THE VALUE OF DISCRETE-EVENT SIMULATION IN THE COMPUTER-AIDED PROCESS OPERATIONS

Ricki G. Ingalls
Texas State University
San Marcos, TX 78666
Diamond Head Associates, Inc.
Encinitas, CA 92024

Ron Morgan
Halliburton Energy Services
Duncan, OK 73536

Abstract

This paper considers the value of discrete-event simulation in the process industry and in the overall supply chain. The paper begins with an overview of models used today and then discusses how discrete-event simulation could be used in today's context. In addition, the paper proposes a *distribution-correlation forecast* as a way to pass stochastic information between tiers of the supply chain in order for most robust planning and scheduling.

Keywords

FOCAPO, Discrete-Event Simulation, Process Industry

Introduction

This paper is a think piece. It is written by a two people outside of your industry. One, Dr. Ricki Ingalls, is a PhD in Management Science and a modeling expert with over 30 years of applying large-scale optimization models and discrete-event simulation models in industry and teaching both optimization and simulation at the university level. The other, Dr. Ron Morgan, is a PhD in Chemical Engineering and a chemical process and business process expert with over 30 years in the food and energy services industries. Our goal in this paper is simple: To challenge your thinking about discrete-event simulation and how it could be valuable in your industry. It is that simple.

In order to accomplish this, the authors will lay out segments of your business and describe the typical modeling techniques used in that segment. Then we will describe if, and when, discrete-event simulation can add value to that segment of the industry. At the end of this paper, perhaps you will be challenged enough to look at a different analysis technology so that you can use it to better analyze your business.

The Example Company

In order to facilitate this discussion, we will pick a given type of company – one that is in the plastics extrusion business. We will assume that the production facility in this business handles a variety of standard, custom and semi-custom products for their customers. The nature of their product mix means that the company is reacting to demand. Whether those products are being delivered from their distribution centers to stores (for standard products) or shipped directly to stores (for custom and semi-custom products), the company's manufacturing must respond to demands in those different markets. In addition, the company deals with its own raw material suppliers that supply key product to the manufacturing facility.

This is not a terribly complicated supply chain. We are certain that your company supply chain is much more complicated!

Customers (Stores)

In our plastics extrusion business, the customers are becoming more demanding each day. They want to keep low inventory in their stores for the standard products and fast delivery of the custom products. Their increasing demand of custom products shows a desire for more variety in their product selection. And, of course, they always want low prices.

Managing the Distribution Centers (DCs)

The company has 5 regional distribution centers to supply to the stores. These distribution centers were established before custom parts became part of the company's offering to the customer and they are located in Indianapolis, Los Angeles, Dallas, Atlanta, and New Jersey. Each DC has the issues of inventory management, repackaging product for the needs of the store, and effectively managing seasonal demand in the business. The DC managers often feel like the they have little control their product receipts and how they configure shipments.

Managing the shipment of product from the DCs to the stores is becoming increasingly complicated. In the past, the stores were happy to get weekly shipments and would place orders weeks before the shipment occurred. This gave the company time to efficiently plan the warehouse operations. Today, the stores are demanding multiple shipments per week where they order just hours before the truck is scheduled to leave the distribution center.

Another issue that concerns management is that freight costs are increasing at a rate where they are close to their manufacturing costs.

Manufacturing

Manufacturing is located in one facility in the Dallas area. It was built to do long production runs very efficiently. With the increased product variety, and especially the custom orders, manufacturing has become less efficient. In addition, manufacturing deals with a set of issues that are unique to the plastics extrusion process. They include:

1. The waste created by the process. With each run, it takes 30 minutes to get the process to produce quality product and 15 minutes to clean out the product at the end of a run. Manufacturing wants to minimize waste.
2. The process must be controlled. Elastic jet swell, exit pressure and temperature and other viscoelastic properties must be constantly monitored to be sure that they are within expected operating ranges. In addition, manufacturing must adjust the equipment whenever the process is outside of specifications. If the process is out of control, it must be stopped and adjustments must be made.

Manufacturing is dealing with increased pressure to shorten production runs and changeover the process more often to accommodate custom products.

In addition, the company is also shipping product from the manufacturing facility directly to the stores. The management has questions about the cost effectiveness of this policy since the company is shipping very small lots at higher prices just to get the order to the store quickly.

Raw Materials and The Suppliers

The company is under pressure to keep in-house inventories low and push ownership of the inventory to the suppliers with just-in-time delivery.

Supply Chain

The company want to keep overall costs as low as possible and still deliver to the client. The company monitors and adjusts inventory and transportation that is under its control to keep costs at a minimum.

Supply Chain Trade-off Issues

The company is faced with the same tradeoff issues that are found in many companies (Simchi-Levi, et. al, 2008). The lot size vs. inventory trade-off is found here because manufacturing wants to reduce setup costs and be more efficient, which creates more inventory. The distribution centers and customers want shorter delivery lead times, more product variety and lower inventory. The trade-off involves finding the balance between manufacturing efficiency and inventory costs.

The inventory vs. transportation trade-off is found here because the company wants full trucks going to a single destination. This minimizes transportation costs and allows for efficient loading and unloading of the trucks. However, it also increases inventory. In the case of this company, you also have the custom products being shipped less-than-truckload (LTL) to a variety of stores, which also drives up the transportation costs.

The lead time vs. transportation cost trade-off is found here because the customer is demanding shorter lead times (more frequent deliveries) to drive down inventory costs. Again, transportation wants full trucks going to a single destination.

The product variety vs. inventory trade-off is found here because the customer is driving the company for custom and semi-custom products. This increased variety of choices makes the inventory more complex and difficult for both the manufacturer and the customer.

The last trade-off, but the most important overall trade-off, is the cost vs. customer service trade-off. This is the trade-off that drives most companies. Customers want high quality products delivered more often with quick response if there are quality issues. But this costs a lot of money. The company has to determine where to spend money to improve customer satisfaction. This is clearly a supply chain issue. It is clear that the other trade-offs all contribute to this overarching trade-off.

Models That Are Used to Run the Company

There are a variety of "models" used to run the company from day-to-day. When we use the term "models", we are talking about any mathematical model or heuristic that helps makes decisions in the company. These models can be found in spreadsheets, heuristic algorithms, linear optimization, mixed-integer optimization, non-linear optimization, stochastic optimization, continuous simulation and discrete-event simulation.

In perfect world, we would all be running physics-based stochastic optimization or simulation optimization models that would give optimal controls on our manufacturing process, determine manufacturing schedules, coordinate logistics and delivery to the customer while taking in to account random demand, random disruptions in the supply chain and random disruptions in manufacturing that would run instantaneously. Since that model does not exist, the modeling techniques that we actually use have applicability based on two criteria:

1. What question are you trying to answer?
2. What constitutes a quality answer?

The first question deals with each modeling technique's applicability in addressing the question. Table 1 outlines the different types of questions and which modeling approaches would address those questions.

Table 1: Modeling Techniques based on Type of Question

Type of Question	Modeling Approach
Has a static set of inputs and only one possible solution to those inputs	Spreadsheet Heuristic Algorithm
Has a static set of inputs and want to choose the best solution from a large set of possible solutions.	Linear Optimization Mixed-Integer Optimization Non-Linear Optimization
Has random inputs (such as demand), but has static processes that deal with the random inputs.	Stochastic Optimization
Has both random inputs and random processes. You want to determine statistics-based outputs.	Discrete-Event Simulation

One stark fact about models currently being used in industry is this: *Even though stochastic (random) behavior is seen throughout the business, stochastic models are not used in the decision making process*.

The second question deals with scale, efficiency, and the assumptions of the model being run. Every model that is run in a business operations setting has a time limit on it. If the model is being used interactively in an on-line setting, the answer must come back in 2 seconds or less (Akamai Technologies, 2009). If the model is used for plant scheduling, it has to be able to run in minutes or seconds. If the model is used for monthly production planning, it has a larger scale and may be able to run for an hour or more and still be considered "efficient." If the model is used for supply chain design, it may be acceptable to run for several hours.

The second question also deals with the assumptions of the model being run and a proper understanding of the output. One of those key assumptions is the abstraction level of the model. Let's take an example of line setup time. If we were dealing with a supply chain planning model, the line setup time would be abstracted in some way. It would likely be a percentage of the run-time or a constant per batch being run. However, if we were dealing with line scheduling model, we would certainly incorporate sequence dependent setups as part of the model.

Customers (Stores)

The most common demand forecasting algorithms look at history and determine a forecast. The classic algorithms include exponential smoothing and Box-Jenkins. Under the assumption that past demand is an indicator of future demand, this is a legitimate approach. Also, marketing often uses demand elasticity models to determine demand based on price and promotions. In many companies, demand forecasting is a group effort that settles on a reasonable demand forecast.

Managing the Distribution Centers

Given a demand forecast (and actual demand), shipments to the stores are scheduled. There are a range of methods for scheduling these shipments. The simplest method schedules 1 truck for delivery on a given date and then loads the orders based on a first-come basis. If one truck is scheduled to service 3 stores on Tuesdays, then the orders for those three stores are scheduled on that truck as they come in.

The most complex method uses mixed-integer optimization to determine the most efficient routes and assignment of orders to those routes.

These shipments must be scheduled in conjunction with the DC constraints and inventory policies. These inventory models range from simple to complex. The simple model, and it is widely used, is the "X weeks of inventory" model. The management dictates that "X weeks" of (customer) demand be held in inventory. "X weeks" can be forward looking (the forecast over the next X weeks) or historical (actual demand over the previous X weeks).

The more complex models are replenishment models such as (R,Q), (S,s), etc. The good news about these models, they can incorporate the variance in demand and supplier lead times.

After the inventory models are set and put in place, orders are sent to manufacturing for replenishment either on a schedule (for the "X weeks" model) or when the inventory drops below the reorder point. Those replenishment orders become demand for the manufacturing facility.

Manufacturing

Manufacturing models are the most difficult to generalize because the models used to manage (schedule) a manufacturing facility can be both complex and very application-specific. Since that is true, we will discuss the models used in our plastics extrusion facility in our example company.

In our plastics extrusion company, the schedule must be constructed in order to:

1. Get the orders out on time.
2. Include the setup and teardown times based on sequences of products. This also includes the waste created by the process.
3. Determine the batch size (or run size) of each batch.

As we mentioned above, the manufacturing management wants to make batch sizes (both in time and quantity) large so that they can get the most efficiency out of the line, where efficiency is measured as *production time/total time*. The setup time of 30 minutes and the teardown time of 15 minutes means that the batch size must be 45 minutes *just to get to 50% efficiency*. A batch size of 3 hours is 80% efficiency. These efficiency numbers do not include planned and unplanned maintenance, quality problems on the line, or idle time.

Because of this complexity, manufacturing schedules tend to be rules-based models. Many times, the rules are in the master scheduler's brain and are not actually written down anywhere. In more companies that you would want to admit, the manufacturing schedule is created by the master scheduler and it resides on a giant whiteboard in the office.

In more advanced companies, they use some form of optimization or rules-based simulation to create the schedule. In those environments, rescheduling based on unexpected events is more automated and efficient than the whiteboard counterparts.

Raw Materials and The Suppliers

For the sake of this paper, we will assume that the raw material suppliers are using vendor-managed inventory and delivering to the lines in a just-in-time fashion. From a model standpoint, this relieves the company from worrying about the constant volatility that they are forcing on the suppliers. The volatility is real, though, and it costs money, which shows up in the price of the raw material.

Supply Chain

In today's companies, the supply chain models can be as simple as spreadsheets and as complex as large-scale mixed-integer models. These models are almost always strategic decision models and not tactical decision models.

The Value of Discrete-Event Simulation Today

How Today's Models Change Using Discrete-Event Simulation

So, here is the key question – *If there is so much randomness in the supply chain, why don't our models reflect that randomness?*

Table 1 shows that if you want random inputs, you should use stochastic optimization for a static (expected value) output or discrete-event simulation for stochastic output. Yet, we do not plan or schedule based on random inputs and we do not give random outputs to the next tier in the supply chain.

It should be noted that most (not all) of these applications would be a custom application for the business.

Customers (Stores)

The random input to a model that we are most interested in is the random arrival of orders (customers) for the store. Some of those orders will be custom orders and the rest will be off-the-shelf orders. An initial forecast, including some random demand information, would need to be created before a discrete-event simulation would be useful. Given that you have random demand; a resource-constrained discrete-event simulation model could be run at the store level to determine how much demand can actually be satisfied. The model could be run with or without stock-outs as well. The discrete-event simulation model would give results on projected sales, which could be aggregated to a forecast over time.

Managing the Distribution Centers

The random input into the model that we are interested in is demand (replenishment orders) coming from the stores. If the stores provide this demand in a traditional way, perhaps units per week per product, then the discrete-event simulation can use business rules to order the demand or the simulation can use assumptions to have random demand over time. The limiting constraint at this tier includes the trailers, trucks, dock doors, labor, material handling equipment and available inventory. We would have to assume that the inventory policies are already in place and effective. The discrete-event model would primarily be reacting to the random demand within the operating parameters of the DC. In addition, some of the internal DC process are themselves random. Random processes include any human activity including picking and packing and most product movement activity. Those processes would need to be understood and their dynamic nature would be part of the simulation.

The DC tier would also benefit from the discrete-event scheduling capability in some simulation software. This would schedule the facility based on resources and business rules. It would then evaluate the on-time delivery of each order or truck.

The result of this model is demand for the manufacturing tier.

Manufacturing

Manufacturing is the area where discrete-event simulation has been applied most often and it is the most likely benefit for the operations. Manufacturing is the best application because the environment is the most complex and usually cannot be handled with optimization techniques.

In our example company, the discrete-event simulation would be able to evaluate alternative schedules that deals with the issues unique to the extrusion process, including waste, length of production runs, effect of setup and changeover, and random issues such as quality issues and equipment failures. As a result, the manufacturer would have more confidence in the schedule.

The best part of this application of discrete-event simulation is that manufacturing simulation is readily available today through several different suppliers.

Supply Chain Issues

The design and planning of the supply chain have typically been handled with large-scale mixed integer optimization algorithms. These are the best algorithms for facility location and other supply chain design issues. However, the large scale mixed-integer formulation does not evaluate the performance of the supply chain under dynamic conditions. This is a second step in the supply chain design process that should be added. It is the only way to address key customer delivery metrics such as on-time delivery under the random conditions such as supplier performance, resource availability, etc.

Discrete-Event Simulation Applications Available Today

Simulation has been used in supply chain design since the late 1990's (Ingalls and Kasales 1999). The leading vendor in supply chain optimization software also has supply chain simulation capability (Llamasoft). Also, simulation companies such as Simio, (Simio LLC), ARENA (ArenaSimulation), FlexSim (FlexSim Simulation Software), and AnyLogic (AnyLogic) all advertise supply chain simulation capability.

Distribution center and manufacturing simulation has also been performed since the 1960's when discrete-event simulation was first introduced (Goldman, Nance and Wilson 2010). All of the major discrete-event simulation packages have the ability to simulate distribution centers and manufacturing sites. Some of the packages, including AutoMod (Applied Materials) and Demo3D (Emulate3D Inc.) were built specifically to model this environment. Historically, these simulation packages have been to evaluate facility designs or changes to an existing facility design.

Simio (Pegden) has implemented a simulation-based scheduling package that has the ability to imbed all of the decision rules for a schedule, generate Gantt charts that can be used to fine-tune the schedule and then Simio can analyze the schedule under dynamic conditions to determine the performance of the schedule based on key performance indicators such as on-time delivery of each order, cost variance, etc.

The Value of Discrete-Event Simulation in the Future

The Distribution-Correlation Forecast

Now, back to our key question – *If there is so much randomness in the supply chain, why don't our models reflect that randomness?*

Today, we do not have standard mechanisms in place to pass stochastic information from one tier of the supply chain to the next. Without this standard for stochastic information for planning and scheduling, if a model uses stochastic inputs, the inputs must be determined outside of the normal planning and scheduling systems.

Because of this issue, we are proposing a new idea. The idea is *schedule on actual orders, plan based on a distribution-correlation forecast*. The *distribution-correlation forecast* has distributions for each time period and correlations between those time periods. This *distribution-correlation forecast* gives much more information for the decision makers in the business than a traditional forecast. In Figure 1, we give an example of a distribution-correlation forecast. This example is based on a triangular distribution (min/mode/max), but it could be a Beta-PERT distribution, normal distribution, or others that might fit the business.

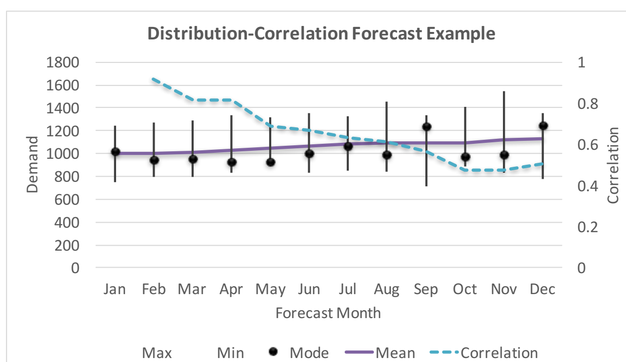

Figure 1: Distribution-Correlation Forecast Example

What is the advantage of this type of forecast? A traditional forecast would be the *Mean* in Figure 1. With the additional information, we also get the shape of the expected demand. We can see big potential upsides in April, May and August, and downsides in September and December. In addition, the *Correlation* statistic gives meaningful information on how each month is related to the previous month. The traditional forecast would give us an indication of some growth over the next year. The distribution-correlation forecast would give us a real picture of the volatility.

In addition, the two modeling techniques that can use stochastic inputs would be able to effectively use this data. For stochastic optimization, this forecast can be used to generate scenarios for the model. It would be trivial to generate any number of scenarios with this data. An example of 10 demand scenarios is shown in Figure 2. Discrete-event simulation can use this data to generate randomly arriving individual customer orders under a set of assumptions.

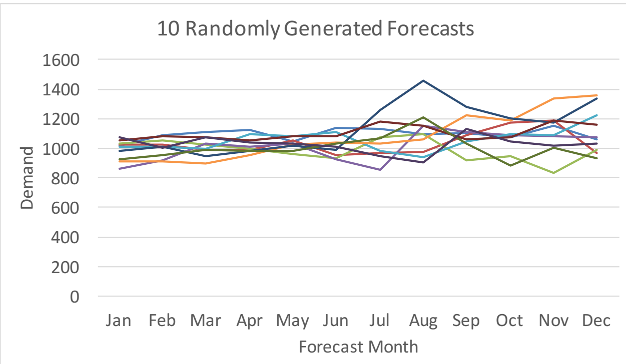

Figure 2: Randomly Generated Forecasts

Discrete-Event Simulation Generates the Distribution-Correlation Forecast

The power of discrete-event simulation in this environment is that it can model the business rules for decision making at any level. It can abstract the model at any level as well. Given a set of actual customer orders and a distribution-correlation forecast, the shipments to the stores can be scheduled for actual orders. Given that this is static information; traditional scheduling methods or discrete-event simulation can be used. If the company uses discrete-event simulation, then the schedule output can also include the probability of delivering the order on time.

However, the output of the shipment forecast is a distribution over time. Simulation is used because random customer orders (generated from the customer order forecast) can be put through the standard business processes and generate a distribution of resource constrained shipment schedules for those orders. The output can be arranged to any time-period needs of the distribution center.

Using this philosophy, it is possible to use simulation at each tier of the supply chain. The distribution center would schedule and plan for the loading of the trucks and then pass the manufacturing orders schedule and plan to the manufacturing site. The manufacturing site will use its complex scheduling algorithms to schedule and plan and be able to pass supplier orders to the suppliers based on stochastic information.

Conclusion

This paper has proposed a methodology so that the stochastic information inherit in a business can be used for planning purposes. This proposed methodology, using *distribution-correlation* plans, is best implemented using discrete-event simulation for planning and scheduling.

In addition, discrete-event simulation is a key technology for the analysis of stochastic systems today. Recent advancements in discrete-event simulation software have made the software more robust, better able to link to corporate databases, and to model objects for re-use. All of these advances place discrete-event simulation at the edge of wider applicability and use.

References

Akamai Technologies, (2009) Akamai Reveals 2 Seconds As The New Threshold Of Acceptability For ECommerce Web Page Response Times. https://www.akamai.com/us/en/about/news/press/2009-press/akamai-reveals-2-seconds-as-the-new-threshold-of-acceptability-for-ecommerce-web-page-response-times.jsp

AnyLogic, Multimethod Simulation Software The only simulation tool that supports Discrete Event, Agent Based, and System Dynamics Simulation. http://www.anylogic.com/areas/supply-chains

Applied Materials, Applied SmartFactory Simulation. http://www.appliedmaterials.com/global-services/automation-software/automod

ArenaSimulation, Supply Chain Simulation & Modeling Software for Improved Process Flow - Arena Simulation. https://www.arenasimulation.com/industry-solutions/supply-chain-simulation-software

Emulate3D Inc., Demo3D - Awesome Models, Fast. https://www.demo3d.com/demo3d/

FlexSim Simulation Software, Supply Chain Simulation - FlexSim Simulation Software. https://www.flexsim.com/supply-chain-simulation/

Goldsman, D., Nance, R.E., Wilson, J.R. (2010) A Brief History of Simulation Revisited. *In Proceedings of the 2010 Winter Simulation Conference*. 567-574.

Ingalls, R. G., Kasales, C. (1999) CSCAT: The Compaq Supply Chain Analysis Tool. *In Proceedings of the 1999 Winter Simulation Conference*. 1201-1206.

Llamasoft, Supply Chain Network Simulation Software & Tools - LLamasoft. http://www.llamasoft.com/solutions/supply-chain-simulation/

Pegden, C.D. Simulation versus Optimization Based Scheduling. http://www.simio.com/resources/white-papers/Simulation-versus-optimization-based-scheduling/index.php

Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E., (Designing and Managing the Supply Chain, 3rd Edition.

Simio, LLC. Simulation, Production Planning and Scheduling Software. http://www.simio.com/applications/supply-chain-simulation-software/