, base simulation model-building objects and simulation engine, C++-like scripting language, GUI (graphical user interface) builder, access to external tools (e.g. MSExcel and MSAccess, web pages, etc.).

## **RECOMMENDATIONS**

Since the project provides a solid foundation for a high-level toolset to analyze alternative supply paths, further development and application is a natural next step. .



## REFERENCES

1. Lambert, D.M., Stock, J.R. and Ellram, L.M. (1998), *Fundamentals of Logistics Management*, McGraw-Hill, New York, NY.
2. Burnson, P. (1999), “Going global offers both pitfalls and rewards”, *Logistics Management and Distribution Report*, Vol. 38 No. 9, p. 92.
3. Saccomano, A. (1999), “Controlling logistics costs”, *Traffic World*, May, p. 20.
4. Johanson, J., & Vahlne, J. E. (1990). The mechanism of internationalization. *International marketing review*, 7(4).
5. Monczka, R. M., & Trent, R. J. (1991). Evolving sourcing strategies for the 1990s. *International Journal of Physical Distribution & Logistics Management*, 21(5), 4-12.
6. Vis, I. F., & de Koster, R. (2003). Transshipment of containers at a container terminal: An overview. *European Journal of operational research*, 147(1), 1-16.
7. Petersen, E. R. (1977). Rail yard modeling: Part I. Prediction of put-through time. *Transportation Science*, 11(1), 37-49.
8. [https://wikileaks.org/syria-files/attach/147/147014\\_STANDARD%20OPERATIONAL%20PROCEDURES%20161208.pdf](https://wikileaks.org/syria-files/attach/147/147014_STANDARD%20OPERATIONAL%20PROCEDURES%20161208.pdf)
9. <http://ngureco.hubpages.com/hub/Maps-and-Directions-Which-Is-Better---Mapquest--Yahoo-Maps--Google-Maps>
10. <http://techcrunch.com/2006/04/17/comparing-the-mapping-services/>
11. [http://www.pewworld.com/article/206702/best\\_online\\_mapping\\_service.html](http://www.pewworld.com/article/206702/best_online_mapping_service.html)
12. [http://news.cnet.com/8301-17939\\_109-10156727-2.html](http://news.cnet.com/8301-17939_109-10156727-2.html)
13. Jannat, S. and Greenwood, A., “Specifying the Triangular Distribution Using Non-standard Parameters, ” *International Journal of Applied Industrial Engineering (IJAIE)* (Under review).
14. Jannat, S and Greenwood, A., “Estimating Parameters of the Triangular Distribution Using Non-Standard Information.” *Proceedings of the 2012 Winter Simulation Conference*.

15. Jannat, S. and Greenwood, A., “Using Simulation Modeling and Analysis to Assess the Effect of Variability and Flexibility on Supply Chain Lead Time.” In *Logistics Operations, Supply Chain Management and Sustainability*, P. Golinska (Ed.) Springer International Publishing, 2014.

## **APPENDIX**

National Center for Intermodal Transportation for Economic Competitiveness

**Simulation Modeling of Domestic and International Intermodal Supply Paths  
Transmission Supply Change Analysis**

**Case Study**

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NCITEC Project No. USDOTDTRT12-G-UTC14

## **Executive Summary**

This case study utilizes a simulation toolset developed as part of a National Center for Intermodal Transportation for Economic Competitiveness project, to evaluate a sourcing decision in order to determine the best supplier for obtaining transmissions from for an automotive assembly plant. Two potential suppliers include one located in Japan and another located in Tennessee. The automotive assembly plant is located in Mississippi. Using the simulation toolset, each supply chain is rapidly developed and evaluated using the *FlexSim* simulation software. Then key performance measure are captured and analyzed.

The supply chain from Japan to Mississippi includes the supplier, the intermodal transportation network and the automotive assembly plant. The transportation network includes roadways, rail and sea transportation and transportation hubs (e.g. ports and rail yards). The Tennessee supply chain is much simpler and only includes the supplier, a roadway and the automotive assembly plant. Data were provided for each part of these supply networks from the automotive assembly plant, ports, and the internet (specifically, distance information for roadways).

To perform the analysis, a simulation model was developed using the simulation toolset. The simulation toolset includes components that represent the key portions of the supply chains, such as the supplier plant, transportation hubs, roadways, railways, sea lanes, and consumer plants. These components were rapidly configured for both scenarios, data were applied, and the simulation analysis was performed considering various levels of risk – low, medium and high. The results show a difference in how the two supply chains impact the automotive assembly plant's operational performance. This leads to a more informed decision concerning sourcing.

As a result, the case study revealed that the sourcing problem can be rapidly modeled and analyzed using the simulation toolset. Some future work is still needed in order to enhance the toolset by making it more flexible. Also, additional cases need to be evaluated in order to ensure the toolset can handle a range of supply chain requirements.

## **Introduction**

The supply of material to a manufacturing facility obviously has a major impact on enterprise performance, whether measured in terms of cost, timeliness, quality, etc. Sourcing decisions involve analyzing which suppliers to use, where to locate suppliers and what intermodal transportation methods to use. These decisions are complex since they involve a large number of factors and considerations, as well as interdependencies between the factors, and considerable variability and uncertainty. This is especially true when considering international sourcing options, but is important in assessing alternative domestic intermodal paths as well.

This case study takes considers a transmission-sourcing problem for a U.S. automaker. A new simulation toolset, developed to enable rapid simulation model development of supply chains, is used to evaluate two sourcing options. The following sections discuss the details of the problem, the approach, the simulation model and results.

## **Background**

The supply of material to a manufacturing facility obviously has a major impact on enterprise performance, whether measured in terms of cost, timeliness, quality, etc. Most material that is input to a manufacturing process is transported to the manufacturing facility via multiple modes of transportation, i.e., it involves intermodal transportation. Since the material must be acquired from outside of the manufacturing site, sourcing decisions have significant impact on overall enterprise performance. Critical elements of those sourcing decisions include specifying from where to acquire the material, in what quantity, etc. It may also involve deciding the modes that should be used to transport the material from the source to the manufacturer. Even if specifying the mode is not part of the decision process, it is a significant driver in terms of cost, reliability, timeliness, etc. These issues pertain to domestic supply, but more importantly to international supply.

The sourcing decision is complex since it involves a large number of factors and considerations, as well as interdependencies between the factors, and considerable variability and uncertainty. This is especially true when considering international sourcing options, but is important in assessing alternative domestic intermodal paths as well.

This case study represents a proof-of-concept scenario for the automotive assembly plant in evaluating a sourcing decision for the supply of automotive transmissions. The current supplier for automotive transmissions to the facility is located in Japan. In this case study, we will compare the current supplier with a domestic supplier in Tennessee.

## Methodology

### 1. Simulation model development toolset

Simulation modeling and analysis is commonly applied to complex problems similar to those in the sourcing decision. Simulation provides a means to perform sophisticated what-if analyses on complex problems, such as assessing alternative intermodal supply paths. A simulation toolset was developed to provide a means to quickly develop simulation models of both domestic and international supply chains. Using the *FlexSim* simulation software as the base, a library of modeling objects was developed to represent key intermodal logistics supply-chain components. These components include links (e.g. roadways, waterways, and rail), transportation hubs (e.g. ports, rail yards, and truck terminals), supplier plants, and consumer plants. The components are configured together to represent intermodal logistic situations. This toolset is used to analyze whether or not the production of automotive transmissions should be relocated from Japan to Tennessee.

### 2. Problem definition

The models developed using the toolset are used to analyze and compare locating an automotive transmission plant in Japan or Tennessee. The period of performance for the analysis is two years. The comparison is performed assuming three levels of risk – low, medium and high. Risk represents variation in various aspects of the supply chain such as travel times and supplier lead times. Low risk is defined as being between -5% and +5% variation in time; medium risk is between -5% and +15%; and, high risk is between -5% and 30%.

Due to the variation, the simulation models are run multiple times for each scenario and the performance measures are the means of multiple runs/replications. A trial run of the model for the high-risk scenario is used to determine the number of replications required to obtain the desired level of precision in the performance measures.

The performance measures of interest are average time in the system, jobs completed per day, and consumer plant's incoming queue capacity. Average time in system measures the time from when an order is placed until the corresponding finished good is complete. Jobs per day is a measure of throughput – it is used to ensure the supply chain is meeting the desired rate to support the automotive facility. Consumer incoming queue capacity is a measure of whether the facility must have additional space to absorb the fluctuations caused by ordering constraints and intermodal delays.

### 3. Input data

In order to evaluate the possibility of moving transmission production from Japan to Tennessee, Table 4 provides the lead times and order constraints for each supplier. The data includes how long it takes to deliver transmissions under current conditions such as time at supplier’s facility, time at sea, time at transportation hubs (e.g. Port of Los Angeles, Rail Yard in Memphis, TN).

**Table 4: Supplier Data**

<b>Scenario</b>	<b>A</b>	<b>B</b>
<b>Supplier Location</b>	Japan	Tennessee
<b>Transmissions/Container</b>	96	96
<b>Supplier Lead Time (days)</b>	35	35
<b>Minimum Order Quantity (containers)</b>	4	1

Table 5 provides the data regarding intermodal logistics, including time in motion e.g., at sea, on rail and in truck) and times required for processing containers at transportation hubs (e.g. ports and rail yards).

**Table 5: Intermodal Data**

<b>Scenario</b>	<b>A</b>	<b>B</b>
<b>Time at port (Japan) (days)</b>	2	N/A
<b>Time at sea (days)</b>	9	N/A
<b>Time at port (Los Angeles, CA) (days)</b>	2	N/A
<b>Time on rail (days)</b>	10	N/A
<b>Time at rail yard (Memphis, TN) (days)</b>	3	N/A
<b>Time on truck (days)</b>	0.208	0.417

Table 6 provides the consumer-specific data for the facility being analyzed. This includes demand rate, time for processing, and transmission storage capacity.

**Table 6: Consumer Data**

<b>Scenario</b>	<b>A</b>	<b>B</b>
<b>Transmissions/Vehicle</b>	1	1
<b>Demand Rate (vehicles/hour)</b>	31	31
<b>Time from unit start to transmission install (hrs)</b>	10	10
<b>Install Time (min)</b>	1.935	1.935
<b>Time from install complete to finished good (hrs)</b>	4	4

All of this data are incorporated into the simulation model and are used for analysis.

#### 4. Simulation

An overall view of the simulation model for Scenario A is shown in Figure 21. The simulation model starts with an order being generated for the supplier in Japan. Orders consist of multiple containers. The minimum order quantity is defined by the supplier. Each order is processed through the supplier and a container load of transmissions is placed on a truck. Once the container is on a truck, it is transported to a port in Japan via a road-link object. At the port, the container is processed and loaded onto a ship. The ship travels to the port in Los Angeles, via a sea-link object, where it is unloaded. The container is processed and then placed onto a train with other containers. The train delivers the loaded containers to the transportation hub in Tennessee. The containers are offloaded and individually leave via truck to the consumer plant. The container is unloaded and the transmissions make their way through the plant. Throughout the process performance metrics such as time in system and throughput are captured.



**Figure 21: Scenario A Simulation**

The simulation model for Scenario B is composed of much fewer objects than Scenario A, due to its simplified, shorter route. A 3D view of the simulation model for Scenario B is shown in Figure 22. Orders are received by the supplier, processed and loaded into containers. The containers are loaded onto trucks and are transported to the consumer. Once at the plant, the container is unloaded, transmissions are removed from the containers, and consumed in the plant.



**Figure 22: Scenario B Simulation**

## Outcomes

### 1. Model Replications

With any analysis that considers variability, the number of replications to run,  $n$ , must be determined using the following equation:

$$n = \left[ \frac{z_{\alpha/2} * \sigma}{E} \right]^2$$

Since a 95% confidence level was assumed,  $z_{\alpha/2} = 1.96$ . A margin of error,  $E$ , of 60 minutes was used. A trial simulation with 5 replications was run to determine the standard deviation ( $\sigma$ ) of the Average Lead Time performance measure for the high-risk scenario. The standard deviation of these replications was 92.08 minutes.

$$n = \left[ \frac{1.96 * 92.08}{60} \right]^2$$

$$n = 9.05$$

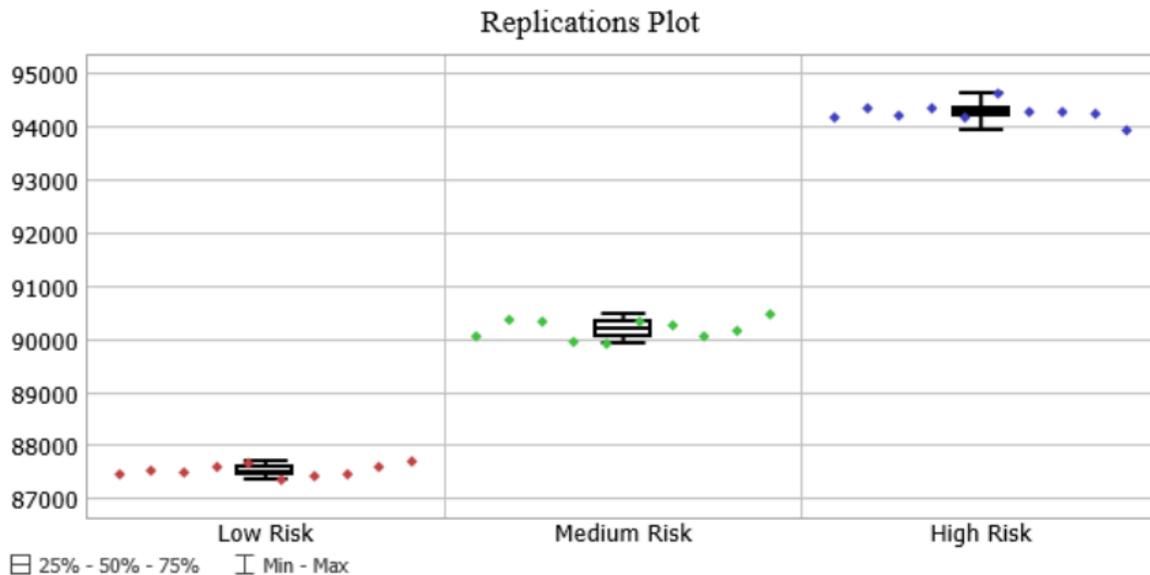
Therefore, the minimum number of replications to be run is 10.

## 2. Model results

### a. Scenario A results:

The average time in system is a measure of the amount of time from when an order is placed until the corresponding finished good is complete. The average time in system for Scenario A under varying risk conditions is provided in Figure 23.

Summary						
	Mean (90% Confidence)			Sample Standard Deviation	Min	Max
Low Risk	87464.69	< 87529.36	< 87594.02	111.57	87358.96	87706.65
Medium Risk	90079.68	< 90188.73	< 90297.77	188.12	89917.51	90460.42
High Risk	94166.93	< 94269.86	< 94372.78	177.56	93924.8	94628.06

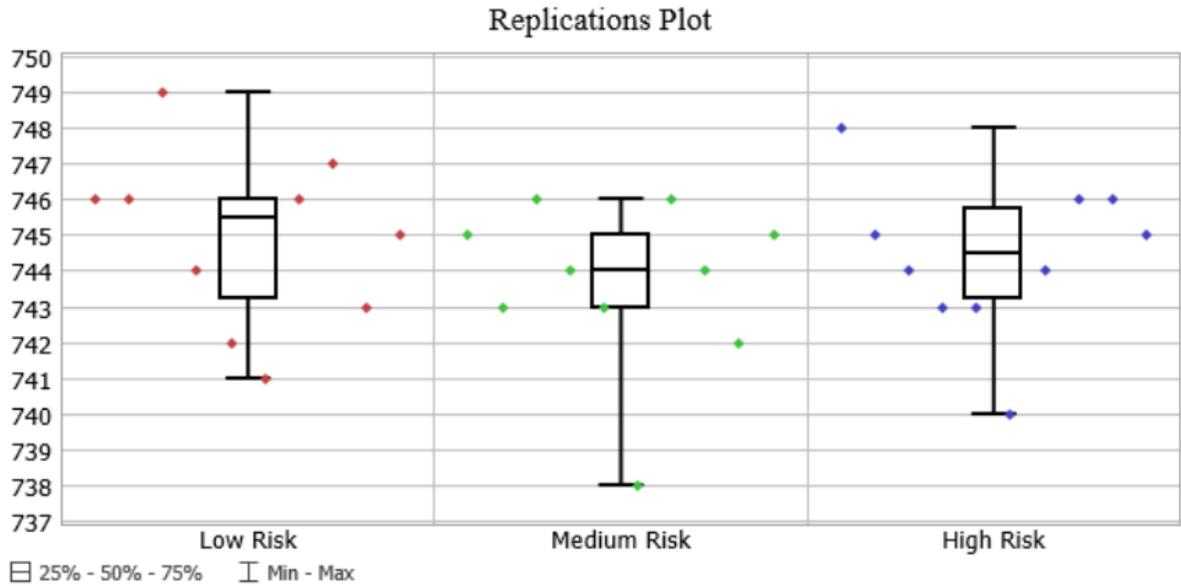


**Figure 23: Average Time in System – Scenario A**

The data shows that the average time in system increases appreciably as the risk level increases.

The jobs per day performance measure is used to determine if the supply chain is providing sufficient throughput to support the consumer. The jobs per day for Scenario A is provided in Figure 24. It shows that the levels of risk do not have a significant effect on the overall throughput. At each risk level, the jobs per day met the requirement.

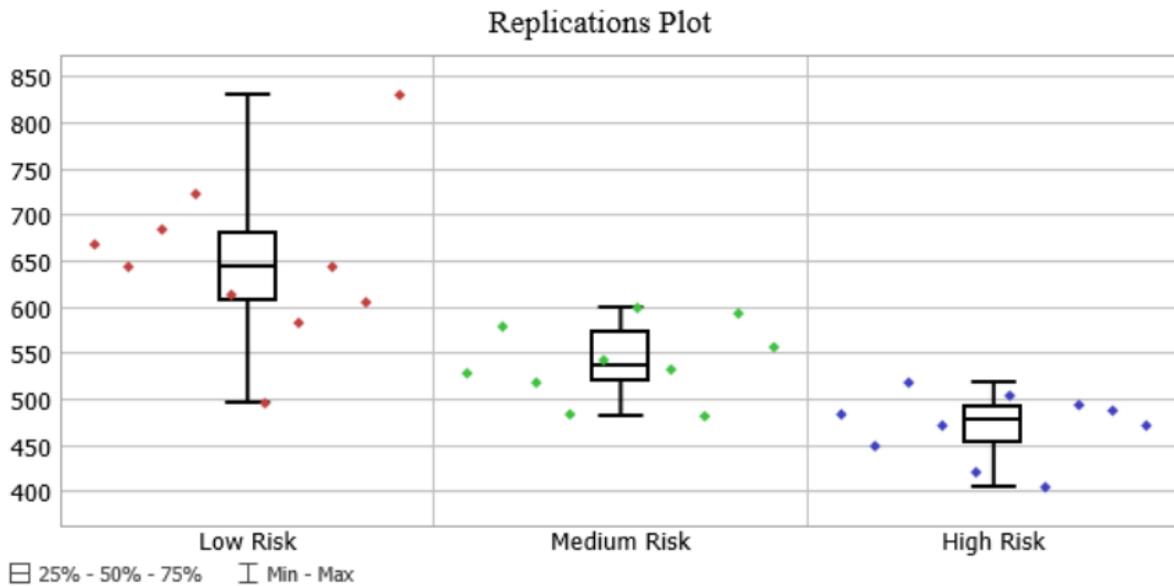
Summary						
	Mean (90% Confidence)			Sample Standard Deviation	Min	Max
Low Risk	743.49	< 744.9	< 746.31	2.42	741	749
Medium Risk	742.23	< 743.6	< 744.97	2.37	738	746
High Risk	743.14	< 744.4	< 745.66	2.17	740	748



**Figure 24: Jobs Per Day – Scenario A**

Consumer incoming queue capacity is a measure of whether the facility must have additional space to absorb fluctuations caused by ordering constraints and intermodal delays. The consumer incoming queue capacity data for Scenario A is provided in Figure 25.

Summary						
	Mean (90% Confidence)			Sample Standard Deviation	Min	Max
<b>Low Risk</b>	597.86	< 649.33	< 700.79	88.78	496.47	830.65
<b>Medium Risk</b>	517.42	< 541.35	< 565.28	41.29	480.78	598.63
<b>High Risk</b>	449.24	< 470.09	< 490.95	35.98	404.33	518.55



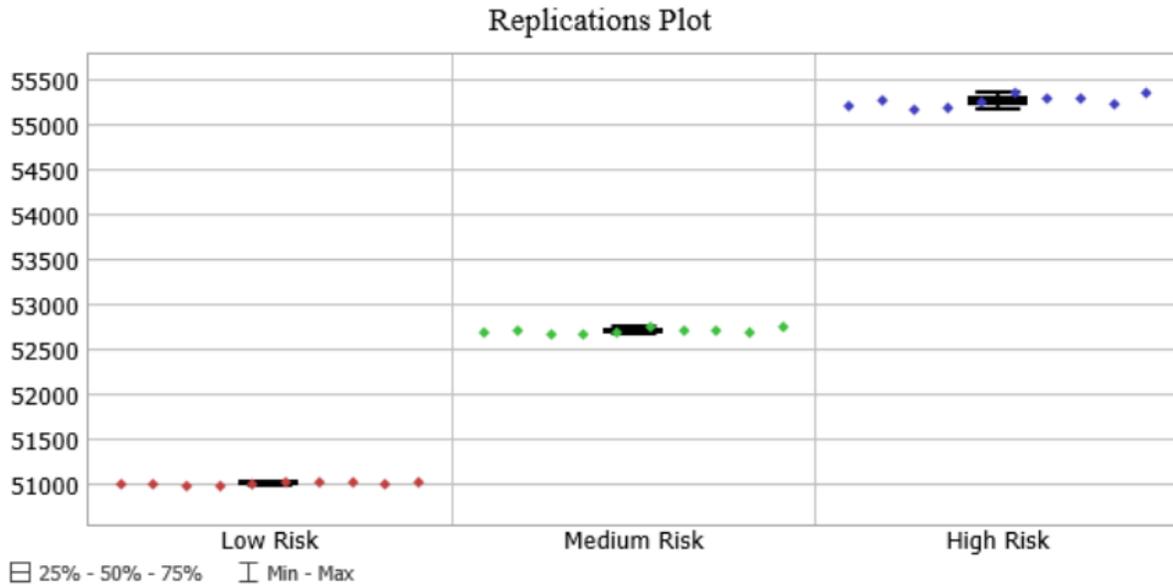
**Figure 25: Consumer Incoming Queue Capacity – Scenario A**

As the risk level increases, the contents of the consumer incoming queue decreases. This is due to the increased variation in the model. The longer it takes for containers to get to the consumer plant, the more the plant uses up the products it has in its queue resulting in lower average contents.

b. Scenario B results:

The same performance measures used in scenario A were used to analyze scenario B. As the level of risk increases in scenario B, the average time in system increases. This is an artifact of the increased variability in the system. It takes longer for orders to be fulfilled and reach the consumer plant. The average time in system for Scenario B is provided in Figure 26.

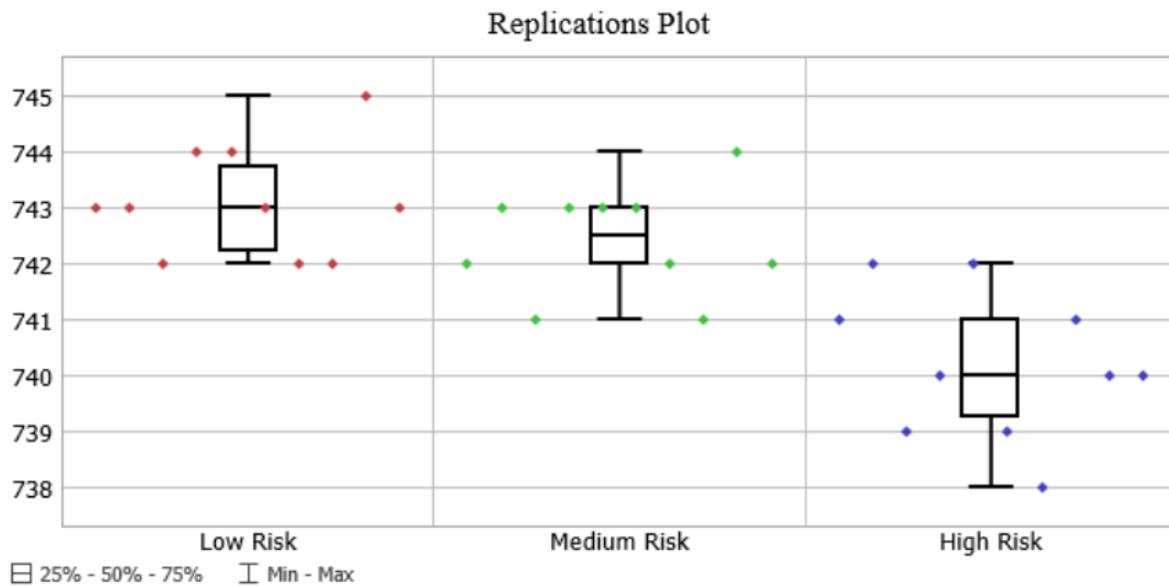
Summary						
	Mean (90% Confidence)			Sample Standard Deviation	Min	Max
Low Risk	50995.74	< 51005.01	< 51014.28	15.99	50981.49	51027.82
Medium Risk	52684.83	< 52703.94	< 52723.06	32.98	52658.31	52755.62
High Risk	55219.58	< 55255.69	< 55291.8	62.29	55167.14	55352.73



**Figure 26: Average Time In System – Scenario B**

The jobs per day for Scenario B are shown in Figure 27. At low and medium risk levels, the jobs per day remains at the desired level. As the risk level is increased to high, it significantly drops in response to the increased variation in the system.

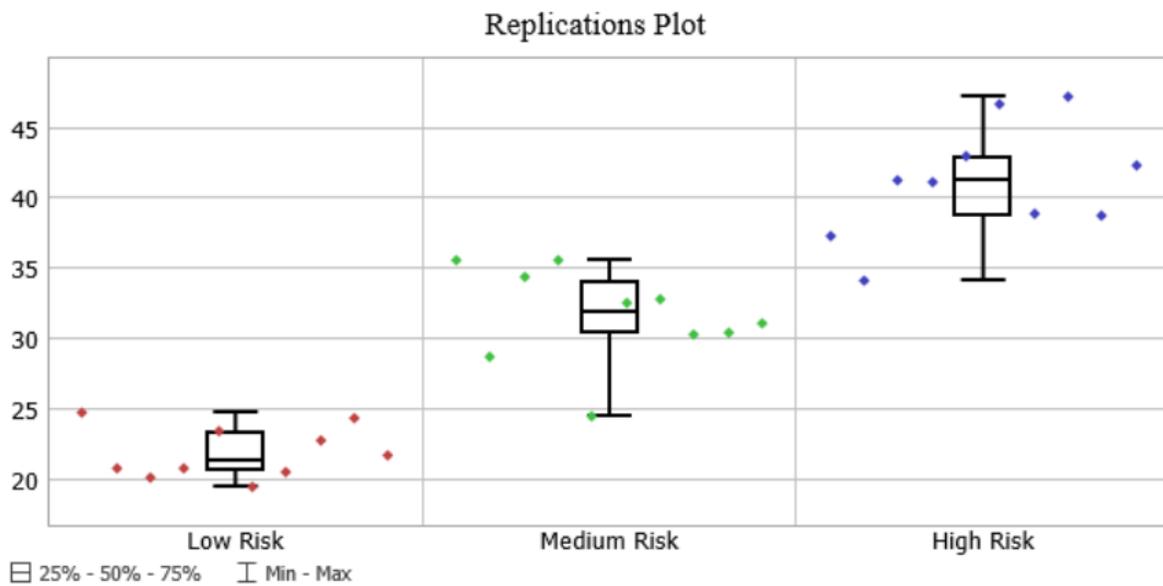
Summary						
	Mean (90% Confidence)			Sample Standard Deviation	Min	Max
Low Risk	742.52	< 743.1	< 743.68	0.99	742	745
Medium Risk	741.84	< 742.4	< 742.96	0.97	741	744
High Risk	739.44	< 740.2	< 740.96	1.32	738	742



**Figure 27: Jobs Per Day – Scenario B**

The consumer incoming queue capacity for Scenario B are shown in Figure 28. At the high-risk level, the capacity is nearly double the value at the low risk capacity. The increased variation in the less complex system causes this increase.

Summary						
	Mean (90% Confidence)			Sample Standard Deviation	Min	Max
<b>Low Risk</b>	20.79	< 21.87	< 22.94	1.85	19.44	24.72
<b>Medium Risk</b>	29.6	< 31.57	< 33.55	3.41	24.47	35.6
<b>High Risk</b>	38.69	< 41.04	< 43.38	4.05	34.05	47.2



**Figure 28: Consumer Incoming Queue Capacity – Scenario B**

c. Scenario Comparisons

As the risk level increases in both scenario A and B, the average time in system increases as well. This is expected and due to the increased variation of travel times through the system. Both scenarios follow the same trends. The average time in system for Scenario A is much greater than that of Scenario B at all risk levels because of the increased complexity of the system. The jobs per day metrics is equal for both scenarios meaning that both supply chains are capable of meeting the consumers demand. The consumer incoming queue capacity is much less for scenario B compared to A due to the reduced order size requirement of the different suppliers. A side-by-side comparison of the performance measures for both scenarios at all risk levels is provided in Figure 29, Figure 30, and Figure 31 respectively.

<b>Low Risk</b>	<b>A</b>	<b>B</b>
<b>Average Time In System (minutes)</b>	87529.4	51005.0
<b>Jobs Per Day</b>	744.9	743.1
<b>Consumer Incoming Queue Capacity</b>	649.3	21.9

**Figure 29: Scenario Comparison - Low Risk**

<b>Medium Risk</b>	<b>A</b>	<b>B</b>
<b>Average Time In System (minutes)</b>	90188.7	52703.9
<b>Jobs Per Day</b>	743.6	742.4
<b>Consumer Incoming Queue Capacity</b>	541.4	31.6

**Figure 30: Scenario Comparison - Medium Risk**

<b>High Risk</b>	<b>A</b>	<b>B</b>
<b>Average Time In System (minutes)</b>	94269.9	55255.7
<b>Jobs Per Day</b>	744.4	740.2
<b>Consumer Incoming Queue Capacity</b>	470.1	41.0

**Figure 31: Scenario Comparison - High Risk**

## Conclusions

This case study provides the foundation for analyzing and comparing intermodal transportation alternatives via a simulation toolset. The toolset enables rapid model creation and analysis. The components in the toolset accommodate a variety of options for modeling systems of varying complexity levels. Cost attributes are established in the toolset, but due to the limitations of data available for the case study, a cost analysis was not performed. This analysis would provide a means of comparing the costs of the two alternative supply chains. In addition, the lack of rework/scrap data for the consumer plant limited the analysis of impacts on the system. Although the order quantity size, the demand, and the period of performance were provided, additional analysis of these factors would enhance the sourcing decisions. Examples of analyses include the effects of:

- order quantity size
- demand levels and/or patterns (determine whether suppliers or intermodal network options can meet a company's demand)
- ramp up conditions for new products.

The case study also demonstrated that the sourcing problem could be rapidly modeled and analyzed using the simulation toolset. Some future work is still needed to enhance the toolset to make it more flexible and be able to handle a variety of cases.