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MODELING AND ANALYSIS OF INTERMODAL SUPPLY PATHS TO ENHANCE SOURCING DECISIONS

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ABSTRACT

Since most material that is input to a manufacturing process is transported via multiple modes of transportation, oftentimes over long distance, the sourcing decision has a major impact on enterprise performance, in terms of cost, timeliness, quality, etc. Critical elements of those decisions include specifying from where to acquire the material, in what quantity, the modes that should be used, etc.

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 paper describes a simulation-based toolset that was developed to assess the expected performance of alternative intermodal supply paths. The toolset provides a means to quickly develop simulation models of both domestic and international supply paths.

1 INTRODUCTION

Organizations select materials from a variety of possible suppliers, both domestic and international, and use multiple modes of transportation, e.g. rail, truck, and ocean carrier, to obtain the material. Alternative intermodal transportation paths between suppliers and the end user 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 they drive manufacturing and product performance. 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." Critical elements of sourcing decisions include specifying from where to acquire the material and in what quantity; and, it may involve deciding the modes to use to get the material from the supplier to the manufacturer

In order to obtain and maintain competitive advantage, U.S. firms receive raw materials and components from all over the world. For example, products may be developed in Europe and the U.S., 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, such as truck, railroad or ocean carrier. The transfer across multiple modes is referred to as intermodal. For example, items shipped in containers by ocean carrier must be transferred to rail or truck usually several times.

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) model the activities in a Japanese container terminal in order to analyze bottlenecks and improve performance. The approach described in this paper represents such elements at a much higher level. Of course, detailed models provide a good means for abstracting to a higher level and identifying key performance drivers. These detailed models are complementary, not contradictory, to the approach described in this paper.

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. This paper builds upon their work and extends the capabilities of their models in several important ways. We develop general objects that represent key intermodal supply chain transportation elements which can be applied to any industry. Our object-oriented architecture and designed data and user interfaces enable supply-chain simulation models to be constructed very rapidly. This simulation-based toolset directly supports sourcing decisions by providing a means to analyze and assess the expected performance (e.g. lead time, variation in lead time) of alternative domestic and international intermodal supply paths.

The toolset provides a library of generalized intermodal transportation-related objects that can quickly be configured to represent specific intermodal routes or paths. That is, simulation models are constructed through the assembly of standard components that represent and simulate common transportation elements in a supply chain. The intermodal transportation *paths* between supplier and end-user are composed of a series of intermodal *nodes* (e.g. container port, rail yard) and *links* (e.g., roadways, rail lines, shipping lanes). The nodes and links are simulation modeling objects that contain basic operational logic and data values for properties that represent its operation and performance. Once the objects are assembled into paths, they can be simulated and used to assess lead times, lead time distributions, costs, risks, etc.

Terzi and Cavaleri (2004) survey the use of simulation in supply chains focusing on papers that are industrial case studies or simulation software specifically designed for supply chain analyses. Based on their classification scheme, this paper would best fit the broader category of processes and include supply chain planning, inventory planning, distribution and transportation planning, and production planning. The toolset described in this paper appears to provide a unique capability for analyzing supply chains. It provides a quick means to build high-level simulation models of alternative supply paths in order to assess overall system performance and risk.

In intermodal global supply chains the basic unit of transport is the container. Several transportation modes are used to transport containers from one destination to another – ships, trucks, and trains/rail. Containers are transferred from one mode of transportation to another at ports and terminals. For example, a container terminal at a port transfers containers between ships and rail or truck. Since the capacities of ships have increased dramatically, intermodal facilities have become very efficient in processing containers, aided by sophisticated information technology and automated control technology.

This paper is organized as follows. Section 2 describes the basic architecture for the simulation-based decision-support toolset. Section 3 demonstrates the use of the toolset via an illustrative example from the automotive industry. Section 4 provides conclusions and areas for future research.

2 SYSTEM DESIGN AND ARCHITECTURE

In order for the toolset to be able to perform quick tradeoffs between alternative supplier locations and transportation means, obtaining detailed process information is usually not feasible. Simplifying the data requirements and internal logic of the objects simplifies development and use. However, data specifications for the toolset enable detailed simulation models of logistics nodes (factory, port, etc.) to be used if desired.

Another design issue is the degree of commonality among various components in a logistics system. Again, to simplify development and use, it was found that ports, rail yards, and truck terminals can be represented as one general object, which we refer to as a transportation hub. Similarly, supplier and end-user manufacturing facilities can be represented as one common object, generally referred to as a factory. Finally, the means of transport – road, rail, and sea – can be logically be represented as one common object and differentiated by property values. Each of these basic object types are described below.

For simplicity of specifying probability distributions, we assume all random variables are triangularly distributed so that the user need only to provide its three location parameters. Of course, the system is flexible and open so that any distributions could be used.

The toolset is developed using *FlexSim* simulation software and leverages its rich and open object set, hierarchical object-oriented architecture, ability to create custom user interfaces, and effective links to other software

2.1 Overall System

An intermodal supply path is composed of a series of intermodal nodes (e.g. factories, ports, and rail yards) connected by links (e.g. railways and roadways). An example supply path is shown in Figure 1; it represents the transport of an order from a supplier to an end user via rail, ship, and truck links. In this case, a fulfilled order initially travels by rail from the supplier to a rail yard. From there, it is transferred to a truck for travel on a roadway, transferred to a ship at a port where it travels by sea to another port, and transferred to a truck for road travel until it reaches the end-user factory.

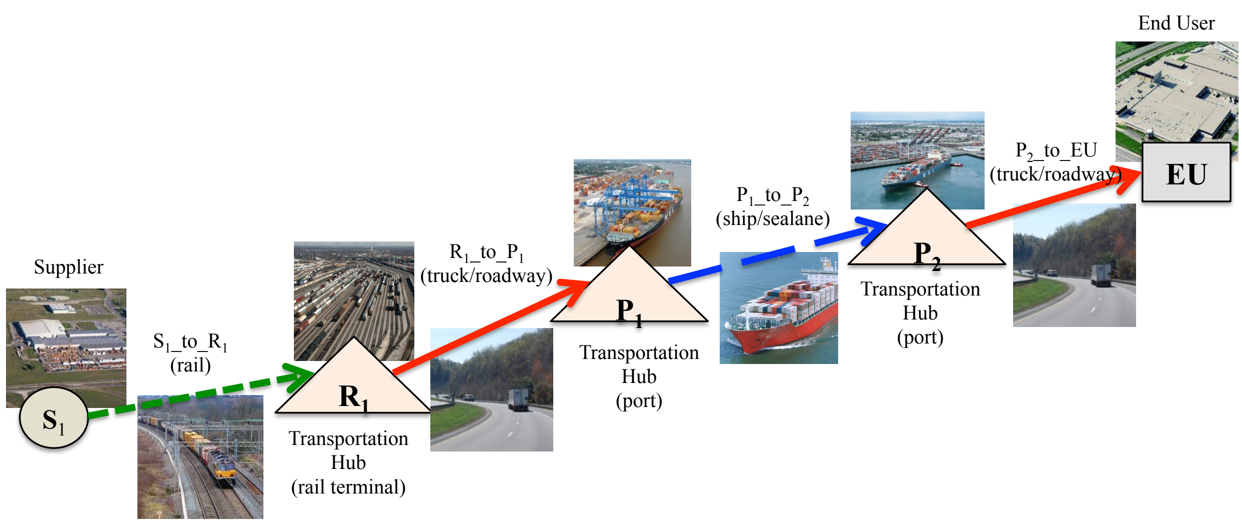

Figure 1: Basic elements (nodes and links) define high-level intermodal supply path.

A supplier is defined as the provider of a material that is needed by an end user, the factory that consumes the input. Suppliers and end users are both manufacturing facilities; therefore, there is a lot of operational commonality between them. However, we decided to consider them as separate objects. As explained below, end users are more complex versions of supplier objects since they are the focus of the analyses; i.e., simulation is used to measure their performance using alternative supply paths.

2.2 End-User Factory Object

Figure 2 provides the underlying logic of the end-user factory object. The object is very similar to a general factory object; the greyed-out areas indicate sections that do not pertain to the end-user object. The functionality of the object includes:

- For each key production step, materials for production are transferred either to a staging area for the production line or to a rework process. Percentage of rework is an input in the end-user factory graphical user interface (GUI). Rework represents incoming materials that are damaged, out of specification, or the wrong product. If a material can be repaired, it is delayed based on a rework time and then sent on to the production line; otherwise, it is scrapped.
- The materials needed for each key production step are combined in the specified quantities.
- Each final product is sent to a finished goods queue where it waits until the specified container batch size is satisfied.
- A container of products is transported when it is full and when a truck is available.

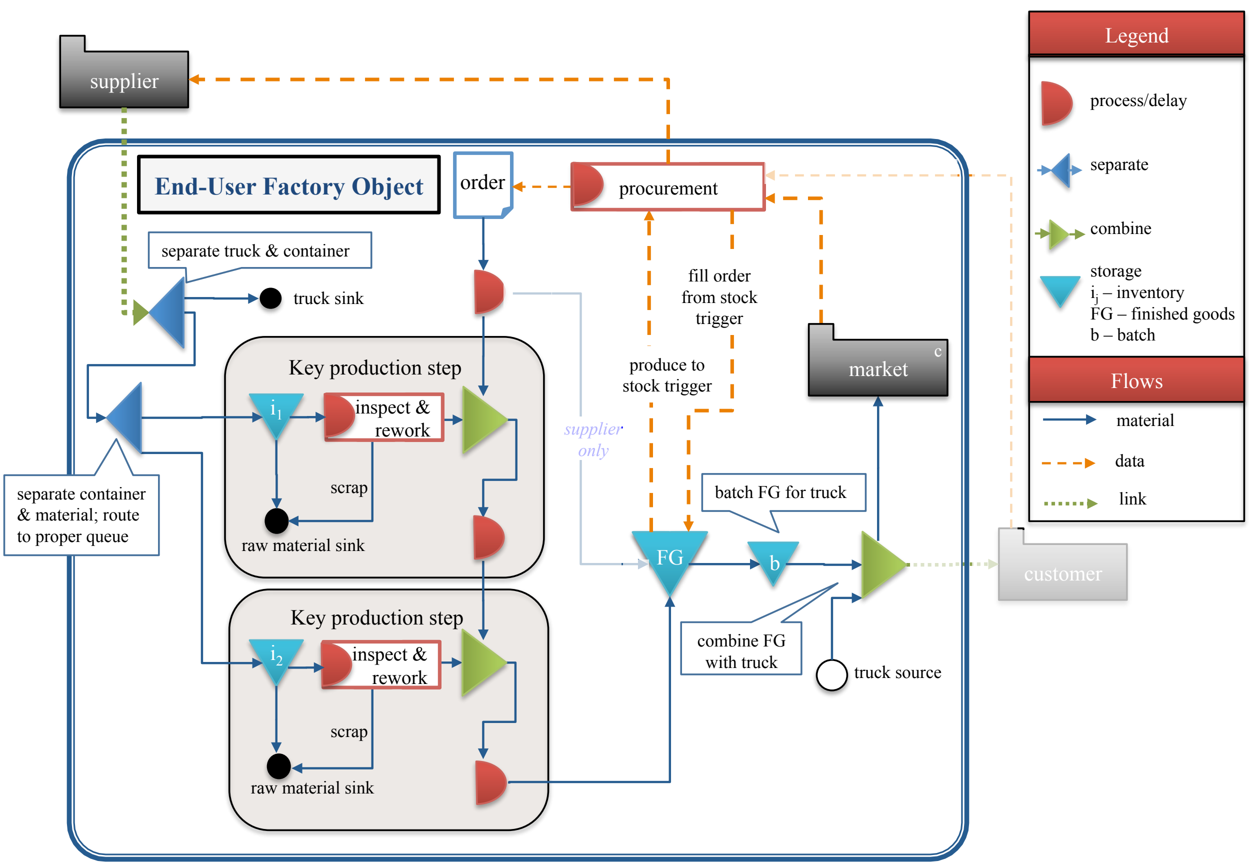

Figure 2: Underlying logic of the end-user factory object.

As shown in Figure 2, the end-user factory object is driven by a virtual market. Market orders are sent to a single production line on a make-to-order basis and the order frequency, average sales per day, is provided via an end-user object GUI. Orders to suppliers are placed as needed.

The production line processes orders as long as it has the needed materials. Once a market order is generated, the procurement function determines if additional supplies are needed to fulfill the new order. The calculation is based on the amount of material currently on hand in the end-user factory, in transit from a supplier, and being produced at a supplier's factory.

Supplies are received via transport into the factory object where container loads are separated into the basic unit of material that is used for production and is then routed to the appropriate production input queue to await use.

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 3. Each production input queue and corresponding processing task are considered a building block. For example, t_2 in the sample timeline is the time to produce a product between where the first two critical materials are needed. The number of blocks depends on how many processes are being analyzed in the end-user factory and can be combined to represent a complex production system. Process times are based on information provided via the end-user GUI.

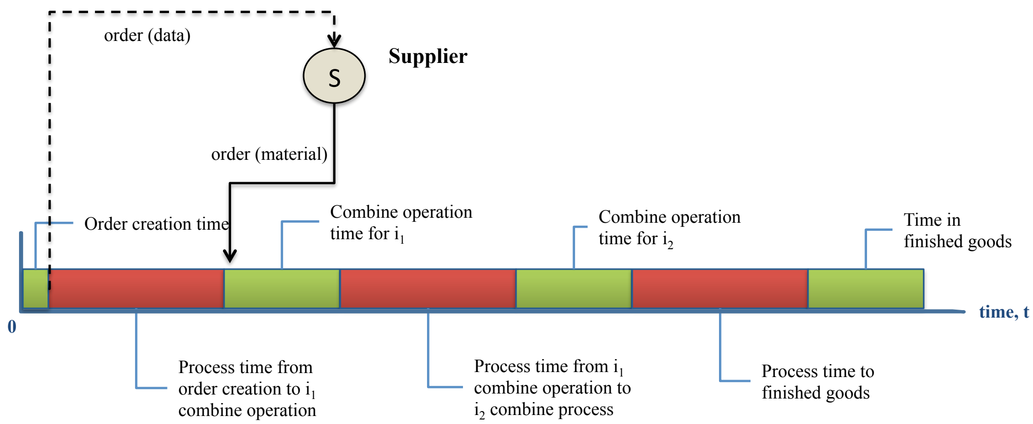

Figure 3: Example production timeline for an end-user factory object.

Each of the objects have their own custom GUI to facilitate data entry. An example GUI, a portion of one used for the end-user factory object, is shown in Figure 4.

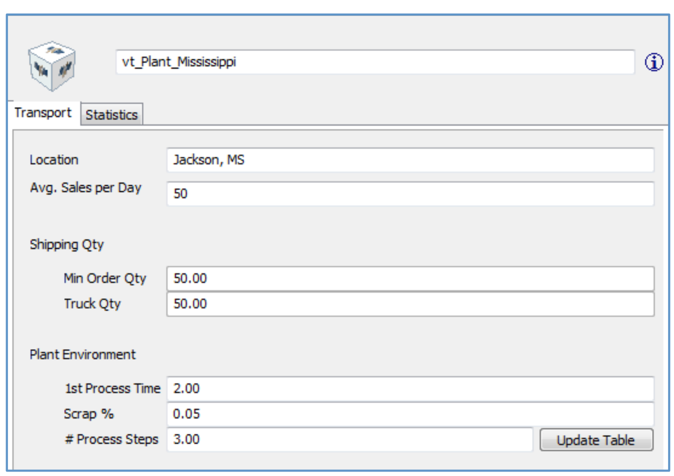

Figure 4: Example of a graphical user interface (GUI) in the toolset, in this case for an end-user factory object.

2.3 Supplier-Factory Object

Figure 5 provides the underlying logic of the supplier-factory object. The object is a subset of a general factory object, but is much simpler. The greyed-out areas indicate sections of a general factory object that do not pertain to the supplier object. It is driven by its customer - the end-user factory object. It receives orders and creates the number of items required to fill the end user's order quantity (a system input). Order lead time is the product's cycle time multiplied by the minimum order quantity. Once the items are processed, they are combined with other items, based on the container capacity and are combined with a truck for transport.

The supplier-plant object contains a GUI that allows users to set and view important attributes of a supplier, such as: supplier location, minimum order quantity, and product lead time (process time per part at the supplier).

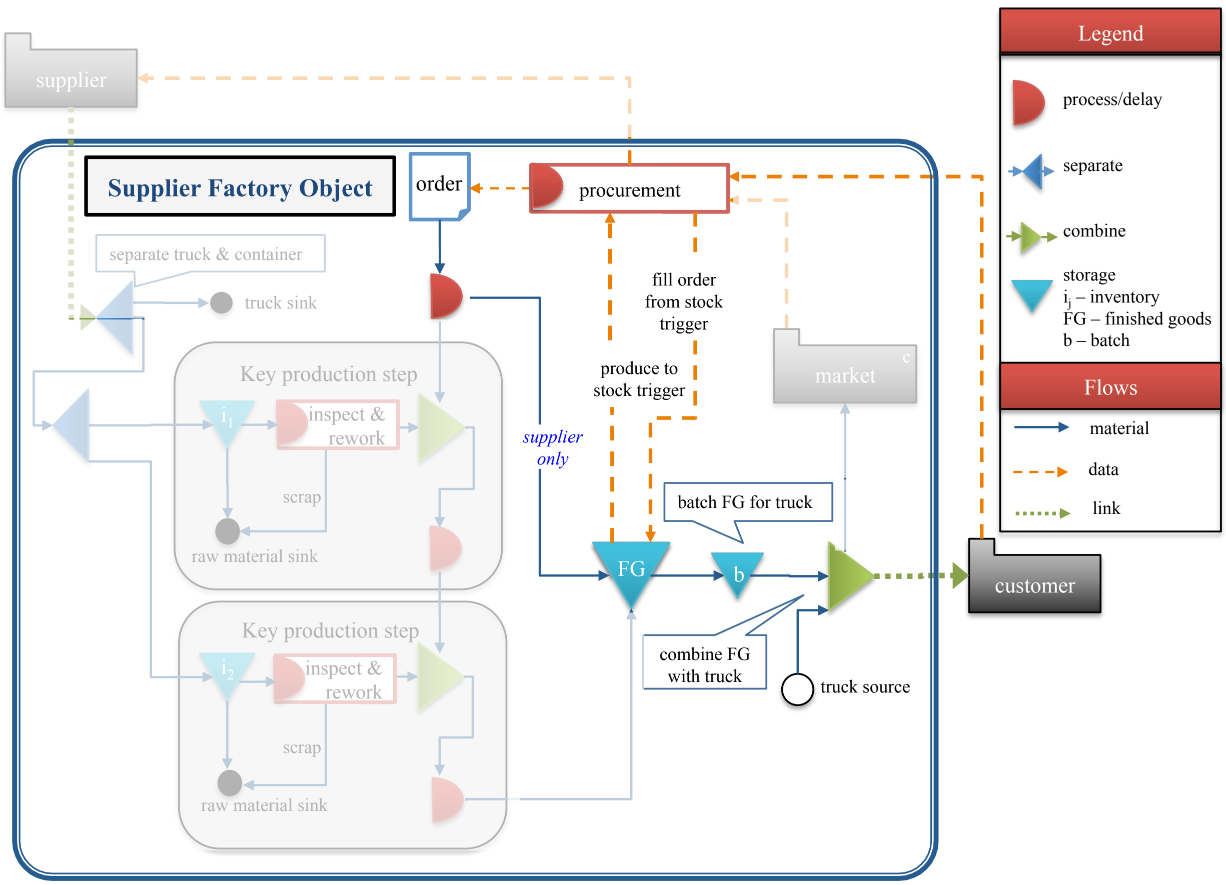

Figure 5: Underlying logic of the supplier-factory object.

2.4 Transportation-Hub Object

A transportation hub represents a facility that processes and transfers containers between multiple modes of transportation (ship, rail and truck). Since it can represent a port, rail terminal, or truck terminal with input from any type of mode, it is a complex simulation object. However, this inherent complexity facilitates its application and use.

The left-hand portion of Figure 6 provides a conceptual view of a transportation-hub object. It is built on a centralized container queue where items representing ship, rail, and truck handling push and pull from the queue.

The underlying logic of the generic transportation hub is shown in right-hand portion of Figure 6. The flow for each mode of transportation is similar. For example, trucks arrive from either of two places: an internal truck source or roadway transportation links that are connected to the transportation hub. If a truck needs to be unloaded, it is separated from its container and the container is put into the outgoing area of the central container queue. The freed truck is then made available to be loaded with 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. Rail and ship transports work in a similar manner with a few slight differences. Both the rail and ship transporters carry multiple containers; therefore, multiple containers must be separated before being sent to the central container queue. The number of containers pulled off is an attribute of the rail or ship component.

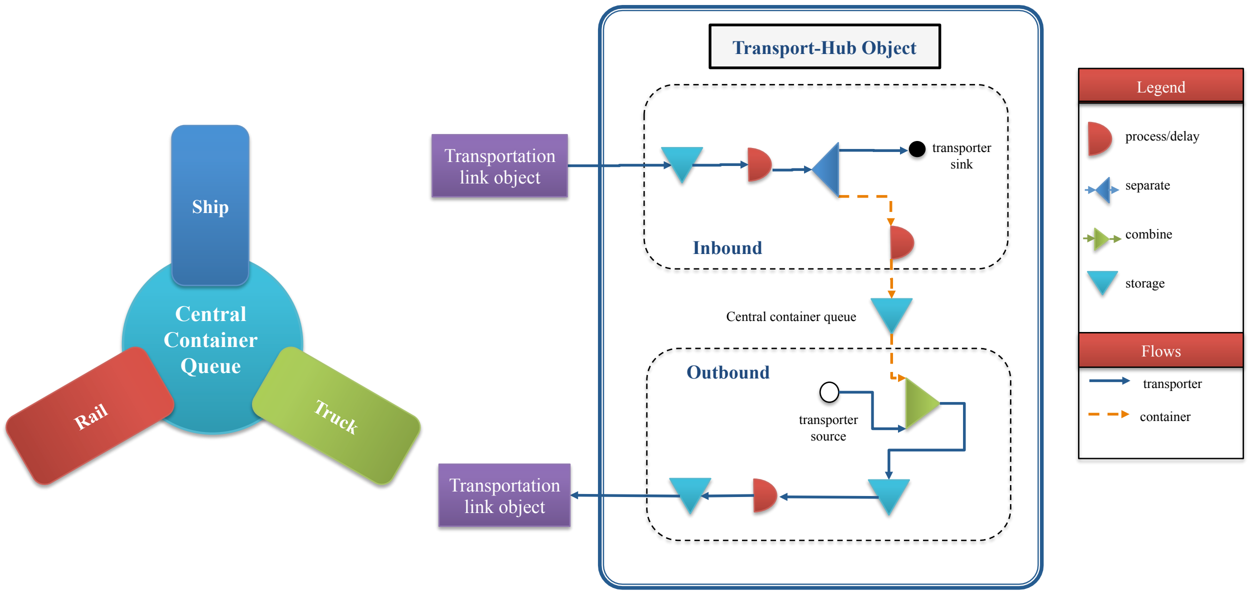

Figure 6: Underlying logic of the transportation-hub object.

Key attributes of the 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), inter-arrival time of transporters for each mode of transportation, container load and unload times for each mode, and capacity of the central container queue.

2.5 Transportation-Link Object

Transportation links define a path between two locations, e.g. from a supplier-factory object to an end-user-factory object; they represent rail lines, roadways, or sea-lanes. The links determine how long it takes for a mode of transportation to move items from one location to another. The link object can be connected to any type of node object. One object is considered the source and the other the destination for items to flow between. In the example in Figure 7, one link represents the road system from New York City to Dallas-Fort Worth; the other represents the rail system from San Diego to New York City. The link object automatically uses attribute values from the objects it is connected to. When a connection is made between two locations, the link object automatically populates the distance and travel time between the locations. These attributes can be obtained from various sources, e.g. *Google Maps*. The time and distance between locations are stored in a global table by mode of transportation. The table is populated manually or from an external source, such as a simple *MSExcel* file or an online provider (e.g. *Google*

Maps). As part of this research, primary map information service providers were investigated. Based on online reviews and our evaluation of the options, *Google Maps* and its application program interface (API) is used for this object. In this implementation, time and distance information are obtained from *Google Maps* via a *MSExcel* spreadsheet and *VBA* interface and stored in a global table in the simulation model. It is possible to access the *Google Maps* API directly from within the simulation software (through application commands in *FlexSim*), but imbedding the external link to the web would require additional interfaces and checks and may also require file parsing to extract the needed information. Also, a major concern with running simulations with direct calls to *Google Maps* is the negative impact on runtime performance.

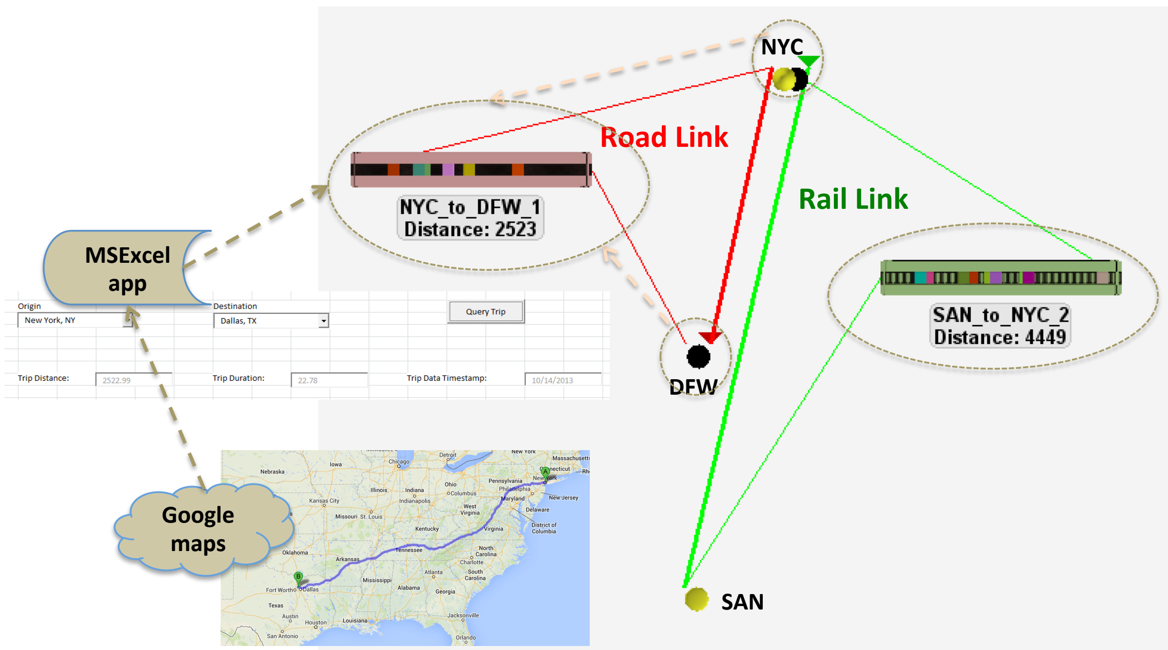

Figure 7: Example transportation-link objects and population of object properties.

Travel times used in the application are assumed to be mean values. However, 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 sufficient storage space at the receiving location and there is an increased risk of damage. Therefore, to assess risk, variability is introduced by user-specified probability-distributions in the simulation object. For simplicity, travel times are assumed to be triangularly distributed, but could be any distribution. The objects use the triangular distribution parameterization method developed by Jannat and Greenwood (2012).

Airport codes are used to represent locations. A variety of formats were considered, but the standard 3-letter airport code was chosen for this implementation. 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 was the use of postal zip codes, but for a worldwide model, postal code formats are not standardized.

3 ILLUSTRATIVE EXAMPLE

A case-study example is used to illustrate the application of the simulation-based toolset to support the evaluation of sourcing alternatives. The actual industry example involves deciding between two potential suppliers that would provide transmissions to an automotive assembly plant located in Mississippi. One supplier is located in Japan, the other in Tennessee. For both locations, the number of transmissions per container and the supplier lead times are the same. The period of performance for the analysis is two years. Data for each object are obtained from the automotive assembly plant, ports, and the internet (distance information for roadways). Information and data are representative, but have been modified so as to not violate non-disclosure agreements and reveal proprietary information.

The supply chain from Japan to Mississippi includes the supplier, an intermodal transportation network and the automotive assembly plant (end user). The transportation network is comprised of various transportation links (i.e., roadways, railways, and seaways) and transportation hubs (e.g. ports and rail yards). As shown in a snapshot of the simulation model in left-hand portion of Figure 8, the process begins with an order being generated by the end user for the supplier in Japan. The minimum order quantity is four containers. Each order is processed through the supplier and each container load of transmissions is placed on a truck where 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 where it travels to the port in Los Angeles via a sea-link object. It is unloaded, processed, and loaded onto a train with other containers. The train delivers the containers to the transportation hub in Tennessee where they are offloaded and individually leave the transportation hub via truck to the end user's factory. Once at the plant, each container is unloaded, transmissions are removed from the containers, and make their way through the factory.

Figure 8: Simulation model built from the toolset to assess two alternative suppliers – one international and one domestic.

The Tennessee supply chain is much simpler and only includes the supplier, a roadway and the automotive assembly plant. It is coincidental that the domestic supplier and the transportation hub for the international supplier are both in Tennessee. As shown in a snapshot of the simulation model in right-hand portion of Figure 8, the process begins with an order being generated by the end user for the supplier in Tennessee. The minimum order quantity is one container. Each order is processed through the supplier and each container load of transmissions is placed on a truck where it is transported directly to the end-user plant in Mississippi. Once at the plant, each container is unloaded, transmissions are removed from the containers, and transmissions make their way through the plant.

The simulation analysis considers three levels of risk – low, medium and high – to assess their impact on the automotive assembly plant's operational performance. Risk represents variation in various aspects of the supply chain such as travel times and supplier lead times. Low risk is defined as ±5% of the mean, medium risk between -5% and +15%, and high risk between -5% and 30%.

Three primary performance measures are considered. Average time in the system measures the time from when an order is placed until the corresponding finished good is completed. Average jobs per day is a measure of throughput and is used to ensure the supply chain is meeting the automotive assembly plant's desired rate. End-user (incoming) queue capacity is a measure of whether the end-user factory needs additional storage space in order to absorb the fluctuations caused by ordering constraints and intermodal delays.

Table 1 summarizes the comparison between the two suppliers (Japan and Tennessee) in terms of the three primary performance measures defined above and the three levels of risk. All values in the table are mean values. The upper and lower confidence interval limits for the first two measures (time in system and jobs per day) are within 0.2% of their mean, based on ten replications. Similarly, the limits for end-user queue capacity are within 8% of their mean, again based on ten replications. There is no significant statistical difference in throughput (jobs per day) between the two suppliers or among the risk levels, implying both supply paths are capable of meeting market demand.

Table 1: Performance measures by level of risk for each alternative supplier.

	Average Time in System (hours)	**Jobs per Day**	**End-User Factory Incoming Queue Capacity (units)**
Japan			
Low	1458.8	744.9	649.3
Medium	1503.2	743.6	541.4
High	1571.2	744.4	470.1
Tennessee			
Low	850.1	743.1	21.9
Medium	878.4	742.4	31.6
High	920.9	740.2	41.0

In terms of average time in the system, as expected, the international supplier takes considerably longer. Similarly, as expected, time in system increases for both suppliers as variability increases.

End-user factory incoming queue capacity is much larger for the Japanese supplier, as expected. However, the risk comparisons are interesting. For the Tennessee supplier, the queue capacity must increase as variability in the system increases, which is as expected. In fact, the capacity at the high-risk level needs to be nearly twice the low-risk level. For the Japanese supplier the needed storage capacity decreases with increasing risk levels. This is due to the very long time in system – the longer it takes for containers to reach the factory, the more production consumes, and thus there is less inventory.

The model's accuracy was assessed through the case study based on face validity. Experts in the supply-chain area of the company indicated the model results were reasonable and sufficiently accurate to make supplier decisions.

4 CONCLUSIONS

This research provides an approach for developing and using a high-level simulation-based toolset to support procurement decisions for selecting alternative suppliers based on characteristics of their supply paths. 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. The tool was effectively developed in a state-of-the-art simulation environment using *FlexSim.*

The case study demonstrates the toolset's ability to rapidly model and analyze competing supply chains and understand their impact on performance in an end-user factory. Cost attributes are incorporated into the toolset objects, but due to the limitations of data, a cost analysis was not performed. In addition, rework/scrap data was not available for the end-user factory which limited the assessment of impacts on the system. The simulation-based toolset described in this paper provides the foundation for comparing the costs of the alternative supply chains. The toolset would need to incorporate a more holistic cost framework, such as described in Zeng and Rossetti (2003).

Future work would make the toolset more flexible and additional case studies should be considered and evaluated to ensure the toolset can handle a wide range of supply chain requirements. Although order quantity size, demand, and period of performance were considered, additional analysis of these factors would enhance sourcing decisions. Also, total outstanding inventory, including both that in transit to the facility and in the incoming queue, should be tracked.

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