Dynamic Simulation and Supply Chain Management

White Paper

Abstract

This paper briefly discusses how dynamic computer simulation can be applied within the field of supply chain management to diagnose problems and evaluate possible solutions, optimize operations, and mitigate risk factors. The paper also provides a methodology for building supply chain models and identifies the critical criteria for selecting appropriate simulation software. Finally, a simple example of a supply chain model using GoldSim simulation software is described.

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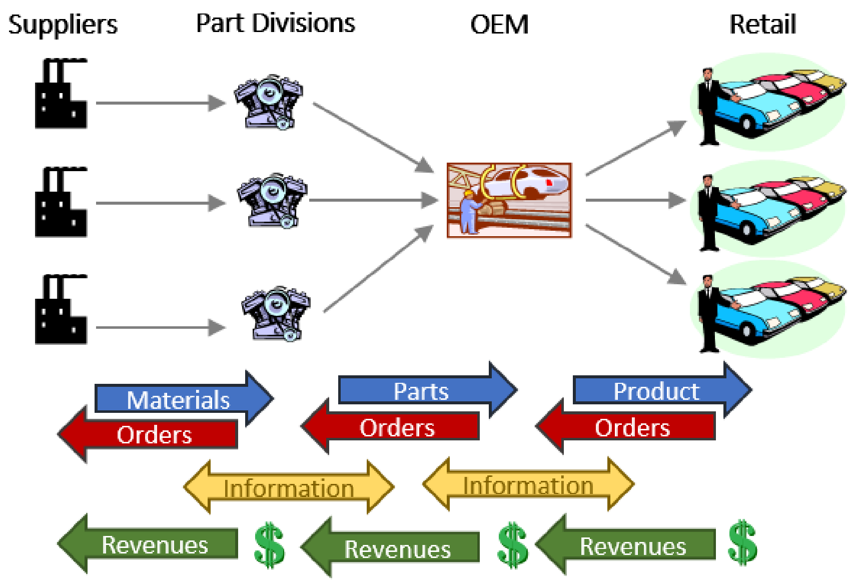
Introduction

Companies face an increasingly challenging marketplace with a growing field of competitors, higher customer expectations, and complex supplier relationships. Increased competition means that companies face the dual challenge of cutting costs while being more responsive to the market. The need to cut costs is driving companies to outsource business operations, minimize inventories, divest underutilized capital equipment and facilities, and in general run as close to the edge as possible. The need to be more responsive to the market drives companies to expand their product lines and increase options, minimize the time to bring new products to market, and quickly modify product delivery rates to match changes in demand.

As competition and complexity has increased, supply chain management has emerged as an increasingly important issue for companies. The challenge of supply chain management is to identify and implement strategies that minimize costs while maximizing flexibility in an increasingly competitive and complex market. This paper briefly discusses how dynamic simulation tools can be used to better understand supply chain dynamics, diagnose problems and evaluate possible solutions, optimize operations, and mitigate risk factors.

Supply chain dynamics. The term “supply chain” generally encompasses the web of interconnected relationships between the sales channel, distribution, warehousing, manufacturing, transportation, and suppliers (see Figure 1). Each component of the supply chain is connected to other parts of the supply chain by the flow of materials in one direction, the flow of orders and money in the other direction, and the flow of information in both directions. Changes in any one of these components usually creates waves of influence that propagate throughout the supply chain. These waves of influence are reflected in prices (both for raw materials, labor, parts, and finished product), flow of materials and product

Figure 1: Schematic Automotive Supply Chain



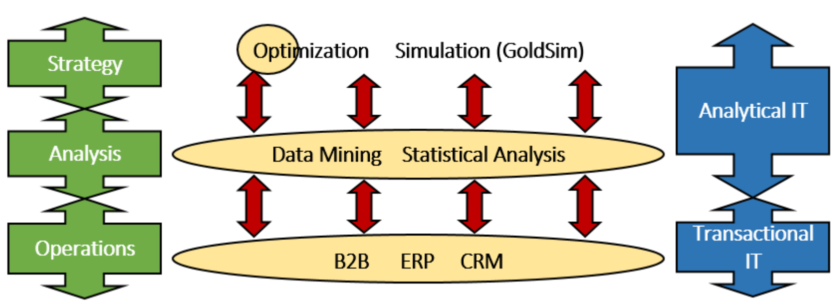
(within a single facility or between facilities within the supply chain), and inventories (of parts, labor capacity, and finished product). How these influences propagate through the system determines the “dynamics” of the supply chain.

It has been observed in many cases that supply chain dynamics demonstrate cyclical fluctuations and instability. These fluctuations are typically a result of information delays (e.g., orders may be based on inventory data that is several week old) and inertia (e.g., once an order is placed it may be weeks or months before the production rate can be changed). These fluctuations can result in many undesirable and/or costly inefficiencies, including stock outs, obsolete inventories, unfulfilled customer demand, or idled factories. The objective of dynamic supply chain simulation is to understand the dynamics of the system and ultimately to identify and evaluate strategies to minimize inefficiencies in the system.

What is dynamic simulation? In this context, the term *simulation* is defined as the process of creating a computer model (i.e., a representation) of an existing or proposed system (in this case, a supply chain) in order to identify and understand the factors that control the system. Any system that can be quantitatively described using equations and/or rules can be simulated. In a *dynamic simulation*, the system changes and evolves with time and the objective in modeling such a system is to understand the way in which it is likely to evolve, predict the future behavior of the system, and determine how to influence that future behavior.

Transactional versus analytical information technology (IT). To understand how dynamic simulation fits within the realm of corporate IT, it is important to differentiate between transactional IT and analytical IT (Figure 2). As discussed by Shapiro[1], transactional IT is concerned with the acquisition, processing, and communication of information regarding the past and present and is primarily used at an operational level. Most of the enterprise resource planning (ERP) software and systems implemented over the past 10 to 20 years fall into the category of transactional IT. In contrast, analytical IT is concerned with forecasting, decision-making, and solving problems. Analytical IT can be divided into analysis software (such as data mining and statistical packages) and strategy software (such as optimization and dynamic simulation software). To maximize the benefits of these different types of software, they should be integrated such that the analytical IT applications can directly utilize the information provided by the transactional IT applications.

Figure 2: Role of Simulation Software within the Enterprise Software Space.



Large companies typically have very complex supply chains with tens or hundreds of distributors, factories, warehouses, transporters, and suppliers. Although ERP software has greatly increased the amount of current information, having timely access to information doesn't always help to understand the system, nor does it tell us much about the future. It is virtually impossible for the

[1] Shapiro, Jeremy F. (2001), *Modeling the Supply Chain*, Duxbury Press, Pacific Grove, California.

human mind to fully comprehend and predict the dynamics of a complex supply chain system. Dynamic simulation software, such as GoldSim, provides the means to incorporate all the data and dynamics regarding a complex supply chain into a computer model that can be used to gain a better understanding of its behavior and make better management decisions.

If the future were predictable, it would be relatively straightforward to design a supply chain that was optimized for that particular future. In reality, however, the future is uncertain, and a well-designed supply chain must be flexible and fully capable of adapting to a wide range of potential futures. Therefore, any simulation of the supply chain must account for all the possible futures by providing a means of incorporating uncertainty into the analysis.

Typical Applications of Supply Chain Models

The process of building a dynamic supply chain simulation model provides valuable insights and understanding regarding the behavior and characteristics of a supply chain. Beyond this expanded knowledge, however, most models are developed to address particular issues. Types of issues that can be addressed using dynamic simulation generally fall into the following categories:

- **Optimization**: Optimization usually involves finding the optimal operational guidelines that either maximize or minimize a particular result, such as minimizing costs and/or risks and maximizing profits. Examples of operating conditions that could be optimized include factors such as inventory levels, investment in maintenance, or geographic distribution of warehousing facilities.

- **Decision Analysis**: Decision analysis typically involves the quantitative evaluation and comparison of two or more alternatives. For example, the decision to build a new production facility could be evaluated by simulating how the supply chain would be impacted by the additional facility. Alternatively, the analysis might be focused on comparison of ten different locations for a new production facility.
- **Diagnostic Evaluation**: Diagnostic evaluation is typically conducted when the cause of a particular problem is unknown. Supply chain simulation can provide insight into the cause of the problems and facilitate development and evaluation of various solutions. For example, a recurring inventory stock-out problem could be investigated using a supply chain model.

- **Risk Management**: As discussed earlier, supply chain dynamics can be severely impacted by unanticipated disruptive events. Examples include labor strikes, destruction of key facilities due to fire or floods, a major customer or supplier going out of business, political upheaval in a country that provides a key raw material, and so on. Many corporations are attempting to determine how to prepare themselves for such events. Supply chain simulation can play an important role in helping companies design redundant systems or mitigation plans to minimize the impacts of disruptive events.

- **Project Planning**: Changes to a portion of the supply chain can result in major disruptions and short-term or even long-term inefficiencies. Examples include outsourcing a major manufacturing process, building a new plant nearer to your major customers, or switching a major supplier. In contrast to decision analysis, which is focused on whether to implement a project, project planning is focused on implementation of the project in a manner that minimizes cost, stays on schedule, and minimizes potential risks.

The GoldSim Planning Methodology

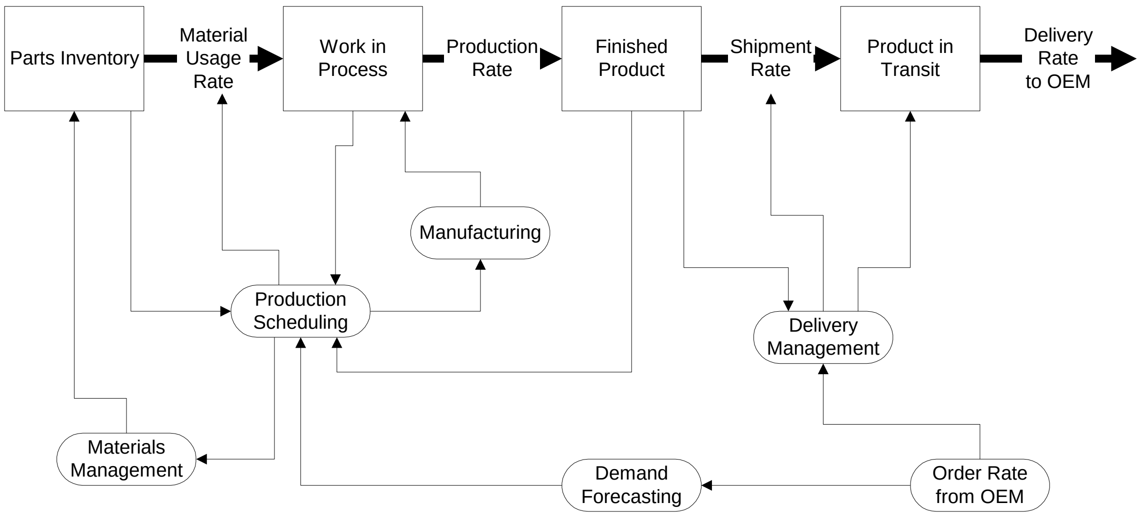
The GoldSim Planning Methodology is designed to support the full spectrum of supply chain management, from a strategic planning level to a more detailed operational level. The overall objective of the GoldSim methodology is to empower decision-makers to design and select the supply chain strategy that offers the highest likelihood of success. The key tenets of the GoldSim Methodology are described below:

1) **Establish Clear Objectives:** The methodology starts by reviewing and clearly stating the objectives of the exercise, and an assessment of their feasibility. Defining the objectives is critical to keep the analysis focused, on time, within its budget, and ultimately, successful.

2) **Decomposition**: It is important to understand that a GoldSim model will not provide useful results if it isn't based on an understanding of the system to be modeled. Therefore, building a conceptual model of your system is probably the most important part of any simulation effort. The greater your understanding of the critical factors that determine the behavior of your system, the more likely your simulation effort will provide useful results.

   Building a good conceptual model of the supply chain system involves an analysis phase that results in decomposition of the system into a series of linked subsystems that define the key components of the system, the relationships between these components, and all relevant feedback mechanisms. Decomposition typically results in an influence diagram that is a conceptual picture of the system, its main components, and their interactions. A simple example of such a diagram is shown below:

Influence Model for Tier 1
Automotive Supplier



3) **Integration:** In order to address the full range of influences identified in the decomposition, the analysis must provide an integrated model of the supply chain system that couples each of the subsystems, rather than treating each part of the system independently. Developing such an integrated understanding of the system typically involves input and feedback from many people within the organization and thoughtful investigation of how the different elements of the system relate.

   The integration phase provides a critical opportunity to foster communication, and get buy-in and support from a broad range of constituents within the organization (e.g., operational managers, technical experts, senior management). As a result, prior to even running the simulation model, most people find that the exchange of information and ideas that occurs while formulating the conceptual model in and of itself provides valuable insights and better understanding of the system.

4) **Top-down/relevance driven:** Models of large complicated supply chains can be difficult to calibrate, explain, and maintain. As a result, the analysis should begin at a high (simplified) level and detail should be added only when the preliminary results indicate that the additional detail is necessary and relevant.

5) **Explicit uncertainty:** Complex supply chain systems have many uncertainties: How will demand vary? How will transportation costs change? What if our largest distributor stops carrying our products? What if currency rates change or political instability impacts our suppliers?

   Since most supply chain systems are characterized by significant uncertainty, it is critical that the analysis explicitly accounts for the full range of possibilities. This includes uncertainties in costs and durations of activities, uncertainties in the consequences and effects of carrying out various activities, and uncertainties regarding the occurrence of outside events (e.g., labor disputes, accidents, a supplier going out of business) or new developments (e.g., a change in currency rates, new distribution channels).

Incorporating uncertainty regarding the *consequences* of carrying out various activities and/or the occurrence of unanticipated incidents or developments can alert the supply chain planner to flaws in the strategy and provide guidance for improving the strategy. Typically, it is not possible to eliminate the possibility of unanticipated incidents or developments (e.g., a drop in commodity prices). However, if these possibilities are explicitly considered in the planning stage of the project, then additional activities can be carried out beforehand and/or contingency plans can be prepared that will reduce the likelihood of the incidents or lessen the impact should they occur.

6) **Dynamic Simulation:** Sound supply chain planning must allow for changes in the operational assumptions depending on future conditions. It should be expected that supply chain managers will make future decisions based on information available at the time. For example, in the situation where transportation cost increase significantly, it is likely that supply chain managers will seek suppliers located closer to their manufacturing facilities.

   In short, the simulation model should specify the planned responses to the uncertain aspects of the supply chain, and how these in turn will affect the manner in which the system behaves from that point forward. Thus, good supply chain systems incorporate the contingency plans necessary to respond to new developments or incidents in the system. Dynamic (time dependent) simulation provides the mechanism to then predict the full range of possible futures, analyze the results, and communicate findings to stakeholders and decision-makers.

7) **Communication:** The process should be conducted in a clear and transparent manner that provides the means to communicate the structure of the model and the results to the stakeholders. This communication element is critical for several reasons:
   - Communication during the model development phase is necessary to ensure that the conceptual model accurately represents reality.
   - Stakeholders find it much easier to trust an analysis that they can understand.
   - Decision makers need to be able to quickly understand a model and the associated results in order to make informed decisions.

Development of a supply chain model requires a team approach that typically includes the following roles:

- **Sponsor**: Usually a senior-level manager who is focused on improving operations and bottom-line results. This person should have the authority and the knowledge to marshal the proper resources throughout the organization and direct the model development activities effectively.

- **Operational Managers**: These managers are usually responsible for some part of the supply chain related to production and manufacturing, transportation, warehousing, purchasing, inventory, marketing and sales, information systems, financial management, and human resources. These are typically the people who know how things work, what processes are in place, and how decisions are made in the real system. Their participation is critical to ensuring that all the important components and decision rules that make up the existing supply chain are identified and incorporated into the conceptual model.
- **Supply Chain Experts**: These participants may either be internal line managers or external consultants with expertise in supply chain management. They typically operate at a corporate level, and focus on coordinating and optimizing overall operations across the supply chain. It is critical that these participants have the expertise to ask the right questions of the operational managers, formulate the conceptual model, and review the computer model of the supply chain to ensure that it accurately represents the conceptual model.
- **Modelers**: These are the people that translate the conceptual models into the mathematical expressions and relationships that make up the computer model. The modelers should be familiar with general computer modeling concepts (e.g., mass balance, unit consistency, Monte Carlo analysis, probability distributions, etc.). It is critical that the modelers be involved in the conceptual model development to ensure that the operational managers and supply chain experts are providing adequate information regarding relationships between critical components of the supply chain, documented or undocumented operational procedures, and feedback mechanisms.

Selecting Simulation Software

Numerous vendors and consultants claim to provide packaged or custom simulation software suitable for supply chain modeling. Although many of these simulation software packages are suitable for modeling simple supply chain systems, some of these packages lack critical features necessary to address real-world problems. When selecting simulation software, key features to look for include the following:

- **Capability to explicitly incorporate variability and uncertainty into the analysis**: Attempting to simulate the future behavior of a supply chain system is complicated by the presence of significant variability and uncertainty (e.g., seasonal changes in demand, variations in production rates, fluctuations in the price of raw materials). Simulation software must have the ability to represent uncertainty regarding input data and system dynamics, the ability to conduct simulations that address the full range of uncertainty, and the ability to present the results in terms of the range and likelihood of different outputs (i.e., probability distributions). This ability is critical for supply chain modeling because many of the important governing parameters and processes are highly uncertain and/or variable.
- **Capability to explicitly represent discrete events**: Supply chain dynamics can be significantly influenced by random discrete events, such as a labor strike, a warehouse fire, or a supplier going out of business. Simulation software must have the capability to represent

random discrete events in a manner that accounts for the likelihood of occurrence, the severity of the event, and the full range of consequences. This is critical for supply chain simulation since discrete (usually disruptive) events, such as labor strikes, supplier bankruptcies, equipment failure, and power outages, can play a critical role in the flexibility, robustness, and overall performance of the supply chain. Moreover, it is not possible to evaluate mitigation plans or alternative strategies without the ability to represent random discrete events.

- **Top-down hierarchical model structure**: Depending on the depth of analysis, large supply chain models can be very complex with thousands of interrelated components. It is infeasible to comprehend and work with such models if they are viewed as a single layer. Complex models must be built using simulation software that allows the investigators to construct hierarchical multi-layer models that represent greater detail at lower levels in the model structure. In this manner, investigators can build, explore, and explain highly-complex models without losing sight of the overall model structure and high-level relationships.
- **Capability to dynamically link to external data repositories**: Supply chain simulation should be based on current information regarding inventories, order rates, production rates, etc. For large models with large amounts of input data, it can be labor-intensive and burdensome to enter data by hand each time investigators want to update the model. Therefore, it is important that the simulation software have the ability to link to ERP and other database systems that represent the most recent information.

The GoldSim suite of software meets all the requirements outlined above. A simple example of a supply chain simulation conducted using GoldSim is presented next.

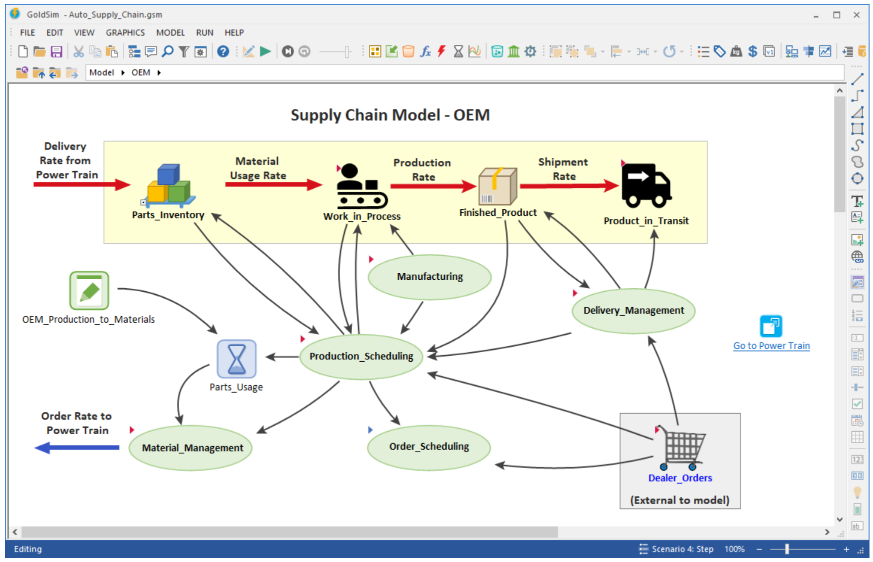
Example Supply Chain Model

The simple example presented here was created using the GoldSim simulation software package (www.goldsim.com). It represents a portion of the supply chain for an automotive manufacturing company. The scope of the model was limited to the OEM and a single tier 1 supplier, the powertrain supplier. The objective of the analysis was to assess the impact of reducing several key information delays (e.g., time to place order for required parts) within the system.

The screen in Figure 4 illustrates the conceptual model for the OEM. The powertrain supplier has a similar conceptual model. The model represents a number of processes, including the following:

- Cyclical and stochastic (random) variability in the dealership order rate
- Production scheduling given constraints in plant capacity, materials and labor
- Manufacturing productivity
- Delivery management and logistics
- Materials management (purchasing) with information delays
- Demand forecasting
- The potential for a labor strike (simulated as a discrete event)

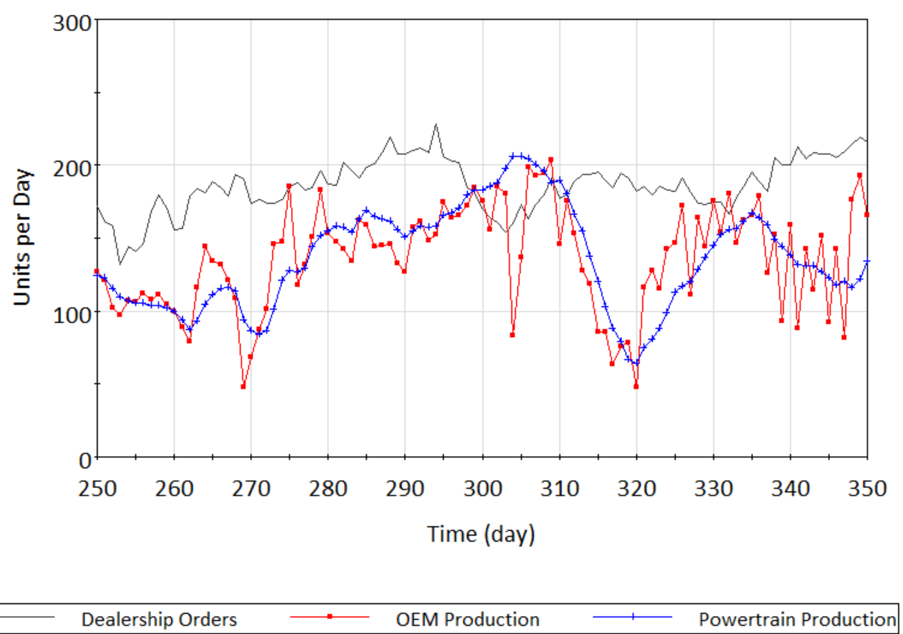
Figure 4: Screen Shot from GoldSim Supply Chain Model.



Quantities that are tracked within the model include: parts inventories, backlog, work-in-progress, finished product, and product-in-transit.

In this simple example, OEM production scheduling is based directly on dealership orders. As a result, the finished product and powertrain production rates go up and down in response to changes in the dealership order rate. Figure 5a shows results for the period from 250 days to 350 days assuming that several key information delays are seven days long. Over this period, dealership order rates vary between 170 and 230 units per day, while the OEM production rate varies from 80 to 230 units per day and the powertrain production rate varies from 50 to 270 units per day. This behavior is consistent with typical supply chain dynamics, in that the amplitude of fluctuations in orders and production

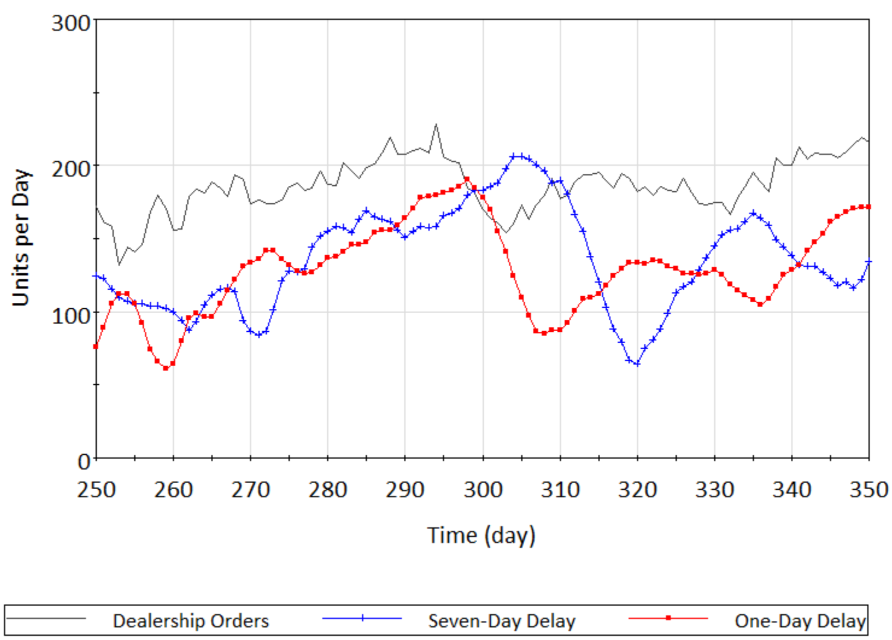
Figure 5a: OEM and Powertrain Production Rates with Seven-Day Delay



increase in magnitude as they propagate down the supply chain. Note that production rates tend to track changes in dealership order rates with a lag of approximately 20 days.

Figure 5b demonstrates how the powertrain production rate is affected if several key information delays are significantly reduced (from seven days to one day). First, changes in the dealership order rate tend to be reflected in the powertrain production rate much sooner, with a reduction in the delay from 20 days to less than 10 days. Second, the range in production rates is significantly reduced, with a maximum production rate of about 200 units per day (compared with 270 units per day) and a minimum production rate of 80 units per day (compared with 50 units per day). Although financial factors are not included in this demonstration model, it is clear that significant cost-savings would result due to the more stable production rates.

Figure 5b: Powertrain Production Rates with Seven-Day and One-Day Delay



Summary

Supply chain management has emerged as an increasingly important issue for companies. The challenge of supply chain management is to identify and implement strategies that minimize costs while maximizing flexibility. This paper discussed how dynamic simulation tools can be used to better understand supply chain dynamics, diagnose problems and evaluate possible solutions, optimize operations, and mitigate risk factors.

Supply chain simulation models can be used to address a broad range of problems and issues. Most of these applications fall into one of the following categories:

- **Optimization**
- **Decision Analysis**
- **Diagnostic Evaluation**
- **Project Planning**
- **Risk Management**

When selecting dynamic simulation software, key features to look for include the following:

- **Capability to explicitly incorporate variability and uncertainty into the analysis**
- **Capability to explicitly represent discrete events**
- **Top-down hierarchical model structure**
- **Capability to dynamically link to external data repositories**

About the GoldSim Technology Group

The GoldSim Technology Group is dedicated to delivering software and services to help people understand complex systems and make better decisions. The GoldSim Technology Group focuses on building great simulation software and supporting the technical aspects of building effective GoldSim models. To provide other dimensions of complete solutions, we maintain close relationships with partners around the world, including consulting firms with specific industry expertise.

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