7-2003

Simulation as a Tool for Evaluating Strategic Policies for Flexible Supply Chain Systems

Janice L. Forrester
Portland State University

Wayne W. Wakeland
Portland State University, wakeland@pdx.edu

Citation Details

Forrester, J.L., W.W. Wakeland (2003). Simulation as a tool for evaluating strategic policies for flexible supply chain systems, proceedings of PICMET '03 (Portland International Conference on Management of Engineering and Technology), Portland, Oregon, 12 pages.

Simulation as a Tool for Evaluating Strategic Policies for Flexible Supply Chain Systems

Janice Forrester[1], Wayne Wakeland[2]

[1]Portland State University, Engineering and Technology Management Dept., Portland, OR USA
[2]Portland State University, Systems Science Ph.D. Program, Portland, OR USA

Abstract- The emergence of flexible supply chain systems (FSC) has sparked increased interest in real-time planning, scheduling, and logistics--with particular consideration for strategic implications and overall cost control. Important aspects of an FSC include forecasting, production, materials handling, transportation, and distribution center inventory. There exists a variety of software applications for addressing *tactical* issues, such as adaptive scheduling, and short term forecasting. However, these programs typically do not permit the user to assess the strategic implications of different policies for flexing capacity and making alternative commitments to manufacturing plants. Recently there has been increased interest in the use of simulation models for strategic policy analysis. Simulation compares favorably to purely analytical methods that often fail to capture the complex interactions of a particular FSC. The challenge is to create an FSC simulation model that is general enough and flexible enough to allow the user to analyze the overall costs and benefits of different policies. This paper presents just such an FSC model, implemented in a system dynamics modeling language. The model is specifically designed to help the user evaluate different policies for scheduling production in the factories and policies that govern factory capacity…in terms of their impact on overall production cost and inventory turns. Preliminary results include new insights regarding the conventional wisdom that minimizing the incremental amount that a factory can fluctuate at any given point in tam will reduce cost. The model suggests the contrary, that requiring larger fluctuations actually reduces the frequency and overall magnitude of the changes without adverse impact on factory utilization.

I. INTRODUCTION

The emergence of flexible supply chain systems (FSC) has sparked increased interest in real-time planning, scheduling, and logistics--with particular consideration for strategic implications and overall cost control [9]. Important aspects of an FSC include forecasting, production, materials handling, transportation, and distribution center inventory [14]. Strategic activities focus on setting integrated global policies and contract negotiations. Real-time activities primarily refer to weekly operations that require efficient, timely, and adaptive responses to customer expectations, short-term scheduling, and execution concerns [6]. There are a variety of software applications that provide visibility and control of the tactical issues. What is lacking are tools for assessing the efficacy of global strategic policies including capacity planning, phased commitment to manufacturing, transportation, and distribution center inventory management.

Recently there has been increased interest in the use of simulation for evaluating policies for real-time planning, operational control, adaptive scheduling and planning, and forecasting [14]. The use of simulation appears to compare favorably to purely analytical methods that often fail to capture the complex interactions of a particular FSC[5] and is well established in the literature as highly applicable in operations and strategic management [4,8,10]. Applying simulation as a real-time tool requires insight into the role of the simulation model within the overall FSC [7]. The challenge is to find a way to represent in an operational model the problems and decision-making requirements for an FSC so that one may assess the costs and benefits of various policies or business process changes which would provide managers with a powerful tool which can be used to provide direct competitive advantage [5,15]. This paper presents a system dynamics-based flexible supply chain model for evaluating different capacity planning policies and analyzing their impact on overall production cost.

II. STRATEGY AND EXPECTATIONS

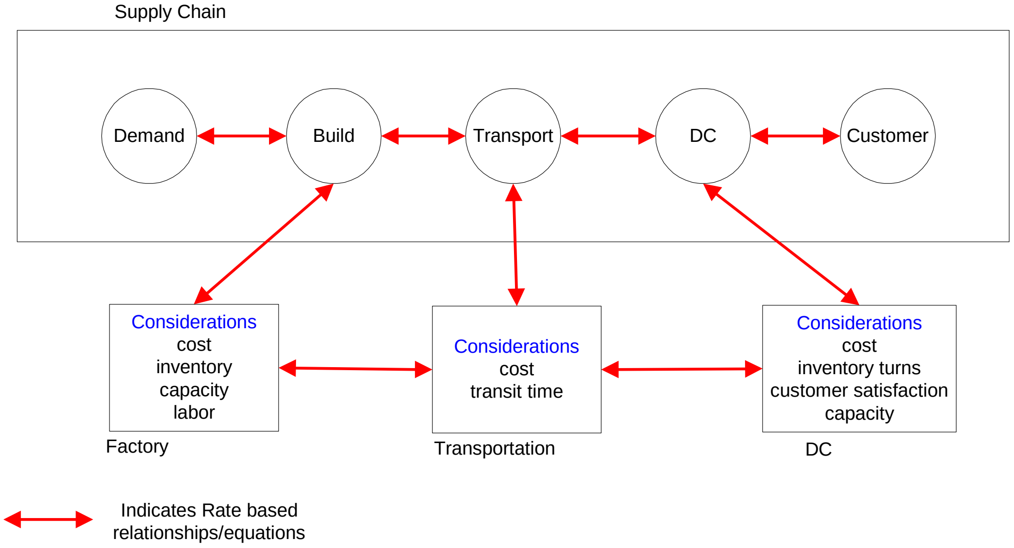
A. Objective

Our objective is to determine a cost optimal aggregate factory load policy (AFLP) that enables high customer satisfaction and responsive to demand swings and perturbations. We have chosen to focus on factory capacity (equals production capacity) since it is key to cost control, customer satisfaction, and efficient resource utilization [11]. Cost is defined to be a combination of real cost and shadow cost for the full supply chain from demand forecast through to the customer. Shadow cost is used in the case when observed prices fail to accurately reflect the social value of a good, or prices do not exist at all. Aggregate factory load is a function of usage, available capacity, and throughput.

B. System Components

We will use five major supply chain components: (1) demand, (2) build, (3) transportation, (4) distribution centers (DC), and (5) Customer [3]. The major components are depicted in Figure 1.

Figure 1: Major Components of the Supply Chain



The components of a supply chain can be clustered into three different categories based on the level of control that the manufacturing companies can exercise; (1) no control, (2) tactical control, and (3) strategic control.

(1) No control is defined as having at best limited reactionary control over the parameters involved, and includes actual demand and customer satisfaction. Demand is the driver of all actions within the supply chain. Although significant effort is placed on forecasting, the forecast does not drive the factory, actual demand does. Thus, the creation of a flexible supply chain that can react to the fluctuations and perturbations in demand is one of the keys to success.

(2) Tactical control refers to supply chain activities that can quickly respond to changing short-term situations. Mode of transportation is the only component of this type considered in our model.

(3) Finally, there are aspects of the manufacturing that are flexible, but only within specified predetermined parameters that are dictated by corporate policy or pre-negotiated contracts. These are classified as strategic control components. Two examples are Factory capacity and distribution center (DC) capacity. For example, a factory could be prepared to manufacture 10,000 units per week, but if they worked double or triple shifts they could manufacture as much as 18,000 units. However, to manufacture more than 18,000 units they would need to physically add manufacturing machines and train additional labor. Similarly, if the factory is prepared to manufacture 10,000 units per week and only receives a request for 3,000 units, sectors of the factory would have to shut down thereby eroding the factories projected revenue, potentially to the point that the factory would need to close.

III. FSC SIMULATION MODEL

Many large companies are structured such that each individual component of the supply chain works to produce optimum results within its sector at a tactical level. For example, logistics will try to reduce airfreight while manufacturing will try and level load the factories resulting in an increase in airfreight. However, we will be presenting an integrated or strategic model representing the interaction amongst the sectors [12] and aid in policy evaluation that will improve customer satisfaction and reduce overall supply chain cost [13]. Of the two factors that are able to be controlled strategically, factory and DC capacity, DC capacity is significantly more difficult to change than factory capacity because a substantial change in DC capacity requires a DC to be bought or sold thus having significant capital dollar impact.

Therefore, for our model, DC capacity will be considered to be static. Factory capacity, however, can be renegotiated as often as quarterly without significant capital expenditure. The objective of the model is to determine the appropriate level of carrying capacity in the factories that will (1) support the required manufacturing plan, (2) preserve the financial viability of the factories, (3) maintain DC inventory turns at an appropriate level, and (4) reduce overall supply chain cost.

Inputs for the model are demand, initial average factory capacity, average DC capacity, and eventually cost. Demand is based on the company's historical demand over a one year time period. Demand includes future orders, two weeks of safety stock, and at once orders collected for all demand regions and submitted once per month. Initial factory capacity is set based on the average factory capacity negotiated by the company in the previous year. Similarly, DC capacity is set to the current DC capacity for the company. There are three sub-models that track factory cost, transportation cost, and the DC costs.

The model allows the user to observe the tactical supply chain events based on demand. The primary control of the system will be the Flex Policy. Flex policy dictates the increase or decrease of factory capacity. Flex Policy can either be incorporated as a dynamic feedback loop based on predefined balance of Factory Cost and DC Inventory Cost or it can be adjusted manually by the user.

The assumed reference behavior pattern (RBP) is that the system will come to a steady state at a point when the factory capacity is sufficient to meet the demand needs and the cost impact within the feedback loop considering both the cost to the factory and the cost of DC inventory is acceptable. It is also hypothesized that when the overall system is optimal, the subsystems may in fact, not be optimal.

Model Requirements:

- Continued economic support of the factories
- Production of supply to meet demand in a timely manner
- Maintain high inventory turns
- Demand has significant spikes
- Factories should be level loaded
- Inventory turn penalties
- Carrying cost of factories

Cost Considerations:

- Air Freight cost
- Factory Costs
  - o Unused capacity costs
  - o Exceeding capacity costs
  - o Flex up and flex down cost to factories
  - o Production costs – tooling cost
- DC Inventory costs
  - o Build risk and cost of closeout
  - o Preorder risk and cost of unused materials
  - o Storage cost
  - o Inventory turns

IV. MODEL CONSIDERATIONS

A. *Factory Considerations*

The ideal situation from the factory's sustainability perspective would be for the factories to be level loaded at some specified capacity. Realistically, based on demand fluctuations, the factories are loaded based on a leveling process that ensures on time production to meet demand and considers that factories can flex from a baseline value to upper and lower capacity limits. The impact of flex can be categorized in terms of the increment and timeframe associated. Considerations were developed based on in depth interviews with several major factory groups primarily in SE Asia such as Indonesia, South Korea, Taiwan and China.

- Flex up or down of Y percent from the baseline does not involve significant cost, only the incremental cost of productivity and is valid only for duration of time t_i for factories i = 1,, n.
- Flex up or down of greater than Y percent from the baseline involves adding workers/lines or removing workers/lines respectively and comes at a much more significant cost and is a permanent change.
- Flex costs to be considered
  - a. Overhead & Capital, Labor, Worker Moral
  - b. Shadow cost of worker moral is important
  - c. Transition cost of flex does not appear to be a consideration.
- Future considerations would be to consider that the factories may be grouped with respect to the relationships and impacts of flexing.
- Underutilizing capacity impacts meeting a company's initiative insofar as throughput increases and reduction in overhead costs.

B. *Transportation Considerations*

Standard Ocean transportation is the most cost effective specifically with respect to transit cost. However, in some cases airfreight transportation is used to reduce time to DC as significant increased cost. The decision to use airfreight can be made just prior to the finished goods reaching the consolidators. Most often, however, the airfreight decision is made just before manufacturing begins.

C. DC Considerations

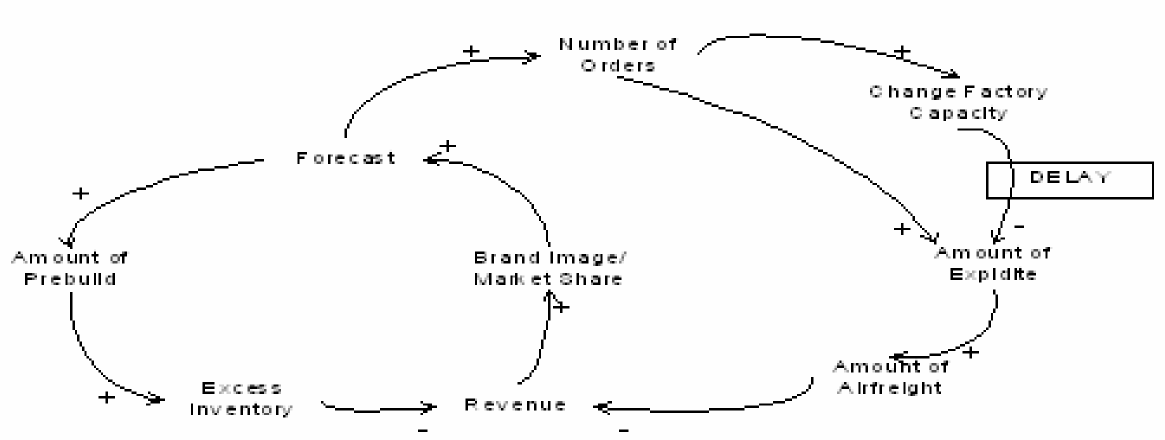
DC capacity is fairly static in that the acquisition of additional space is expensive to purchase or rent, as is the cost of preparing the internal structures that are conducive to displaying and tracking the large number of stock keeping units (SKUs). The most likely scenario when the DCs have reached capacity is to leave the product sitting in the yard and prioritize container unloading. The product in the yard is included in the DC turn calculation.

The turn rate at the DC is impacted by the volume and variety of inventory. The closer to capacity and the more variety the longer it will take process and move inventory out of the DC and to the customer. For example, during the low season (Fall), the DCs are only loaded to 70% capacity with reduced variety of SKUs. Hence, the DC has more space to create pick faces and more space to maneuver machinery to pack and ship the inventory to the customer, so it takes less time.

V. MODEL LOGIC

The model can be thought of in terms of three major sections (1) demand, (2) manufacturing, and (3) logistics. These components together represent the entire supply chain. Flexibility to alter policy is built into the model in the form of various parameters that are controlled by the user. A high-level causal loop diagram, shown in Diagram 1, consists of three feed back loops. All loops serve to increase revenue. The left most loop depicts the requirement of prebuilding as the forecast increases, however, prebuild creates excess inventory inherent with the risk of building before actual confirmed orders are placed. The center loop depicts the impact to orders requiring expedited manufacturing and airfreight due to insufficient factory capacity. The final loop to the right depicts the changes to the factory capacity required based on number of orders.

Diagram 1: Causal Loop Diagram

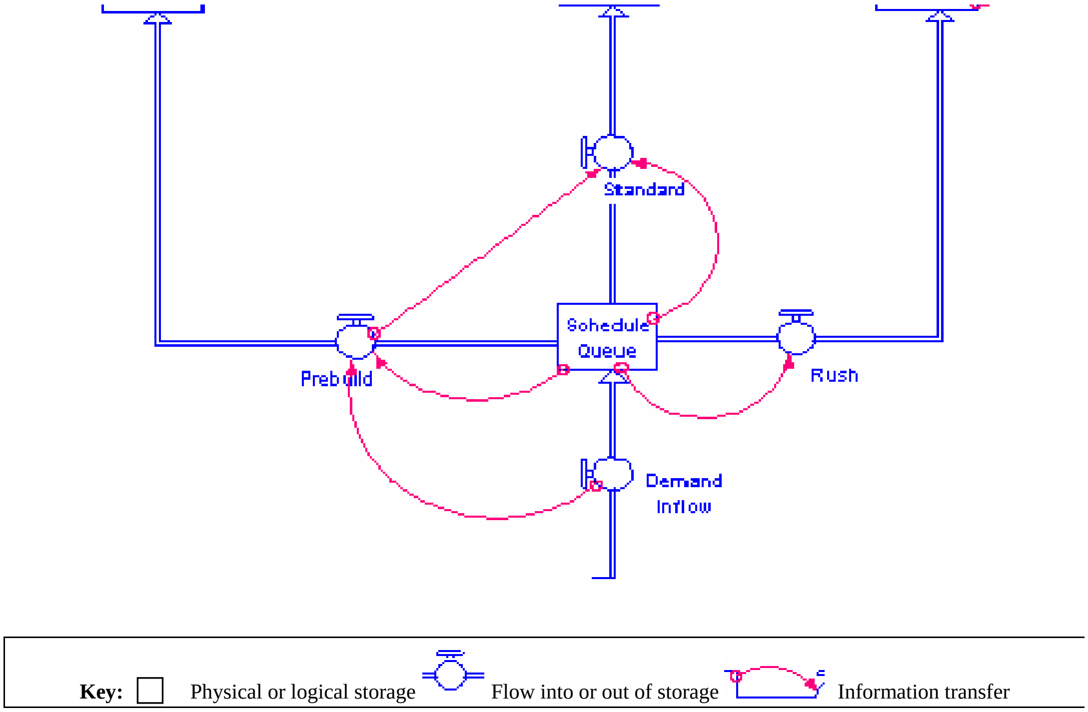


A. Demand

The demand section of this model depicted in Figure 2 is designed to take in the actual demand request from the customer, and the flow of demand into a queue representing the requests for product to be manufactured. In most retail companies, the demand is driven by the customers and will therefore be considered exogenous. The demand flows into a rectangular box called the ***scheduling queue*** until it is determined when it will need to be scheduled for manufacturing. The factories would prefer to build product at a steady rate, to be level loaded. If this were the case, the factories would be able adjust their capacity to a constant value, and would no longer have the additional cost of unused capacity or the high cost of overtime production. However, demand is not constant, but rather has peaks and valleys based on the season, economy, and the product offering. Thus, after the demand is sent to ***scheduling queue*** the decision needs to be made how to schedule the production, either as early production (prebuild), standard production, or rush production.

Demand will flow as early production at a constant percentage of demand inflow unless the factories are being underutilized. In this case, more demand can flow out of the queue as additional prebuild. Prebuild represents schedule placed into the manufacturing queue before the actual orders are approved. There is risk associated with prebuild in terms of possibly building the wrong product or excess product, if it turns out that product is not demanded in the actual orders. Therefore it is important to control the amount of allowable prebuild, and how far in advance of receiving actual orders prebuild can be scheduled. Prebuild is controlled by three user controllable parameters: (1) the

Figure 2: Demand Flow



amount of demand inflow that can be prebuilt on a routine basis, (2) the amount of demand that can be prebuilt if the factories are being underutilized, and (3) number of weeks in advance of receiving actual orders that prebuild can be scheduled.

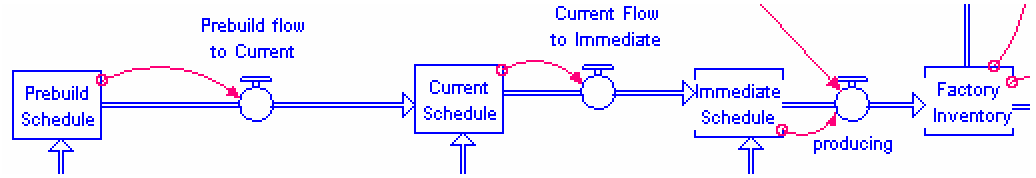
The demand that does not flow into the manufacturing schedule as prebuild is scheduled as standard production unless the standard production schedule is full. Standard production is manufacturing the schedule X weeks in advance of when it is needed, based on actual orders being received, material lead times, ocean transit times, and the amount of allowable inventory in the DCs. Any product placed in the schedule less than X weeks in advance of when it is needed must be shipped by a faster mode of transportation in order to deliver the product on time to the customer.

If the factory schedule for standard and prebuild production is full and there is remaining demand in the schedule queue, some of the demand will flow directly into the immediate schedule, called rush in the model. In this case, when the entire production schedule is full, the amount of airfreight increases. This is modeled by computing the percentage of schedule being added as rush, and then lagging this figure to reflect the delay between adding the schedule and when it is actually shipped to the DC.

B. Manufacturing

The manufacturing section of the model is a simplification of the true manufacturing process. With the passage of time, prebuild schedule is becoming current schedule, modeled as a flow from prebuild to current. At the same time, the current schedule is becoming immediate schedule, modeled as a flow from current to immediate. Actual production is represented as a flow, labeled producing, from the immediate schedule to factory inventory, as shown in Figure 3.

Figure 3: Manufacturing Time Windows

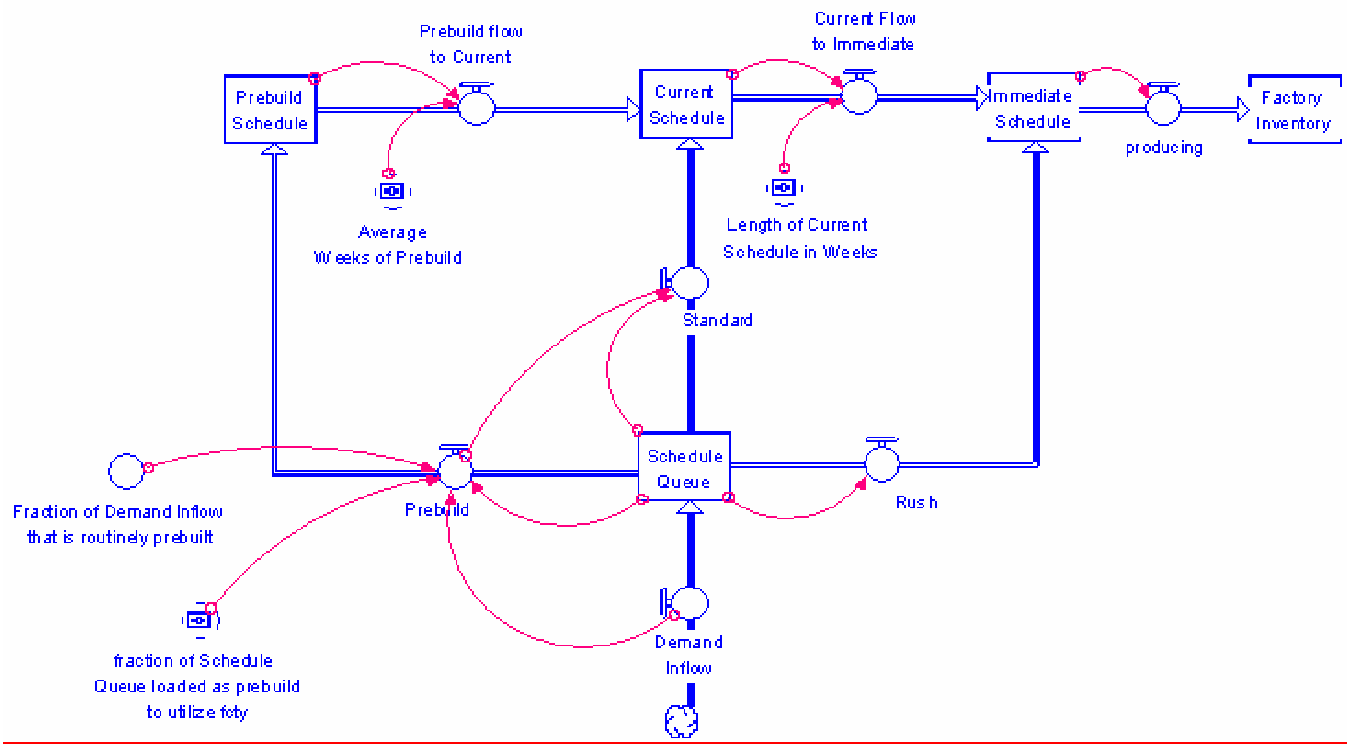


To specify the model logic mathematically, let X be the standard lead-time for production, in weeks, and the Y be the length of the current scheduling period, also in weeks. Assuming that factory capacity is available, product demanded at time t can be scheduled for standard production at time $t - (X \pm Y/2)$. For example, let's assume that today's date is December 1, 2002, that a customer requests product by March 1, 2003, and that standard lead-time for product is one month plus or minus 1 week. The *current schedule is* represented by the factory's capacity available for the weeks of January 27, 2002 through February 10, 2003. The total amount in the current schedule would be the factory's weekly capacity times three, since standard production for the December demand can be built in any of the three aforementioned weeks.

Now let the number of weeks for prebuild equal one, and the percent of prebuild equal to 10% of demand. Then, ten percent of the demand requested at time t will be scheduled for manufacture at time $t - 1 - (X \pm Y/2)$, or one week prior to the standard production time.

As time passes, the prebuild schedule will flow into the standard production window for demand requested for delivery at time $t+1$, thereby consuming capacity in the standard production window for demand for time $t+1$. Hence, the current schedule consists of both standard production plus prebuild from previous time periods. Figure 4 shows the model for scheduling and manufacturing in more detail.

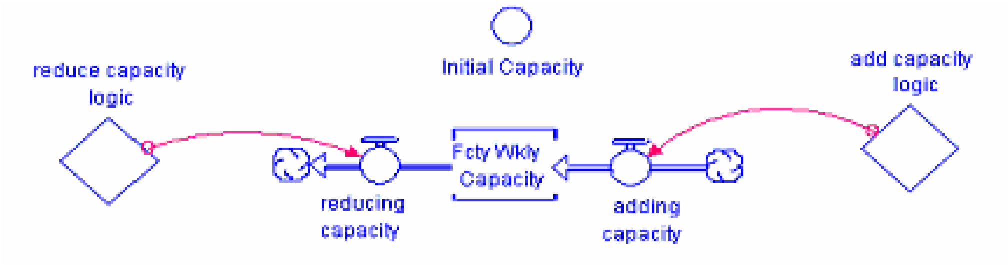
Figure 4: Demand and Manufacturing



The amount of product that the factory can manufacture at any given time is determined by the factory weekly capacity. The company requesting product to be built by the factory will negotiate some initial level of capacity that it believes will be needed, this parameter is the initial capacity for the factory. However, if the demand increases or decreases significantly the factories can accommodate this change within limits. Figure 5 depicts the section of the model that determines the factory weekly capacity.

The logic for adding capacity is as follows. First, current + immediate schedule is computed. If this total exceeds the current Factory Weekly Capacity times the sum of the length of the two queues by more than a specified percentage, then "adding capacity" is triggered. Capacity does not increase immediately; rather, it increases after a specified number of weeks. Additional capacity increases are not allowed to be triggered during the waiting period. The logic for capacity reductions is similar, with parameters being specified for the percentage below capacity that

Figure 5: Factory Capacity

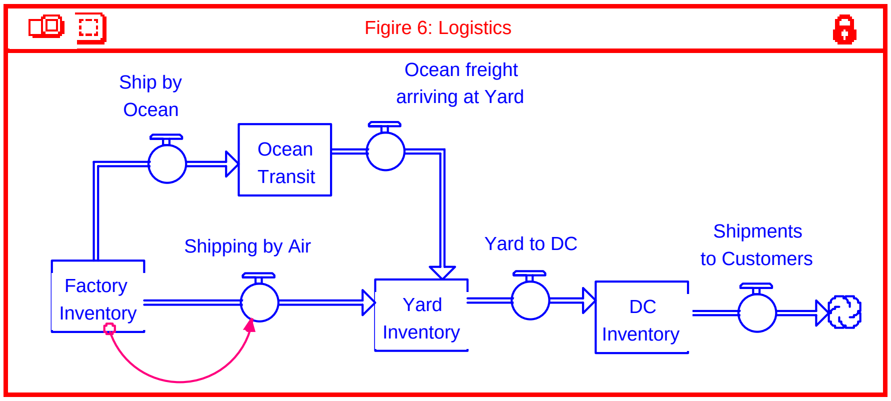


triggers a reduction and the wait period for a reduction (these might or might not be the same as for additions).

C. Logistics

The remainder of the logistic flow is quite simple. The factory can produce what is in the schedule at the rate determined by the factories capacity to produce. The standard ocean vessel will ship the factory production unless it was scheduled for rush production, then it will be shipped by a more expensive mode, airfreight. The product, either arrives by air or ocean transportation into the DC yard and is taken into the DC as inventory. The inventory is relieved from the DC at the rate of demand less the average manufacturing lead-time. Figure 6 shows this logic in diagram form.

Figure 6: Logistics



Costs in the model accrue as production takes place. For production costs, the cost/unit depends on how close the production rate matches capacity. Costs are higher when the production rate is above capacity due to the incremental cost of overtime and other factors. Costs are also hight when production rate is below capacity due to fixed costs and shadow costs. Transportation cost depends on how much airfreight is required. The DC costs are computed as a function of DC turns. When DC turns are high, the DC contribution to cost per unit is lower, and vice versa. Total cost per unit is the sum of these three components.

D. Control Panel

There are ten controls that the users can adjust in order to reflect various policies or process anticipated to change.

- Initialization – initial demand.
- Total Leadtime – average number of weeks to produce and ship product to the DC.
- Length of Current Schedual inWeeks – Average amount of time requred to order raw materials.
- Flex Amount – amount of change in factory capacity required when a capacity change is warrented.
- Short term flex – amount the factory can change its capacity by simply working overtime.
- Average weeks of prebuild – number of weeks in advance of actual orders product can be built.
- Factory Up Flex – the amount of over utilization that can occur before the factory has to initiate a change in capacity.
- Factory Down Flex – the amount of under utilization that can occur before the factory has to initiate a change in capacity.

- Fraction of schedual Queue loaded as prebuild to utilize fcty – amount of product allowed to be built before actual orders exist.
- Fcty Initial Capapcity – initial factory capacity

E. Example Model Run

The objective of the model is to enable compainies to evaluate differenent policies and their potential impact. In this example run we have the parameters set to ones that represent industry norms.

Figure 9 shows a step increase in demand. Accordingly, the amount of prebuild increases, as does the amount of schedule flowing in as standard. When the schedule queue becomes "full" at about week 20, some of the schedule flows directly into the immediate schedule, as rush (shown as vertical stripe, since this flow is normal zero). Shortly thereafter, the rush ceases, because the reduced demand inflow allows the schedule to empty somewhat. The full schedule has triggered an increase in capacity as well, which come on line about week 28, allowing the production rate to step up at that time. At about week 30, the demand drops another notch for a few weeks. As shown in Figure 10, the overall schedule changes in a less dramatic fashion. Figure 11 shows the demand changes, and when the factory capacity changes in response to these demand changes. The production rate is also shown for reference, as the amount shipping via ocean and via air (minimal in this scenario).

Figure 9: Model Response to Step Changes in Demand

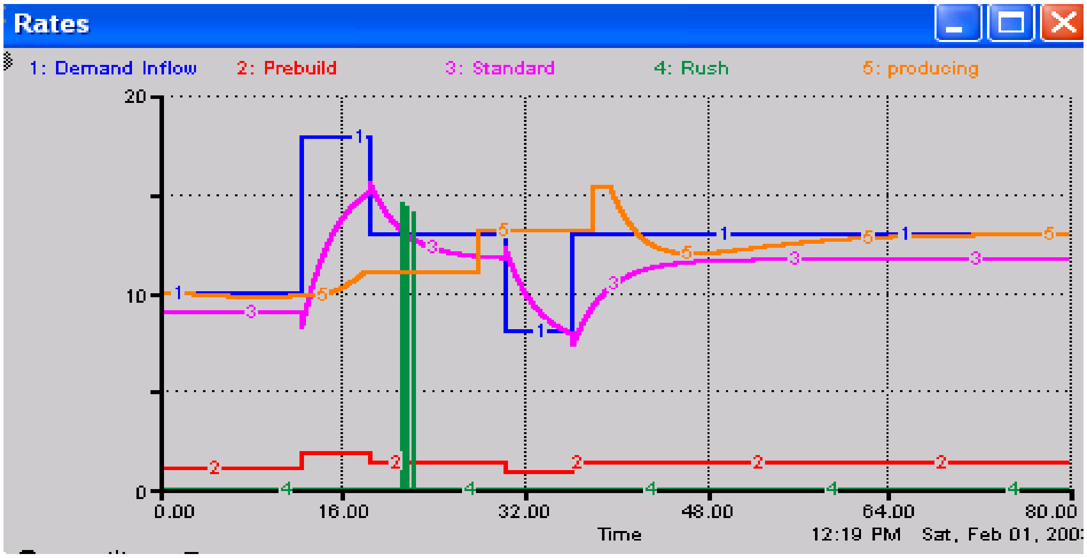


Figure 10: Impact on Schedules

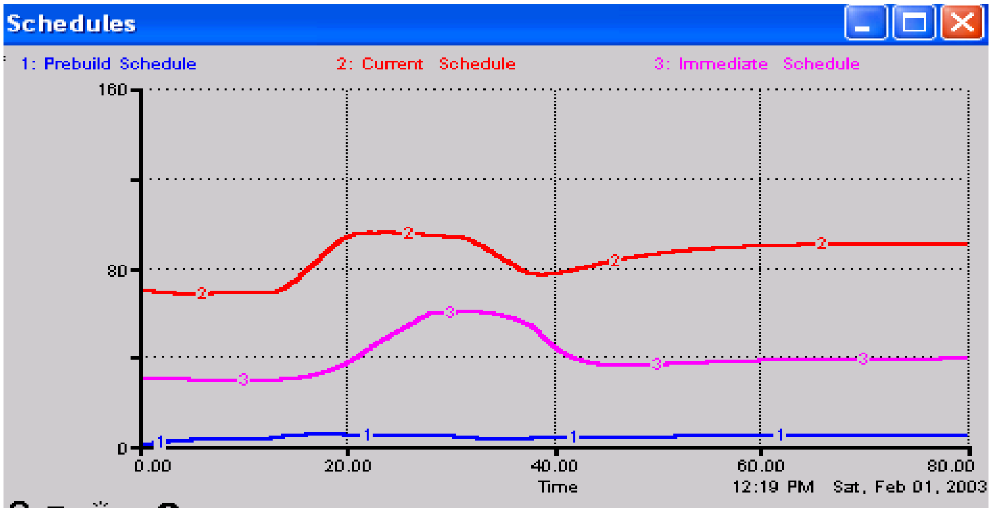
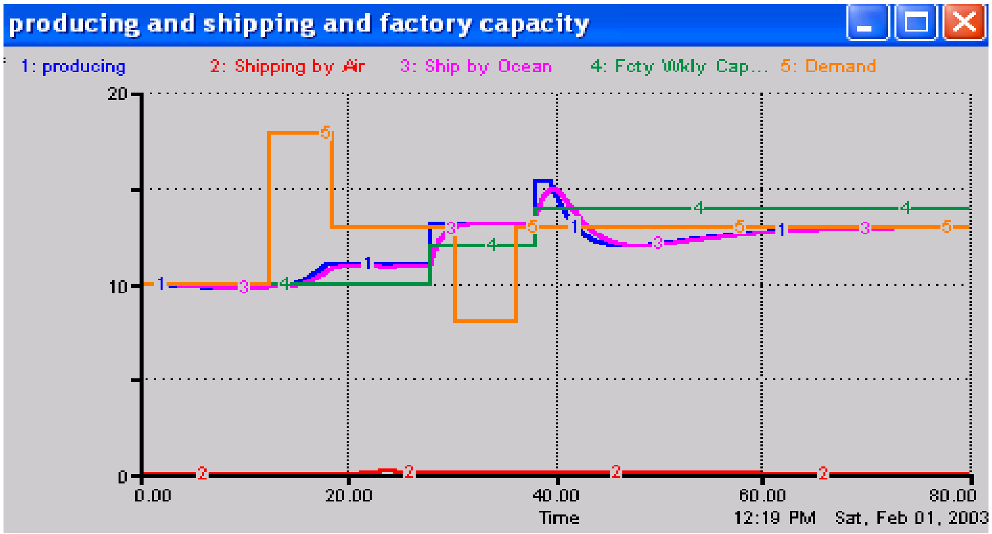


Figure 11: Impact on Producing, Shipping, and Capacity



VI. MODEL TESTING

The model was initially calibrated in steady state to verify that all the parameters were synchronized. Then simple changes in the demand profile were entered and the response of the model monitored. Various parameters were adjusted, one at a time, to verify that the change in response was appropriate. Extreme values were also tested in order to determine the limits of validity of the model—the conditions under which the model breaks down and becomes unrealistic and cannot be used for policy analysis

VII. POLICY ANALYSIS

There are two primary objectives for any supply chain to consider, cost and customer satisfaction [2]. Using this model we assume the latter, that is, we must produce what is requested by when the customer needs it. Then, we consider various policies to determine the most cost efficient way to accomplish the aforementioned objective. The three most significant costs in the supply chain are the DC inventory turns, factory capacity, and airfreight. Evaluation a policy to reduce cost must be based on the relative cost of each of these three components and a balancing between the three. Ideally, the DC inventory turns would remain as close to 5.5 as possible, factory capacity and utilization would remain constant, and airfreight would hold steady between three or four percent.

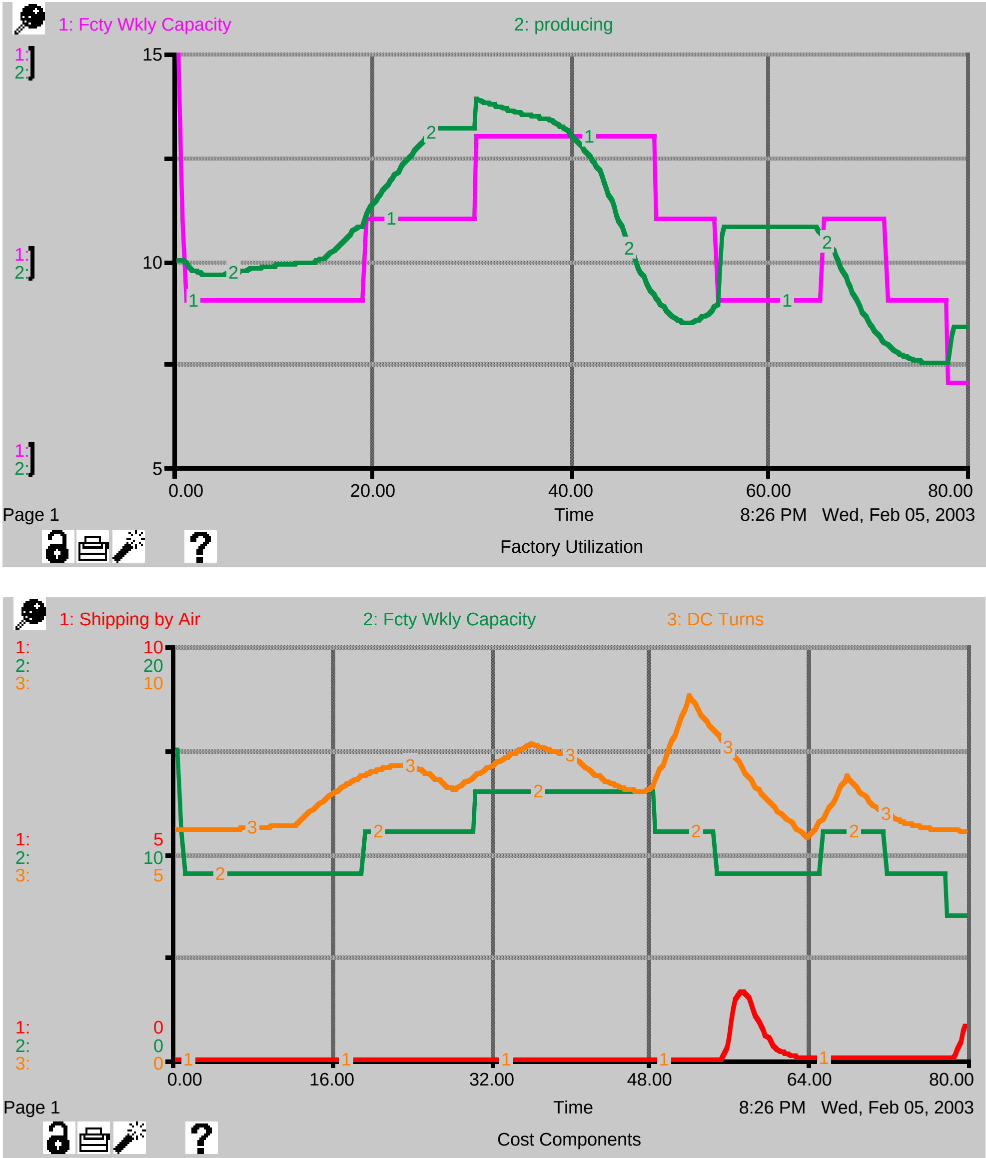
We have run two primary scenarios. The first scenario uses parameter settings that cause the factory capacity to fluctuate with the demand, whereas the second seeks to better stabilize the factory capacity.

A. Simulation Test Scenarios

The first scenario represents what is typically done in industry, the factory capacity and the flex policy attempts to closely follow demand. The hypothesis is that the capacity will flex frequently and ultimately lead to significant under and over utilization of the factories. The threshold that triggers the factories to flex capacity and the amount that the capacity changes is set to 5% up or down at a given time, factories are allowed to flex overall as much as necessary. The model indicates that when the factories operate this way they end up flexing very frequently, as one might expect. Even so, the factories still have ongoing factory over and under utilization issues. Overall costs are significant since a cost is incurred each time the factory must change capacity, as well as the cumulative cost of the under and over utilization of the factories. The outcome is shown in Figure 12. DC turns increase initially due to the increased demand coupled with the requisite delay in the associated inventory increase. Only a small amount of airfreight is needed. The large fluctuation in DC turns is not desired, nor is the persistent over and under utilization of the factories, so alternative policies are explored.

Scenario two is more conservative regarding the addition or reduction of factory capacity. The hypothesis is that less frequent changes in factory capacity will lead to less over and under utilization of the factories. The factory production still follows demand, but is required to flex up and down approximately 15% at each interval. The model shows that factory capacity is more stable, but surprisingly, the overall under and over utilization is approximately the same as in the previous scenario. Thus, the cost incurred in this scenario would be less due to the reduced number of times the factory must change capacity, with comparable overall under and over factory utilization. See Figure 13 for a graphical

Figure 12: Scenario 1, Factory Capacity Follows Demand Fluctuation (two plots)



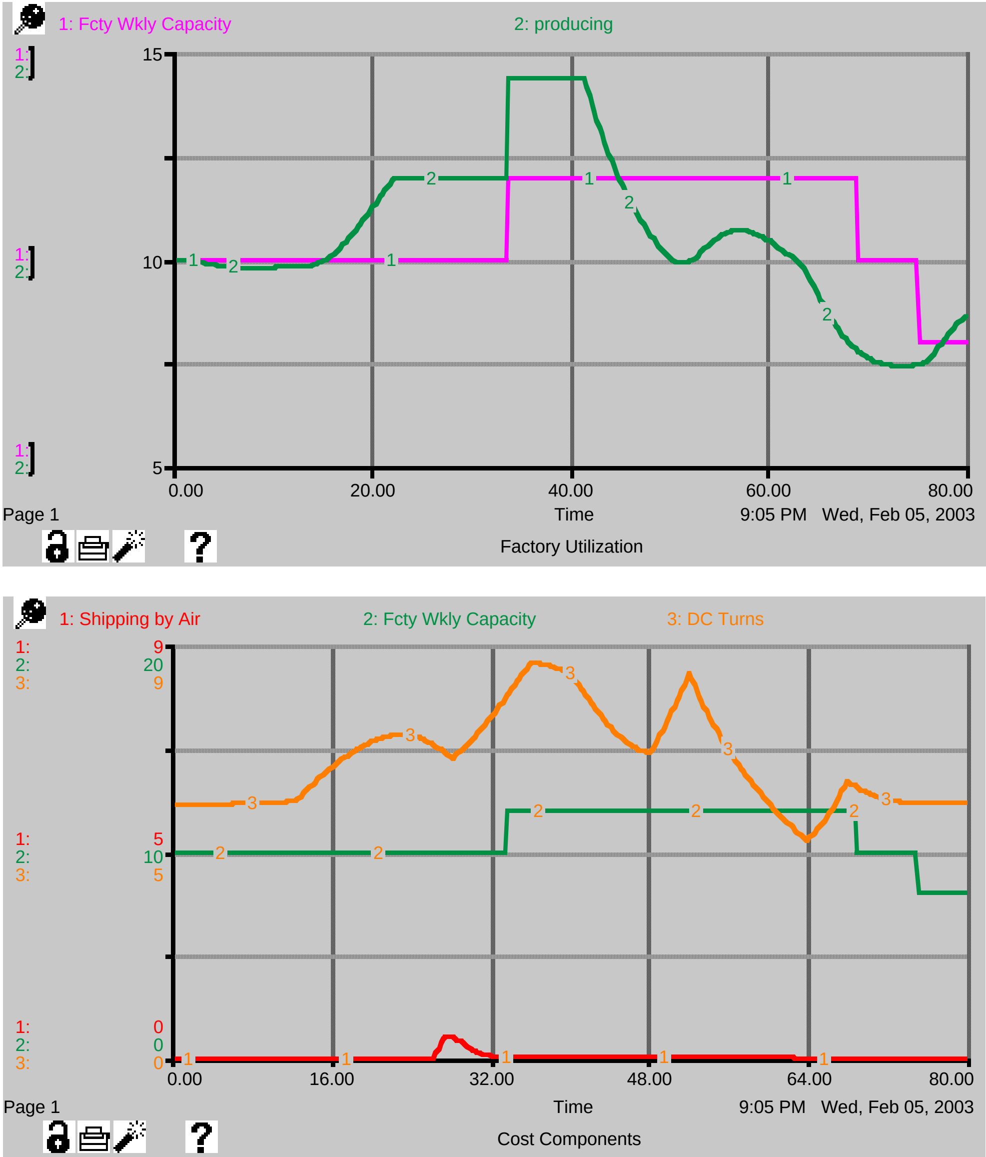
representation of the cost components. DC turns and airfreight were not significantly different from scenario 1. DC turns increased initially due to the increased demand coupled with the requisite delay in the associated inventory increase. Only a small amount of airfreight was needed.

B. Lessons Learned

The outcomes of various policies can be quite dramatic [1]. We have demonstrated only one of many situations that could be evaluated for impact. The specific objective of this simulation was to create a flexible supply chain model for evaluating different capacity planning policies and analyzing their impact on overall production cost. The current model allows the user to input various parameters that control capacity, scheduling, and the production of goods. The user can then evaluate the outcomes associated with the parameter settings. For example, a user could input parameters that would not allow the factory capacity to change.

The impact to factory capacity utilization, mode of transportation and DC inventory turns will be readily available. A full cost benefit analysis could be performed on

Figure 13: Scenario 2, Stable Factory Capacity at a Lower Level (two plots)



each of the outcomes, and fact-based decisions could be made regarding the best policies to invoke.

Specifically, from the scenarios that we ran, we determined that the traditional policy, which states that the factories should flex as little as possible at any one time, in order to mitigate overall under and over utilization and to control cost may not be the best policy. Based on the model, and it does seem reasonable, requiring larger changes in factory capacity overall achieves the desired outcome of reducing overall cost. The model has provided significant information as to the potential impact of particular policies and their respective outcomes. It is evident that simulation can be a valuable tool for evaluating FSC various policies and their associated outcomes.

C. *Next Steps*

The next steps for the model will be to incorporate feedback from the DC turn rate to upstream aspect such as scheduling and production rates. This will aid in the determination of attractive policies that not only consider the cost at the factory, but also factors in the cost of fluctuating DC inventory.

A second consideration for the model will be to include additional costing components to allow the user to enter the relative or real costs associated with each aspect of the model. It is intended that the costing components will directly impact scheduling and production processes and aid in determining the most cost effective manufacturing parameters for balancing the tradeoffs between factory capacity utilization, mode of transportation and DC inventory turns.

APPENDIX

Reference Behavior Patterns

This section was prepared before the model was built to indicate how the real world actually behaves. This served as a reference during model testing as to whether the model behavior was consistent with reality or not.

1. Current Situation – Start of Spring (highest volume from lowest volume)
    a. Factory averages 7% pre-build
    b. Factory will average 5% late product
    c. Factory average load is 90%
    d. Transportation average air freight is 3.3%
    e. DC inventory turn average 4.4 (want 5.5 – 6)
    f. SKU count at approximately 12,000
2. Increase Factory capacity by 50% (High season into low season – spring into fall)
    a. Factory will average 0 pre-build
    b. Factory will average 0 late product
    c. Factory average load should be 60%
    d. Transportation average air freight should be 0%
    e. DC inventory turn average should be just over 3 for the time period lagging the demand by 2 months.
    f. Sku count consistent
3. Demand Flux – demand spike after low (holiday into spring)
    a. Factory will increase to12% pre-build for duration of spike
    b. Factory will increase the amount of late product to 7% for duration of spike
    c. Factory average load should not exceed 95%
    d. Transportation average air freight increase proportionally with late product
    e. DC inventory turn should increase to about 4.5 at lag 3 and maybe as high at lag 5
    f. SKU count consistent
4. Steady state objectives
    a. Bounded factory flux to reasonable levels – strive for level load
    b. Steady DC turns at about 5.6 to 6
    c. Cost efficacy

In fact, the model does NOT behave exactly as described above. This is due in part due to model inadequacies, but is due to the fact that the description of reference behavior was based on experience and not factual data, so it was not held to be an absolute reference.

REFERENCES

[1] Anonymous, "Exploring supply chain behavior with systems dynamics," *Supply Chain Management*, vol. 2, pp. 38, 1997.

[2] Avni, T., "Simulation modeling primer," *IIE Solutions*, vol. 31, pp. 38, 1999.

[3] Copacino, W., "New priorities for supply chain managers," *Logistics Management*, vol. 42, pp. 66, 2002.

[4] Coyle, R., *Management Systems Dynamics*. Chichester: Wiley, 1997.

[5] Fowler, A., "Operations management and systemic modeling as a framework for BPR," *International Journal of Operations and Production Management*, vol. 18, pp. 1028, 1998.

[6] Hugos, *Essentials Of Supply Chain Management*. Hoboken: John Wiley, 2003.

[7] Lee, P. and Davies, M., "Reap or weep," *Supply Chain Management*, vol. Sept 4, 1997.

[8] Lyneis, J., "Corporate planning and design: A system dynamic approach," *MIT Press, Cambridge MA*, 1980.

[9] McCarthy, J., "e-business infrastructure services," *InfoWorld*, vol. 24, 2002.

[10] McClelland, M., "Using simulation to facilitate analysis of manufacturing strategy," *Journal of Business Logistics*, vol. 13, pp. 215, 1992.

[11] McClelland, M., "Using simulation to facilitate analysis of manufacturing strategy," *Journal of Business Logistics*, vol. 13, pp. 215, 1992.

[12] O'Laughlin and Copacino, *The Logistics Handbook*: Anderson Consulting, 1989.

[13] Schwartz, M., "ERP plan cuts costs at factories," *Computer World*, vol. March, 2002.

[14] Shapiro, J., *Modeling the Supply Chain*: MIT, 2001.

[15] Warren, J., Crosslin, R., and MacAuthur, P., "Simulation modeling for BPR," *Information Systems Management*, vol. 12, pp. 32, 1994.