A Discrete Simulation Framework for Part Replenishment Optimization

David Alfred Ostrowski[1], Bradley Graham[2] and Oleg Gusikhin[1]
[1]Ford Resarch and Engineering, Ford Motor Company, Dearborn, U.S.A.
[2]Ford Part Supplies and Logistics, Ford Motor Company, Dearborn, U.S.A.

Keywords: Supply Chain Optimization, Discrete Simulation.

Abstract: Supply Chains are difficult to plan as they involve complex relations and maintain dynamically changing variables that influence them. In this paper, we present a discrete event simulation framework for purpose of decision making in a replacement auto parts Supply Chain. Ford Motor's Parts, Supply and Logistics (PS&L) department supports a Supply Chain that represents a trade-off where parts are either maintained at a central distribution facility or sent directly to local distribution center. This represents a compromise between inventory transportation costs and accessibility in parts distribution. To support decisions within this environment, we present a framework to characterize this scenario as a discrete simulation problem allowing for the means to evaluate controls for the determination of optimal inventory (on-hand inventory dollars), fill rate and labor costs. Our case study results demonstrate the necessary dynamics to support this decision making process.

1 INTRODUCTION

To support a competitive advantage, Supply Chains are continually faced with challenges of process improvement to support adaptation to customer demand. Effective Supply Chains are those designed to deliver products and services in a reliable fashion with low cost and high quality. Fluctuations in demand and production change dynamically making Supply Chains difficult to grasp (Shapiro and Jeremy, 2001) (Sabri et al., 2000). One approach is to develop Supply Chain models for analysing operational, tactical and strategic decisions in order to improve performance (Seppala and Holmstrom, 1997).

Supply Chain Management (SCM) can be divided into two levels: strategic and operational (Cooper et al., 1997) (Gunther and Meyr, 2009). The primary objective of strategic optimization models is to determine the most cost-effective location of facilities (plants and distribution), flow of goods throughout the Supply Chain and assignment of customers to distribution centers. These types of models do not seek to determine required inventory levels and customer service levels. The main purpose of optimization at the operational level is to determine safety stock for each product at each location, size and frequency of product batches that are replenished or assemble, replenishment transport and production lead times and the customer service levels (Mentzer et al., 2001).

Uncertainty is one of the most challenging problems in SCM making it difficult in the practical analysis of performance (Mason-Jones and Towill, 1998) (Van der Vorst and Beulens, 2002). In the absence of randomness, the problems of material and product supply are eliminated. As a result, all demands, production and transportation behaviour would be completely resolved and therefore, predictable. Our goal in this work is to support both strategic and operational analysis to a Supply Chain in light of uncertainty through the means of a discrete simulation.

Ford Motor Parts, Supplies and Logistics department (PS&L) maintains a Supply Chain network that is responsible for the purchase and distribution of Ford and Motorcraft branded service parts for over 3000 Ford and Lincoln dealers. The distribution network is referred to as Ford Authorized Distribution (FAD) representing sales of 2.4B parts annually. To service dealers, Ford Customer Service Division (FCSD) maintains 20 High Volume Distribution Centers (HVC) for high volume parts.

Alfred Ostrowski D., Graham B. and Gusikhin O..
A Discrete Simulation Framework for Part Replenishment Optimization.
DOI: 10.5220/0004633004670473
In *Proceedings of the 3rd International Conference on Simulation and Modeling Methodologies, Technologies and Applications* (SIMULTECH-2013), pages 467-473
ISBN: 978-989-8565-69-3

Among parameters to be considered in this Supply Chain includes the categories of demand, allocation and controls. Each of the given scenarios are guided by the forecast of demand with the ability to measure true demand to determine their performance. Many business decisions are considered around the dynamics of this Supply Chain, including the appropriate intervals and levels of replenishment. When these parameters are changed, it is difficult to understand and analyze how they can affect customer service levels (fill), labor, inventory levels and total inventory over time.

Viewing the Supply Chain across the entire production process, each component is interconnected, by materials in one direction, the flow of orders in the other and flow of information in both. Changes in any one of these components usually create waves of influence that propagate through the Supply Chain. Such waves are reflected in inventory levels.

This paper describes the construction of a discrete simulation framework that allows for the exploration of scenarios across a range of forecasts. A simulation-based program is created using a historical demand, forecast, and inventory plan to determine a time series output representing inventory, fill rate and labor. The eventual goal of this framework is to support a complete system-level optimization. In the next section, we present a survey of related work. Section three continues with the discussion of our proposed methodology. Section Four presents our test cases demonstrating the framework and Section Five presents our conclusions.

2 CURRENT RESEARCH

Simulation is a well-known technique for investigating line-dependent behaviors in complex and uncertain systems (Cooper et al., 1997). This allows a distinct advantage over static models as they do not incorporate dynamic aspects of the Supply Chain that are important for it to perform. Discrete Event Simulations (DES) are effective techniques in Supply Chain planning by enabling evaluation of dynamic aspects as well as influence of variance on Supply Chains, which can be used to support decision making (Angerhofer and Angelides, 2000), (Kleijnen, 2005). A number of variations of DES have been leveraged to real world problems. One example is (Hellström and Johnsson, 2002) who applied DES to simulate the effects of wireless identification technology as applied to unit loads throughout a retail Supply Chain without disrupting the actual system being modelled (Hellström and Johnsson, 2002). (Almeder et al., 2009) demonstrated the utility of integrating discrete event simulation and mixed-integer linear programming into a general framework to support operational decisions for Supply Chain networks (Almeder et al., 2009). Based on initial simulation runs, cost parameters, production and transportation times were estimated for an optimization model. This problem was applied iteratively until the difference between subsequent solutions were determined. (Lee et al.,) proposed an architecture of combined discrete-event and continuous modeling for supply chain, which included an equation of continuous proportion in the supply chain, thus demonstrating the effectiveness of a combined approach (Lee et al., 2002).

(Sabri and Beamon, 2000) supported a multi-objective Supply Chain model to use in simultaneous and operational planning. They were able to incorporate production, delivery and demand uncertainty, thus providing a multi-objective performance vector for the entire network (Sabri and Beamon, 2000). (Chopra and Sodhi, 2004) identified categories of risk within the Supply Chain including effects that include how actions that mitigate one risk and exacerbating others. Examples include where low inventory levels decrease the impact of over-forecasting demand, thus simultaneously increasing the impact of a Supply Chain disruption (Chopra and Sodhi, 2004). Additional examples include genetic algorithms (Altiparmak et al., 2006), fuzzy sets (Chen and Lee, 2004), pre-emptive goal programming (Wang et al., 2004) visual interactive goal programming (Karpak et al., 2001) as well as hybrid models (Aburto and Weber, 2007) (Sarjoughian et al., 2005).

Supply Chain simulations have also explored the affect of information flows within the supply chain and it's effect on the dynamics. Among this area, (Chen et al., 2000) identified demand forecasting and order lead times as contributing to what was determined as the bullwhip effect. By extending their models to multiple-stage Supply Chains with centralized customer demand information they were able to demonstrate that the bullwhip effect can be reduced, but not completely eliminated, by centralizing demand information (Chen et al., 2000.). (Lee and Hau, 2000) also quantified the benefits of information sharing between a simple two-level supply chain with non-stationary end demands. Their results suggested that the value of demand information sharing can be quite high, especially when demands are significantly correlated over time (Lee et al., 2000).

3 METHODOLOGY

Figure 1 below details the paths in Ford PS&L's Supply Chain that are to be considered for our framework. The starting points for all parts are at a manufacturer. Each producer may either send a part first to a packager or directly to the main (centralized – PRC) facility. In case of emergencies, a direct delivery may be performed, thus bypassing the PRC or HVC locations and delivered directly to a dealer. At the PRC, parts are either maintained in inventory or sorted for the each of the HVCs. After delivery to the respected centers, they are delivered to dealers to satisfy the consumer demand. Additional routes exist in this path including three (low-volume) High Cube Centers (HCCs) for large size parts as well as Ford Authorized Distributors (retailers).

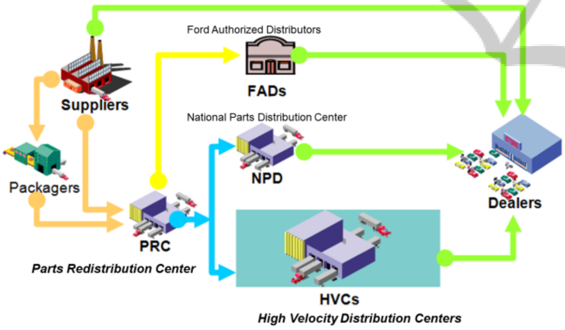

Figure 1: Overview of Supply Chain.

Figure 2. presents the main HVCs along with associated paths for the continental US. Each dealer has an associated sequence of HVC locations to consider for each individual part. Also, in conjunction with each part/dealer reference is a described referral pattern that support the selection process across the sequence allowing each dealer to have a separate methodology of how to search for a potential part through all 27 locations if necessary.

Figure 3. presents the order process along a time line. The PS&L department maintains the inventory positions in both the PRC and local HVCs. Order for replenishment are executed at the PRC level and are influenced by inventory positions as well as forecasted demand. Suppliers have the parts ready for the distribution network along a specified lead time. During the lead time the HVC's observe the central demand and consequently updates the

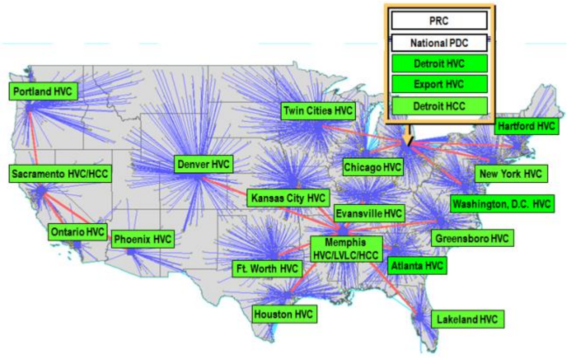

Figure 2: HVC.

appropriate quantity. The PS&L department decides how many parts to push to the HVCs and how many parts to store at the PRC for future pull deployment. Risk pooling is obtained by storing parts in the PRC which is balanced with the extra cost of inventory, storage and labor. The following figure 4. defines the focus of our Supply chain framework

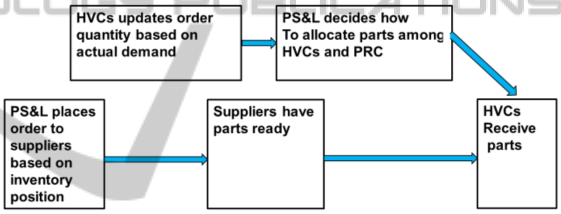

Figure 3: Order Process.

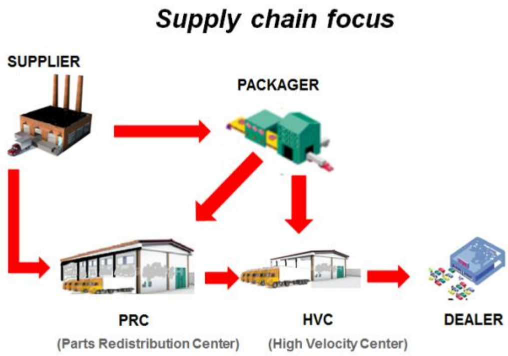

Figure 4: Supply Chain Focus.

3.1 Problem Definition

Optimization of our Supply Chain is assisted through evaluation of past forecasts as well as comparisons between alternative configurations. The three primary parameters of interest in this case are the fill rate (capability to meet demand), labor (transportation costs) and inventory (storage costs).

Two strategies exist in this problem identified as either a “pull” or centralized inventory or a “push” or decentralized inventory. A pull strategy may be beneficial in scenarios in which a specific HVC experiences a lower demand as compared to the forecast during a suppliers production lead time. In this case it may be beneficial to send less parts to the HVC and store the remaining at the PRC (central facility) The parts stored would then be able to satisfy demand at any HVC in the future (due to the effect of risk pooling). On the other hand if the PS&L department decides to push parts to the HVC regardless of the observed demand, the inventory costs would be lower at the PRC while increasing risk of possible redistribution costs. For the description of our implemented framework, we first consider the initial terms:

ltd = Lead Time Demand
fr = Fill Rate
l = Labor
OH = On-Hand Inventory
I = In-transition Inventory
T = Total Inventory

Where lead time demand is calculated as the estimated (forecasted) demand (as a function of lead time between the PRC to corresponding HVCs). Fill Rate represents the ratio of backorder to demand and is calculated as (1 – b/d). Labor is expressed as a unit of cost of transportation from between all noted locations. In-transition inventory is designed as the future expected inventory of a location and T as the total (onHand and InTransition).

3.2 Part Ordering Policy

PS&L applies a variation of the Standard Economic Ordering Model (EOQ) for inventory level maintenance at each local HVC. At the end of each period, the manager checks the inventory level (inventory on hand plus inventory in transition) for each part in each building (HVC). If the level is lower than a predetermined amount (SS plus one month forecast demand) the manager will place an order with a predetermined amount for that part. Within the HVC all orders are aggregated from which they are counted against the current inventory. Orders are also influenced by external factors including production lot size and quantity discount. Following is a breakdown of the formulas that are to be applied in the context of each DRP day of operation:

tgd = total gross demand (forecast)
tgr = total gross receipt
ps = projected stock
rnd = rounded net demand (constrained)
und = unrounded net demand (adapted)
t = time
ps = ps_{t-1} + tgd + rnd

$$und = \begin{cases} ss_t - (ps_{t-1} - tgd), & if ps_{t-1} - tgd < ss \\ tgd, & else \end{cases}$$

$$nd_{ss} = \begin{cases} ss_t - (ps_{ss} - tgd), & if ps_{t-1} - tgd < ss \\ 0, & else \end{cases}$$

$ps_t = ps_{t-1}$ - tgd +nd

$rnd_t = \sum und_t + \sum_{i=1}^{EOQ} nd_{ss}$

Considering the following condensed spreadsheets as an example, each day at an HVC location must consider updated inventory positions and weight them against the necessary forecasts. After the dealer demand has been satisfied, updated inventory will serve as a starting point as net demand calculation will be utilized to influence the allocation tiers as described in the following section.

Parts Redistribution Center								
Q=4000 ss=500 LT=5 BOH=190	5-Jun	6-Jun	7-Jun	8-Jun	11-Jun	12-Jun	13-Jun	14-Jun
Total Gross Demand	1000	1200		1400	1000		1200	1400
Projected Receipt	4000							
Projected Balance	4900	3700	3700	2300	1300	1300	100	-1500
Safety Stock	500	500	500	500	500	500	500	500
Net Demand							400	1400
Order Release		4000						

High Volume Distribution Center								
Q=200 ss=20 LT=3 BOH=380	5-Jun	6-Jun	7-Jun	8-Jun	11-Jun	12-Jun	13-Jun	14-Jun
Total Gross Demand	80	80	80	80	80	80	80	80
Projected Receipt			200					
Projected Balance	300	220	340	260	180	100	20	-60
Safety Stock	200	200	200	200	200	200	200	200
Net Demand					20	80	80	80
Order Release		200			200			

Figure 5: PRC, HVC daily deployment.

3.3 Supplier Order

Supplier order is considered at the end of every inventory calculation at the PRC. An order to a supplier will only occur after a set ‘freeze period’ determined as the interval by which orders may be made to a supplier. A potential order to a supplier is determined as the supplier shortage amount, total gross demand of the PRC inventory, total supplier EOQ demand subtracted by projected stock and total gross demand

Net demand is calculated as:

$$min(0, D_i + Inv_{i-1} - ss_i + R_i)$$

The shipping quantity is an Economic order quantity, calculated as:

$$EOQ_i = \sqrt{\frac{2K\lambda_i}{Ic_i}} \text{ , where}$$

K – order cost
λ_i - forecasted annual volume for part I

c_i – cost of part i
I – annual interest rate (19-21%)

The safety stock is calculated based on the service type II model. σ standard deviation of demand is equal to 1.25 multiplied by the MAD that is the difference between the actual and the forecasted demand. From EOQ, fill rate, and standard deviation of the demand over the lead time L we find:

$$L(z) = \frac{EOQ(1-\beta)}{\sigma} ,$$

Then we find z, and calculate safety stock as: ss = z $\sigma\sqrt{L}$

3.4 Part Replenishment Policy

When parts have been received at the PRC, there are four separate tiers of allocation that are applied. The following sequence is followed: 1) residual backorders, 2) regular demand 3) safety stock 4) sum of net demand. Backorders are calculated as previous projected stock subtracted by current total gross demand. This is the highest level of priority as it indicates a shortage in inventory. The LeadTime is determined as the amount of projected demand that is accumulated over the associated Lead Time days. Safety Stock coverage calculated from historical safety stock evaluations. The EOQ formula is identified as the sum of the rounded net demand for the next end of order quantity data. Each of these levels are calculated on the HVC independent of the events then an incremental building level is designated by eliminating both the higher priority tiers as well as current inventory (physical) position. The value is then rounded and added among the other tiers, to determine an upper limit for the tiers. For extra inventory considered between the tiers of allocation, the following calculations are applied to allow for ameans of proportionate allocation. Identified as the fairshare algorithm each HVC will receive allocations based on the following calculations:

tr = current tier

tr-1 = prior tier

p,b,t = part, building, tier

onHand= pbt_calc_{tr-1}- pbt_tot

delta_req = $pbt\_calc_{tr-1} - pbt\_calc_{tr}$

fill = onHand / delta_req

avg = $\sum onHand$ / $\sum delta\_req$ + quantity - $\sum EOQ\ total$

fs = (ss_pbt + delta_req_pbt * avg) - onHand

4 SIMULATION

Our simulation considers each part independently within our reduced configuration (supplier, packager, PRC, MVC, dealer). This process is detailed in eight steps as presented in the following diagram. The system considering a single part along with a standing inventory begins with step one in which the HVC receives an order that has been ordered in the past. In step two, considering the future (forecasted) demand, an HVC will place an order. In step three, the business day then begins in which customers arrive and HVCs in turn satisfy a given demand. In step four if the given demand is short of the current inventory, an HVC will place it on backorder. Following in step five, the PRC aggregates orders for the HVCs then places them as a single order to a supplier. At step six, Parts are then ready at the suppliers at t + SUPLT (supplier lead time). Next, in step seven the PRC's will allocate parts according to five separate tiers of allocation. Finally (step eight) the day ends (where each process begins as parts ordered arrive and then are ready to be considered against next business day)

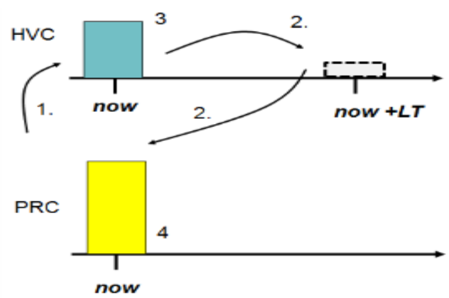

Figure 6: Simulation Timeline pt1.

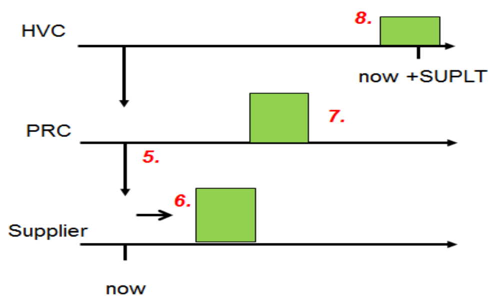

Figure 7: Simulation Timeline pt2.

The overall simulation process description is presented in Figure 7. Four major points are illustrated in the flow of inventory stating with the beginning stock (1), continuing with the net demand determining the planned amount to sell (2). Next the supplier order is presented (3) from which the day is wrapped up with the consideration of exactly what amount sold (4).

5 CASE STUDY

We examine the application of our model to support the characterization of a Supply Chain. We examine a single part AA5Z16138A towards these attributes. Part AA5Z16138A maintains service to five separate HVC centers in which each are characterized along a historical demand for the business days between June-4-2012 to Aug-4-2012 for each simulation run. Considering an individual simulation, the in-transit and total inventory levels and corresponding fill rates are presented as a function of the established lead times and EOQ (figure 8). Following, we examine a characterization of the effect of lead time on service levels. This is characterized along a 60 day month interval (figure 9). As noted in the following diagram the same scenario was explored across ranges of Economic Order Quantity (EOQ) in which all other variables were fixed (figure 10). In our part description – there was an issue with regards to the demand forecast producing an overcapacity – the demand was lowered to one part per HVC in order to produce this effect.

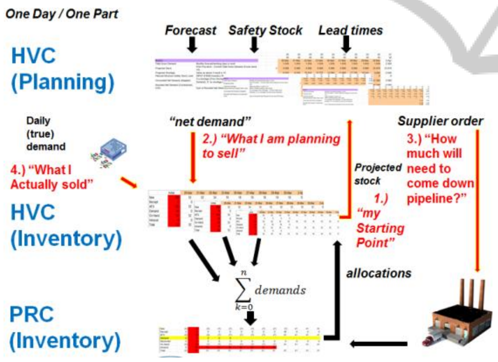

Figure 8: Simulation Overview.

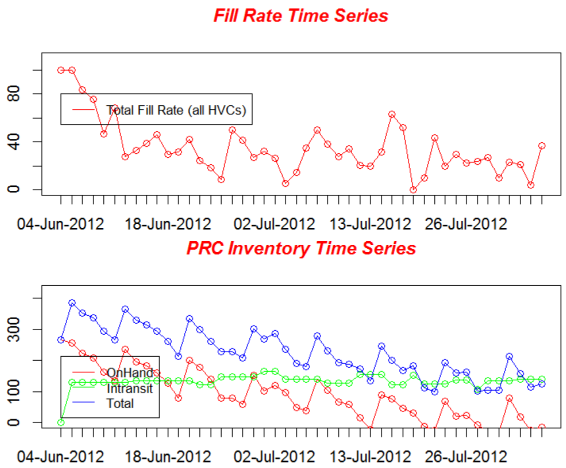

Figure 9: PRC time series inventory, FL for EOQ = 3.

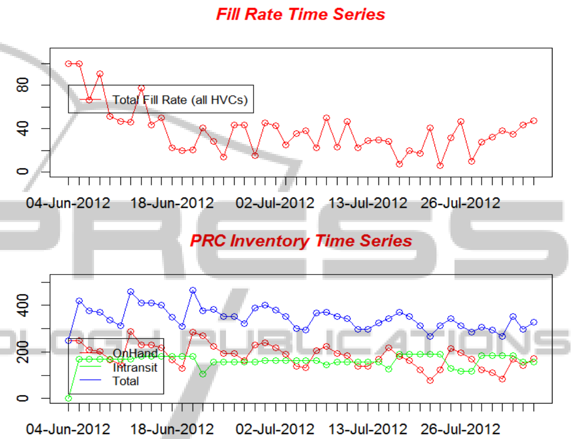

Figure 10: PRC Inventory Time Series and Fill Rate (EOQ= 6).

6 CONCLUSIONS

We have presented a framework so support a discrete event simulation for part replenishment optimization. Our framework considers the interaction between a centralized facility and local distribution centers for a parts distribution Supply Chain. Our simulation accounts for forecast-driven allocations to be evaluated within set configurations including specified order intervals and lead time demands. Supplier Orders are modelled after an EOQ model and service replenishments are driven by a proprietary algorithm to allow for a proportional replenishment. Considering our framework with an individual part, we can generate the effects of Lead Time and EOQ over a specified range and determine associated fill rates which may be compared against corresponding labor and inventory costs for a means of comparison. Future work includes the scaling of parts evaluations as well as incorporation of optimization methods into this framework.

REFERENCES

Shapiro, Jeremy F. 2001. *Modeling the supply chain*. Vol. 971. Pacific Grove, CA: Duxbury

Sabri, Ehap H., and Benita M. Beamon. 2000. "A multi objective approach to simultaneous strategic and operational planning in supply chain design." *Omega* 28.5: 581-598.

Seppala, U, Holmstrom, J. 1997. “Rough modelling of logistics networks”, Integrated Manufacturing Systems, vol 6. No . 5, pp 13-20,1995

Cooper, Martha C., Douglas M. Lambert, and Janus D. Pagh. 1997. "Supply chain management: more than a new name for logistics." *International Journal of Logistics Management, The* 8, no. 1: 1-14.

H. O. Gunther, H. Meyr. 2009. Supply Chain Planning , Springer-Verlag Berlin Heideberb

Mentzer, John T., William DeWitt, James S. Keebler, Soonhong Min, Nancy W. Nix, Carlo D. Smith, and Zach G. Zacharia. 2001."Defining supply chain management." *Journal of Business logistics* 22, no. 2: 1-25.

Mason-Jones, Rachel, and Denis R. Towill. 1998. "Shrinking the supply chain uncertainty circle." *IOM Control* 24.7: 17-22.

Van der Vorst, Jack GAJ, and Adrie JM Beulens. 2002. "Identifying sources of uncertainty to generate supply chain redesign strategies." *International Journal of Physical Distribution & Logistics Management* 32, no. 6: 409-430

Angerhofer, Bernhard J., and Marios C. Angelides. 2000. "System dynamics modelling in supply chain management: research review." In *Simulation Conference, 2000. Proceedings. Winter*, vol. 1, pp. 342-351. IEEE

Kleijnen, Jack PC. 2005."Supply chain simulation tools and techniques: a survey."*International Journal of Simulation and Process Modelling* 1, no. 1: 82-89.

Hellström, D., and M. Johnsson. 2002. "Using discrete-event simulation in supply chain planning." *14th Annual Conference for Nordic Researchers in Logistics*.

Almeder, Christian, Margaretha Preusser, and Richard F. Hartl. 2009. "Simulation and optimization of supply chains: alternative or complementary approaches?."*Supply Chain Planning*. Springer Berlin Heidelberg, 1-25.

Lee, Young Hae, et al. 2002. "Supply chain simulation with discrete–continuous combined modeling." *Computers & Industrial Engineering* 43.1: 375-392.

Sabri, Ehap H., and Benita M. Beamon. 2000. "A multi-objective approach to simultaneous strategic and operational planning in supply chain design."*Omega* 28.5: 581-598.

Chopra, Sunil, and ManMohan S. Sodhi. 2004. "Supply-chain breakdown." *MIT Sloan management review* (2004).

Altiparmak, Fulya, Mitsuo Gen, Lin Lin, and Turan Paksoy. 2006. "A genetic algorithm approach for multi-objective optimization of supply chain networks."*Computers & Industrial Engineering* 51, no. 1: 196-215.

Chen, Cheng-Liang, and Wen-Cheng Lee. 2004. "Multi-objective optimization of multi-echelon supply chain networks with uncertain product demands and prices."*Computers & Chemical Engineering* 28, no. 6 : 1131-1144.

Wang, Ge, Samuel H. Huang, and John P. Dismukes. 2004. "Product-driven supply chain selection using integrated multi-criteria decision-making methodology."*International journal of production economics* 91, no. 1 (2004): 1-15.

Karpak, Birsen, Erdoğan Kumcu, and Rammohan R. Kasuganti. 2001. "Purchasing materials in the supply chain: managing a multi-objective task." *European Journal of Purchasing & Supply Management* 7, no. 3: 209-216.

Aburto, Luis, and Richard Weber. 2007. "Improved supply chain management based on hybrid demand forecasts." *Applied Soft Computing* 7, no. 1: 136-144.

Sarjoughian, Hessam S., Dongping Huang, Gary W. Godding, Karl G. Kempf, Wenlin Wang, Daniel E. Rivera, and Hans D. Mittelmann. 2005. "Hybrid discrete event simulation with model predictive control for semiconductor supply-chain manufacturing." In *Proceedings of the 37th conference on Winter simulation*, pp. 256-266. Winter Simulation Conference

Chen, Frank, et al. 2000. "Quantifying the bullwhip effect in a simple supply chain: The impact of forecasting, lead times, and information." *Management science*46.3 (2000): 436-443.

Lee, Hau L., Kut C. So, and Christopher S. Tang. "The value of information sharing in a two-level supply chain." *Management science* 46, no. 5 (2000): 626-643