ABSTRACT

Simulation modeling is a proven technology to help companies make better decisions for both strategic planning and day-to-day operations. A computer model is created that mimics the operation of a real-world system or process over time. The model is then used to understand, analyze, and predict the system’s behavior across a wide variety of “what-if” scenarios.

In the transportation and logistics community, modeling has traditionally been used by freight carriers to help plan fleet movements and crew scheduling across the entire rail network. However, the customers using the carriers are also starting to recognize the value of simulation for their own planning. For example, given a specific schedule of Class 1 railroad service, what is the best way for a customer to plan for production and assembly of product-laden rail cars? How does this plan respond in case of variation in the production process? What if there is an unexpected change in the schedule of service – is there sufficient on-site or off-site staging space for outbound rail cars, or would production come to a halt? And what is the impact on customer delivery frequency and lead time for order fulfillment?

This paper demonstrates how simulation modeling is increasingly being used by major U.S. companies to answer these types of questions. A specific case study illustrates how a global leader in the production of petrochemical and plastics products utilizes simulation for strategic design, yard operations planning, and justification of capital investment.

INTRODUCTION

Simulation is a widely used operations research technique to improve both strategic and operational decision making in many industries. The technology involves the development of a computer model that mimics the behavior of a real-world system or process over time. The model can then be used to evaluate, understand, and predict the system's performance under a wide variety of conditions. A key benefit of simulation modeling is the ability to evaluate the design of a new system without actually building it, or to investigate potential changes to an existing system without disturbing it.

Other analysis techniques, such as mathematical modeling, numerical modeling, and optimization, are also broadly used for strategic planning and operational analysis. One of the strengths of simulation modeling when compared to other techniques is its capability to capture two key features of real-world
systems: a) the variability inherent in a dynamic environment over time, and b) the complexity of interaction between components or processes (1). It is the ability to capture the dynamics of a real system that makes simulation distinct from other analytical approaches.

In addition, a simulation model can also be accompanied by a 2-D or 3-D animation to visualize the movement of objects through the system being simulated. Animated graphics facilitate the evaluation process by allowing an analyst to visually identify bottlenecks in process flow, rather than have to infer it from statistical results. In addition, adding animation to a simulation model enhances the ability to communicate with non-technical audiences in order to convey results or recommendations (2).

SIMULATION AND RAIL

In the rail industry, simulation modeling is often used for capacity planning purposes (3). As the demand for rail services continues to grow in the United States, particularly in the intermodal and coal markets, there is a growing need among Class 1 railroads to continue or even increase investment in capacity improvement initiatives. The term “capacity” can refer to a wide variety of issues facing the current rail environment: network planning, service plan scheduling, crew or locomotive scheduling, track maintenance, yard operations planning, and others.

Simulation modeling is a sound technology to explore “what-if” scenarios involving any of these capacity initiatives, particularly considering that demand is often seasonal – the pattern of demand changes over time. The focus of modeling to support capacity planning aims to address the general question: “What level of investment is needed to support the expected demands?” Specific flavors of this question include:

- How well does the existing rail infrastructure support the new volume? Is construction necessary, or can operating plans be evolved without requiring additional investment in construction?
- If new infrastructure is needed, does a particular design offer system performance improvements compared to other alternatives? How does Design A compare to Design B in quantifiable terms?
- Are sufficient crews, power, and other resources allocated to handle the forecasted volume increase?
- Given a projected increase in volume, what is the point in time that the system “breaks” such that level of service begins to suffer?

Modeling is often used by the Class 1 railroads and other freight carriers to help plan fleet movements and crew or resource scheduling across the entire network (4). For example, a baseline model is created to represent the scheduled movements of all trains in the system in a particular week or month. The model can be updated periodically to help make decisions about re-positioning road power, allocating crews, or predicting the cumulative effect of unexpected delays. If maintenance is required at a particular section of the network, the model can be modified to reflect the track outage, and the resulting system performance can be studied to determine the impact on the existing service plan in order to develop potential alternative service plans.
Modeling at the Facility Level

Not only can larger-scale network simulations be developed, but more focused smaller-scale models can be created to target strategic or operational issues at a single terminal or facility (5). In today’s rapidly changing market environment, the rail industry acknowledges that while improving main line capacity is a necessary step, it is not the only type of capacity improvement to be considered. As a result, Class 1 railroads are also using simulation modeling techniques to help identify capacity concerns and potential enhancements within a single terminal, such as a flat switching yard, intermodal yard, or hump yard. The complexities of operational practices and processes, combined with the details of the physical rail infrastructure required to support terminal operations, suggest that simulation modeling would be a beneficial analysis tool toward this end.

For example, one of the major Class 1 railroads was interested in evaluating alternative techniques to increase throughput at a busy classification yard in the West (6). Through a series of fact-finding workshops, interviews, and field studies, the simulation team learned the operating rules and flow of rail cars through the facility. Importantly, the interview process uncovered the nuanced yard planning rules used by the yardmasters themselves, such as which blocks to put on which track, and which blocks should be prioritized for assembly. The process flow and planning rules were encoded into a detailed simulation model representing those operations, as well as the switching and other operating constraints defined by the physical infrastructure of the facility.

Running the model through an iterative set of scenarios provided quantitative data to help compare and justify potential physical changes to the yard infrastructure. A sequence of build-outs was identified to support the increase in train volumes, and the investment requirements were balanced with the projected increase in yard productivity. In addition, “best practices” were identified for yard planning to support the education and training of future terminal operators.

Modeling for Rail Customers

Just as the carriers themselves benefit from the value provided by simulation modeling, many of the companies that use these carriers also recognize the value of simulation, incorporating modeling into their own strategic planning initiatives (7). For example, given a specific schedule of service by a Class 1 railroad, what is the best way to plan for production and assembly of product-laden rail cars in order to match that schedule of service? How does this plan respond in case of variation in the production process? What if there is an unexpected delay in the schedule of service – is there sufficient staging space on-site for outbound rail cars, or would production come to a halt? Note that these general questions are independent of the type of goods being produced or shipped, or whether or not the freight type is bulk, break-bulk, or intermodal.

A common theme is that many different factors must be balanced in order to maintain a sufficient level of service for the end customer. The production cycle frequency, combination (and feasibility) of on-site and off-site storage locations, lead time for customer order fulfillment, delivery frequency to the customer, and the transportation service plan are all interacting elements that require coordination in a successful logistics program. If a change were to occur in any one element in this complex system – or if the customer demand itself were to increase – what would be the quantitative impact on other elements? This is where the modeling of “what-if” scenarios becomes a valuable tool in the company’s planning arsenal.
CASE STUDY: PLASTICS INDUSTRY

A global leader in the production of petrochemical and plastics products currently utilizes simulation modeling for strategic design, yard operations planning, and justification of capital investment. The chemicals produced by this company’s three divisions are essential to manufacturing more than 70,000 consumer and industrial products. These products reflect a broad range of recognizable consumer goods, from motor oils, paint, and household detergents, to milk jugs, plastic utensils, and DVDs. With facilities in seven countries, their products are sold to manufacturers in over 80 countries around the world.

A significant portion of the Company’s polyolefin (plastic resin) product is shipped by rail. Polyolefins, often referred to as “commodity thermoplastics”, are the largest group of plastics and are popular due to their low cost and wide range of applications. They are commonly utilized in the manufacture of automotive interior and exterior parts, thin film such as food wraps, cable jacketing, and other wire and cable applications.

Polyolefins, like all thermoplastics, have a molecular structure that allows them to be repeatedly melted and solidified by heating and cooling, without a chemical change taking place. These products are typically supplied in the form of small pellets, often with additives included to provide certain characteristics in the finished product such as conductivity or color. Plastics manufacturing involves a sequence of refining, heating, cooling, and combining steps that starts with crude oil and natural gas and results in melted plastic product which is cooled and fed to a pelletizer, a machine that cuts the product into pellets. When delivery by rail is desired, these pellets can be loaded into hopper cars for bulk delivery to customers.

Production and Staging Challenges

At the Company’s production facilities, a fixed production schedule is executed due to the capital intensive nature of the production process. Batches of different product types are in continuous rotation through the process, and the volumes of each product type are stored in hopper cars. The hopper cars are then moved to a staging area, ready for delivery to a customer. When a customer order is received, it will typically be specified in pounds of product, corresponding to a quantity of hopper cars for one or more product types (or alternatively, in transloaded prepackaged quantities that would be shipped by truck, which is outside the scope of this paper). To fill the order, hopper cars with the proper product type must be retrieved from the appropriate staging area.

Currently, the vast majority of the Company’s unsold inventory is staged at railroad-owned Storage-In-Transit (SIT) yards. As the Class I railroad interchange and SIT yards’ congestion has increased, the price to store cars at those SIT yards has continued to increase as well. In order to address those changing costs and to enable them to improve rail service for their customers, it was recommended that new SIT yards be built at a select number of the Company’s Gulf Coast plants. Construction of these facilities will allow the Company to store their rail cars on company-owned facilities, allowing greater control of SIT yard operations, operating costs, and avoidance of price increases imposed by the railroads.

However, building new facilities presents new operating challenges. The filled hopper cars at the production facility need to be staged for pickup by either a short line or a main line rail carrier. This implies that sufficient rail car staging capacity must exist to meet the differences in the rail service plan
and production facility schedule fill rates. In addition, customer demand may be variable while the production schedule is relatively fixed, implying the need for additional buffer storage. Finally, it is important to understand how the track infrastructure can be designed to best support the planned operations in such aspects as zone allocation by product type.

Since the Company is assuming the responsibility of putting this storage yard and capacity on its own property, it is critical that the design, sizing, and operation of these yards is properly planned and understood.

<table>
<thead>
<tr>
<th>Design Factors for a Storage-In-Transit Yard</th>
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<tr>
<td>• Shape and size of available property</td>
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<td>• Number of cars to be stored</td>
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<td>• Length of tracks required for switching</td>
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<td>leads and head room</td>
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<tr>
<td>• Current use of proposed property</td>
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<td>• Topography</td>
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<td>• Drainage characteristics</td>
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**Figure 1. Selected Design Factors for a Storage-In-Transit Yard**

Introduced during the process of designing the new yards were the capabilities and benefits of rail modeling and simulation as a means of evaluating the performance of specific infrastructure designs prior to construction. Modeling also provided a valuable test bed to explore alternative operating strategies and quantify the costs and benefits. Because of the large capital investment involved in designing and constructing multiple SIT Yards, the ideas of design verification and insight into effective yard management offered through simulation modeling came to the forefront.

**SIT Yard Simulation**

Custom simulation models were developed to represent the rail traffic flow linking production, plant yards, SIT Yards, and arriving / departing trains within each of the new plants. To meet the business goals, each facility model incorporated the production schedule for several hundred products, plant-specific SIT yard rail configuration, and facility procedures for receiving, storing, and blocking rail cars for outbound shipment. The models were used to explore alternative means of assigning rail cars to SIT tracks, retrieving cars for outbound shipment, and operating strategies that effectively use the yard tracks and crews.

For example, there are multiple strategies to assign specific rail cars to individual SIT Yard tracks. One initial strategy may be to allocate individual tracks to different product types. Tracks could also be allocated by relative production volume to segregate slow-moving product from frequently ordered product types. Perhaps the day of the outbound order should be the focus of track assignment, independent of the product type in the rail car. All of these zone allocation strategies have potential; the simulation model provided a quantitative way to compare and contrast them.
However, the model focused not only on track assignments for put-away storage purposes, but also for allocating cars from the yard to outbound trains. Rail cars selected for outbound rail shipment need to be moved from the SIT zone to a departure staging track. Since the movement must start several hours in advance of the scheduled pickup time according to a rail carrier service plan, the sequence of selection is important. In addition, certain blocking requirements were imposed by one of the rail carriers, contributing an additional element to the strategy of rail car selection. By incorporating tasking priority and preferences for these outbound moves, the model helped determine which cars should be allocated in what sequence when building an outbound train. Specific examples are summarized in the Analysis Results section below.

The complexity of the simulation logic required to accurately represent operations within the various SIT yards can be difficult to capture using the basic building blocks within commercial off-the-shelf simulation software packages. Custom logic needed to be developed for this operational detail. In order to more quickly construct the simulation and get results, the model was constructed using the Transportation Modeling Studio, a suite of integrated tools that TranSystems has developed for the rapid configuration of simulation models for network and terminal analysis.

This platform is designed to focus on the capacity planning issues affecting rail, intermodal, and marine terminals – problems ranging in scale from the switching movements within a single classification yard, to the train movements supporting all major terminals in a port, to the cargo flow across an entire region. By leveraging the Transportation Modeling Studio, the model was constructed within a relatively short time period, without having to create an entire simulation from scratch. The authors have each utilized this toolkit in multiple projects for Class 1 railroads, major U.S. ports, and the customers served by these carriers.

Analysis Results

The customized models were used to compare over forty (40) alternative strategies for product put-away to SIT Yard. One set of strategies was based on out-day order fulfillment, which requires pre-allocating loaded cars to customer orders based on expected demand. The model included the ability to vary the amount of customer demand visibility – how many days in the future that demand was known. Other strategies included: numerous combinations of high and low-volume product lines, put-away by filling line, and product-specific track allocation alternatives. These alternatives suggested SIT Yard configurations with differing degrees of product mixture based on the specific facility demand and operations.

The models were also used to compare three different outbound allocation strategies: last-in first-out (LIFO), first-in first-out (FIFO) by product age, and a custom scoring approach. The LIFO method was designed to focus on ease of access, identifying a railcar with the correct product type that was stored closest to the front of the track. The FIFO method by product age aimed to enable timely turnover, identifying the oldest matching product in the yard, regardless of position within or across tracks. Finally, the objective of the custom scoring method was to minimize switching requirements, considering the overall quantity and types of cars needed for the next outbound train. Each track was scored based on the number of cars available for outbound shipment that resided in each track. The highest scoring track would be selected, and all carloads in that track meeting the outbound shipment would be targeted for
retrieval. For the remaining cars on the outbound train, previously selected carloads were removed from consideration and all tracks were re-scored.

After running hundreds of scenarios mixing track assignment strategies with outbound allocation strategies, performance metrics were compiled to compare scenarios for each plant. The table below (Figure 2) shows a selection of metrics used to judge the quality of performance of a scenario. By analyzing these key performance indicators, the design for each facility was validated, and the best method of assigning cars to tracks and allocating cars from the yard was recommended – individually based on each plant’s unique characteristics.

![Table of metrics for SIT Yard simulation](image)

**Figure 2. Example data from a SIT Yard simulation model (not actual data)**

As a result of the analysis effort, the simulation team was able to determine effective strategies for managing the SIT Yard operations for each of the three yards, prior to the completion of yard construction. The simulation models for each plant have been delivered to the Company to support ongoing analysis of the yard operations, and the Company’s analysts have been trained on using the simulation. This will allow the Company to improve its up-front planning on operating the new SIT Yards, educate operations teams in the impacts of these on-site SIT Yards, and evaluate “what-if” questions as future conditions change within each facility. The Company plans to continue to use these models to plan for transition events, where the yard conditions will be stressed as the plants build up inventory for planned processing shutdown periods.

**CONCLUSION**

Simulation modeling is a proven technology to help companies make better decisions for both strategic planning and day-to-day operations. Class 1 railroads are currently taking advantage of simulation technology to help make decisions on many aspects of their operations. Not only can broad simulations be developed to analyze main line network capacity improvement questions, but models can be targeted at a single terminal or facility as well.
The customers serviced by the main line railroads are also beginning to use simulation modeling for planning purposes, to evaluate alternatives and justify capital investment decisions. The article outlines a case study for a global leader in the plastics industry that had committed to the construction of new Storage-In-Transit (SIT) rail yards within their production facilities. Simulation models were developed to help evaluate the SIT yard designs, providing specific quantitative measures of performance that suggest how the facility will operate once built. Hundreds of “what-if” scenarios were executed and evaluated to compare and contrast both put-away strategies for loaded car volume and allocation strategies for outbound departing trains. By analyzing key performance indicators, the designs of the SIT yards were validated, and recommendations were provided as to the best operational strategies, based on each facility’s unique characteristics. The models will continue to be used in both strategic and operations planning as future conditions change within each facility.

REFERENCES


