Simulation-based decision-making scenarios in dynamic supply chain

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Abstract

In this paper we present approach for simulation of supply chain using a simulation package. The objective is to develop general modules for the simulation of supply chain, which can be used for simulation of complex supply chain. Simulation model has flexibility of using different ordering policies and different set of parameters for different nodes of supply chain. Numbers of simulation experiments are performed to generate knowledge. In particular, based on a cost and time performance analysis, the different configurations are analyzed in order to support the selection of suitable polices and parameters of the operations network.

Key Word: *Simulation, Supply chain, Arena modules, Decision Support System (DSS).*

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1 Introduction

Owing to the inherent complexity of decision making in supply chains, there is a growing need for using simulation models in order to identify and innovate strategies for designing high performance supply chain networks. A large number of manufacturing and service organizations are therefore seeking simulation modeling systems that can help identify and implement strategies for designing and improving their supply chain networks.

Supply chain simulation is very useful in either for designing and implementing a new supply chain or for making changes to an existing one. Simulation can be used as a tool for making the strategic, tactical as well as operational decisions. Simulation is an approach in which a model of the system is built so that one can experiment with the various scenarios that might occur during the life cycle of the system.

As per modeling approach Supply chain design and analysis can be divided into four categories :

- Deterministic analytical models, in which the variables are known and specified
- Stochastic analytical models, where at least one of the variables is unknown, and is assumed to
- follow a particular probability distribution,
- Economic models, and
- Simulation models.

Towill (1991) and Towill, et al. (1992) use simulation techniques to evaluate the effects of various supply chain strategies on demand amplification. In supply chain, members choose immediate suppliers based on the given data and rules set (Piramuthu, 2005). Managing a supply chain involves the flow of both tangible and intangible resources including materials, information, and capital across the entire supply chain (Wu and Olson, 2008). The strategies investigated are as follows:

- Eliminating the distribution echelon of the supply chain, by including the distribution function in the manufacturing echelon.
- Integrating the flow of information throughout the chain.
- Implementing a Just-In-Time (JIT) inventory policy to reduce time delays.
- Improving the movement of intermediate products and materials by modifying the order quantity procedures.
- Modifying the parameters of the existing order quantity procedures.

The objective of the simulation model is to determine which strategies are the most effective in smoothing the variations in the demand pattern. The just-in-time strategy and the echelon removal strategy were observed to be the most effective in smoothing demand variations.

Wikner, et al. al. (1991) examine five supply chain improvement strategies, and then implement these strategies on a three-stage reference supply chain model. The five strategies are:

- Fine-tuning the existing decision rules.
- Reducing time delays at and within each stage of the supply chain.
- Eliminating the distribution stage from the supply chain.
- Improving the decision rules at each stage of the supply chain.

- Integrating the flow of information, and separating demands into "real" orders, which are true market demands, and "cover" orders, which are orders that bolster safety stocks.

Makipaa (2008) explores on cooperative inter-organizational relationships levels of cooperation. Biswas, et. (2002) in his study evaluated the various algorithms and tools deployed for supply chain modeling and problem solving. These are based on stochastic models, mathematical programming models, heuristic techniques, and simulation.

Min (2002) argued that most supply chain simulation models have been developed on the basis of discrete-event simulation. Since supply chain systems are neither completely discrete nor continuous, the need for constructing a model with aspects of both discrete-event and continuous simulation is provoked, resulting in a combined discrete–continuous simulation. In this paper, architecture of combined modeling for supply chain simulation is proposed, which includes the equation of continuous portion in the supply chain and how these equations can be used in the supply chain simulation models. The simple example of a supply chain model dealing with the strategic level of the supply chain presented in this paper shows the possibility and the prospect of this approach.

Wadhwa et al (2008) has given three stages inventory coordination mechanisms between chain members and solves a cost minimization model for each. This show that some of the coordination mechanisms can result in a significantly lower total cost than matching production and delivery along the chain.

Nilsson (1999) presents a dynamic simulation model for analysis of various delivery alternatives while designing straw fuel delivery system.

Stephen A. Smith, et. (2002) uses a Decision Support System for a retail supply chain planning for private – Laval Merchandise with multiple vendors. While offering a number of benefits, this approach also poses a different set of supply chain challenges than manufacture-brand – based retailing, in that the retail firm must take a more active role in organizing and coordinating the planning and materials management activates in a supply base that is often dispersed and heterogeneous.

2 Simulation modeling of supply chain model

Due to its inherent complexity, analytical modeling of supply chains becomes difficult. Moreover, a typical supply chain faces uncertainty in many of its activities. Under such complex and uncertain situations, simulation becomes the best alternative for analysis tool for dynamically changing internal supply chain variables. Moreover, simulation can work for the global optimization of planning an entire supply chain with finding local optimum values within each component.

For simulating a supply chain, it is necessary to consider: material flow, information flow, and cash flow. It is also important to model precisely the interaction between the various participants. In addition, both planning and execution activities are to be considered which include inventory management, production management, and delivery of finished goods. Figure 1 shows the various levels of the simplified supply chain and how they are connected through a common information pipeline. The supply chain model simulates the system dynamics in a supply chain system.

Insert Figure 1 about here

Each participant of the supply chain has his own set of activities. Despite differences between these activities, a number of processes are common to the participants of the supply chain. These processes can be explained using a common set of terminology and enables the principle of reuse in bottom-up development of a model. To explore commonality between the participants, a set of modules can be built that can be put together to represent the various activities of the participants. Then these participants can be put together with proper interfaces to obtain a model for the entire supply chain.

This fact is exploited to build standard modules that can be used for building supply chain simulation models. Instead of building models from scratch, these standardized modules can be assembled to obtain the desired supply chain network. This can then be used to analyze different operational and strategic policies in the supply chain.

3 Model Descriptions

There are three kinds of participants in the supply chain. For simulation of supply chain modules are developed for these participants:

- Consumers :

  are those participants who place orders for finished products, but do not supply any products to any other participants. They are the most downstream participants of the supply chain.

- Producers :

  are the most upstream participants of the supply chain. Producers supply parts to other participants, but do not receive any.

- Traders :

  are the intermediate participants in the supply chain. Traders both place orders from other participants and deliver orders to other participants. Traders include manufacturers, warehouses, and retailers.

Modules developed for each type of participants of supply chain i.e. Producer, Trader and Consumer can be used for modeling of complex supply chain. Our model consists of four levels in a linear supply chain and for simplicity one node at each level is assumed. As shown in the figure.

Model execution is determined by the information flow within and between the various participants. Consumers, producers, and traders have certain activities that are carried out periodically. Information flow can be of two types. One type of information flow records the status of the system that will be used for calculating the performance measures. The other type of information flow triggers events in the model. This includes activities that occur while checking the status of the system and events such as placing of an order by the customer. Present simulation model is developed in the modular fashion by developing the basic modules of the supply chain.

3.1 Model Assumptions

Following assumptions concerning SC processes and SC control are made:

- Customer demand is confined to a single product.
- Each inventory in the SC is controlled based on an ordering policy selected at begin of simulation.
- External demand is fulfilled from the end-product inventory. When demand exceeds the end-product stock, unmet demand is backordered and delivered to customers as soon as it becomes available in stock.
- Each production facility replenishes the succeeding inventory and places orders on the preceding inventory in the SC. Complete back-ordering is assumed, i.e., if the order exceeds the stock of the preceding inventory, the order is only partially filled and unmet quantity is backordered. When the backordered quantity becomes available in stock, it is sent to the production facility with the first next delivery.
- Replenishment quantities for each inventory are received with a given, planned lead time. The lead time includes the time necessary for order processing, the production time and/or transportation time.

3.2 Decision Variables

Decision variables are used as a mean to affect the performance measures in supply chain modeling, Decision variables are then chosen in such a way as to optimize one or more performance measures. The decision variables can be like

- Production/Distribution Scheduling: Scheduling the manufacturing and/or distribution.
- Inventory Levels: Determining the amount and location of every raw material, subassembly, and final assembly storage.
- Number of Stages (Echelons): Determining the number of stages (or echelons) that will comprise the supply chain. This involves either increasing or decreasing the chain's level of vertical integration by combining (or eliminating) stages or separating (or adding) stages, respectively.
- Distribution Center (DC) - Customer Assignment: Determining which DC(s) will serve which customer(s).
- Plant - Product Assignment: Determining which plant(s) will manufacture which product(s).

- Buyer - Supplier Relationships: Determining and developing critical aspects of the buyer-supplier relationship.
- Product Differentiation Step Specification: Determining the step within the process of product manufacturing at which the product should be differentiated (or specialized).
- Number of Product Types Held in Inventory: Determining the number of different product types that will be held in finished goods inventory.

In our model following variables are used:

Inventory [i]	: Representing inventory level at ith node.
Demand[i]	: Representing demand at ith node
Previous Demand[i]	: Representing demand of previous day at ith node
Order [i]	: Representing order at ith node
Previous order[i]	: Representing order of previous day at ith node
Sale[i]	: Representing sale at ith node
Capacity	: Factory capacity
Distribution delay[i]	: Delivery lead time of ith node
Ordering delay[i]	: Ordering lead time of ith node
Hold Cost	: Holding cost of inventory for unit item and unit time
Order cost	: Ordering Cost per order at i^{th} node
MAXL[i]	: Order upto point at i^{th} node
MINL[i]	: Reorder level at i^{th} node
Initial[i]	: Initial Level of Inventory at i^{th} node

3.3 Chain Performance Measures

An important component in supply chain design and analysis is the establishment of appropriate performance measures. Performance measures are also used to design proposed systems, by determining the values of the decision variables that yield the most desirable level(s) of performance. Broadly performance measures may be categorized as either qualitative or quantitative.

Qualitative performance measures are those measures for which there is no single direct numerical measurement is possible like

- Customer Satisfaction: The degree to which customers are satisfied with the product and/or service received.
- Flexibility: The degree to which the supply chain can respond to random fluctuations in the demand pattern.
- Information and Material Flow Integration: The extent to which all functions within the supply chain communicate information and transport materials.
- Effective Risk Management: All of the relationships within the supply chain contain inherent risk. Effective risk management describes the degree to which the effects of these risks are minimized.
- Supplier Performance: With what consistency suppliers deliver raw materials to production facilities on time and in good condition.

Quantitative performance measures are those measures that may be directly described numerically. Quantitative supply chain performance measures may be categorized by: (1) objectives that are based directly on cost or profit and (2) objectives that are based on some measure of customer responsiveness. Measures Based on Cost are Cost Minimization, Sales Maximization, Profit Maximization, Inventory Investment Minimization, and Return on Investment Maximization. Measures Based on Customer Responsiveness are Fill Rate Maximization, Product Lateness Minimization, Customer Response Time Minimization, Lead Time Minimization, and Function Duplication Minimization i.e. minimize the number of business functions that are provided by more than one business entity.

3.4 Model Initialization

In addition to building the supply chain model using the modules, the user also has to provide the data corresponding to each module. Some of these data are entered in the Arena model while some others are entered in the Excel file corresponding to input Parameters. Various input parameters are for demand, ordering delay, distribution delay, ordering policy, various costs, factory capacity and policy of information sharing.

Model is capable of generating deterministic as well as stochastic demand. Model has option of generating demand based on uniform, triangular, normal, poison and other distributions. There are different kinds of ordering policy which a particular model can follow. User has option to select one of the ordering policies. Here it is possible for different nodes to follow different policies. Policy of information sharing enable sharing information of customer demand to the other nodes of the supply chain. When information is shared that time decision of the nodes are based on the additional information available.

3.5 Model Execution

This section describes the way the model is executed with the input data. The simulation progresses due to the triggering events. Following are the activities in the model that trigger actions in Arena and determine the course of the simulation:

1. A consumer placing new orders with a trader or producer.
2. At the end of day
3 A trader checking his inventory and placing orders for raw materials with other traders or producers if necessary.

In addition to this, each entity in the simulation model, while passing through the various stages of the supply chain, invokes the corresponding VBA code to record its status and performance.

There are small differences in the way the three kinds of participants, consumers, traders, and producers, are implemented in the supply chain. In the case of the producers, raw material sourcing is not performed. A fixed amount of raw materials is assumed to be available all the time.

The consumer acts as a place for receiving the products corresponding to the orders that he places. So the consumer does not perform production and delivery activities.

Because participants such as distributors or retailers do not have any manufacturing processes, the corresponding models do not have produce modules.

Consumer placing an order

The consumer places orders with the traders and the producers. When a trader (or producer) receives a new order, he tries to allocate material for this new order using his inventory. If not enough material is available, the shortage is marked as back order. These values are used for placing new sourcing orders.

```
if  (Inventory > =Order + backorder)
then  :
        sale = Order + backorder
else
        sale = inventory
end if

Backorder = Order-Sale +Backorder
```

Sourcing

Traders perform sourcing at periodic intervals. The trader orders raw materials from his supplier based on an inventory control policy.

The model currently runs under periodic (s, S) policy. At the end of each day trader check his inventory. Here s stands for the reorder level, and S is the order up to quantity. These values are defined for each node. The net inventory position is checked. If the net inventory position is less than the reorder level, an order is placed so that the net inventory position equals. Each day every node places order to upstream node except end node in upstream direction. Size of order depends upon the type of policy followed at the particular node

3.6 Output of Model

Simulation model generates output in the form of reports. There are two kinds of reports that our model is generating. One is the in-built report generated by the arena and another is the output send to the excel file. Table 1 shows various inputs and Table 2 shows outputs of the model.

Insert Table 1 about here

Insert Table 2 about here

Model is able to answer following questions:

1. What is average, minimum and maximum demand. :
Excel file contain the log of demand experienced by the different nodes during the simulation run. On the basis of this it finds out what is the average, minimum and maximum demand as well as the standard deviation of the demand.

2. What is average, minimum and maximum inventory:

Excel file contain the log of inventory level at different nodes during the simulation run. On the basis of this it finds out what is the average, minimum and maximum inventory level standard deviation of the inventory level.

3. **What is average, minimum and maximum shortage.**
When customer arrives a retailer node his demand is satisfied immediately depending upon the stock position. Some time it is also possible that when customer reaches the retailer that time less or no stock is available at the warehouse of the retailer. Report also tells about the number of stock out situation during the simulation run. It also tells about the average minimum and maximum shortage amount.

4. Total ordering cost, inventory holding cost, shortage cost
Report tells the number of order placed by the different nodes and their ordering cost. From the value of daily inventory level at the node model calculate the total holding cost. Whenever there is shortage of material at the retailer node it affects the chain either by unsatisfied customer or the loss of sale. Model is able to calculate the total shortage cost.

5. Capacity utilization of factory, and warehouse at different nodes
It is the unique feature of this model that it can also study the effect of finite production capacity. Out put also contain the values of capacity utilization of the factory and warehouse at the different nodes of the supply chain.

6 Lead time

Model is able to find out average lead time from the data for a particular simulation run.

7. No of balking customers

If we specify the finite queue space for the customer waiting area in that case additional customer will balked, here it sis possible to find out the number of balked customers.

3.7 Model Implementation

For implementation of SC model first modules for Consumer, Producer and Trader are developed in ARENA and then using these modules complete model is simulated. The modules make use of Arena 7.0, Visual Basic for Application (VBA) and Microsoft Excel 2002. The Arena software interacts with Microsoft Excel using Arena VBA. ARENA is a computer simulation tool with a graphical user interface. Users can model complex systems using the available modules, blocks and elements available in the ARENA templates using simple click-and-drop operations into the model window. Examples of systems that can be modeled are:

- manufacturing plants with people, machines and transport devices,
- bank teller windows, ATMs, and deposit boxes, and
- a computer network with servers, clients and networking capabilities.

ARENA uses SIMAN as the underlying simulation language. So, every time the user places a module in the model window and fills in the required fields, ARENA actually writes its own SIMAN code in the background. The user can view the SIMAN code optionally in a separate window. Figure 2 shows key logical input and outputs in simulation model.

Insert Figure 2 about here

4 Experimentation and Study using simulation model

Arena offers great features in terms of simulating discrete event systems. But the modules available in Arena are at a very basic level for use in supply chain simulation. This limitation can be overcome by developing modules hierarchically from the basic modules that would imitate the supply chain processes. In addition to this, using Arena VBA, the simulation model is interfaced with Microsoft Excel. By combining the simulation capabilities of Arena and the spreadsheet capabilities of Microsoft Excel, a very efficient and flexible library has been constructed for developing supply chain simulation models.

Simulation study is performed using the developed supply chain model with following objectives

- To study supply chain systems as a collection of flow of material, information and cash from one participant to another participant of supply chain.
- To ascertain that the overall performance of the supply chain and reduction in Bullwhip effect can be improved by improving the visibility of information in supply chain by reducing delays in information flow, reduction in lead times and using better forecasting techniques. are nonlinear dynamic systems
- To study the impact of stochastic parameters like customer demand, ordering lead time, distribution lead time on bullwhip effect and supply chain performance.
- Study of supply chain for Decentralized information sharing strategies and Centralized information sharing strategies.
- To study the dynamics of the system when factory capacity is finite instead of infinite capacity assumed by previous models.

Keeping above objectives in mind experiments are performed on the simulation model with following parameters : Demand as Normal (10,1), (10,3), (20,2), (20,5); ordering lead time of 0 day,1 day, Normal (2,1) day; Distribution lead time of 0 day, 1 day, Normal (2,1) day. Figure 3 to 6 shows demand, inventory, order, sale and backorder performance of the each individual supply chin member or node.

Insert Figure 3 about here

Insert Figure 4 about here
Insert Figure 5 about here
Insert Figure 6 about here

There is different kind of ordering police which a particular node of supply chain can follow. Study is done using (s – S) ordering policy and ordering based on moving average of past demand. For (s – S) policy different values of s and S have been tried. This simulation model has option of specifying factory capacity. This capacity can be either infinite or some finite value.

In the long run initial inventory has insignificant effect over the performance of the system. But at the time of simulation it is observed that very low initial inventory leads to unsteadiness in the system right from the start. An appropriate value initial inventory is selected each time depending upon other parameters. Moreover getting this initial inventory level also take time due reason being the model is real time system and when we say that our initial inventory is this much amount then this amount will come through the route of regular material with same delay. To overcome this problem it is assumed that first customer will come in the system only when there is initial inventory at the each node.

Figure 7 shows the impact of various demand pattern and bullwhip effect.

Insert Figure 7 about here

Policy of information sharing has the option of sharing information of customer demand to the other nodes of the supply chain. When information is shared that time decision of the nodes are based on the additional information available.

For all the experiments length of simulation run is taken as 365 days mean one year assuming continuous production throughout the year. In the simulation model parameters are supplied using the data file as shown below on the basis of these parameters simulation experiment are performed.

5. Conclusion

Simulation models of a supply chain have been built to facilitate the use of simulation in designing, evaluating, and optimizing supply chains. Simulation is used to study stochastic natures of demand, and customer lead time, effect of information sharing on the performance of supply chain, effect of finite production capacity over the performance of supply chain.

Simulation is a very efficient way of analyzing what – if scenarios and can be used for improving the performance of the entire supply chain instead of looking at it as a set of independent organizations. With the advent of more and more powerful computers, it has become easier to simulate complex systems. But the amount of time needed to develop the simulation model can be quite high. There is a need for constructing libraries that can be used to build supply chain models. Such a library saves the user's time and effort in developing the model, thus helping the user to spend more time on analyzing the system. The model was tested for many different parameters. It has not been possible to get a range of workable parameters under which everyone gains. The only conclusion one can surely draw is that in a fine tuned web enabled supply chain; collaboration will reduce inventory levels in the system because of aggregation. It would be beneficial to run a real life model on simulator designed for those conditions before actual collaboration and decision variable is put into practice. Our research is continuing n this direction.

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Table 1. Input to the Programme

	Node 1	Node 2	Node 3	Node 4
Initial Inventory	50	50	50	50
Reorder Level	35	35	35	35
Order Upto Level	50	50	50	50

First Customer Arrival	3			
Factory Capacity	500	Unit Holding Cost		1
Type of Demand	Normal	Unit Ordering Cost		50
Demand Mean	20	Unit Shortage Cost		10
Demand Standard Deviation	5	Unit Shortage Cost		10
Ordering Delay Mean	1			
Ordering Delay Std Dev	0			
Distribution Delay Mean	0			
Distribution Delay Std Dev	0			

Table 2. Output of the Programme

	Demand	Inventory	Sale	Order	Backorder	Demand	Inventory	Sale	Order	Backorder
Node	1	1	1	1	1	2	2	2	2	2
Maximum	34	117	50	50	107	50	165	50	50	300
Minimum	0	0	0	0	0	0	0	0	0	0
Average	19.702	31.036	19.702	20.06	17.73	19.943	39.631	19.7	20.2	66.11

	Demand	Inventory	Sale	Order	Backorder	Demand	Inventory	Sale	Order	Backorder
Node	3	3	3	3	3	4	4	4	4	4
Maximum	50	152	50	50	150	50	50	50	0	0
Minimum	0	0	0	0	0	0	0	0	0	0
Average	20.139	39.011	19.877	19.806	61.902	19.806	49.863	19.8	0	0
Inventory Cost		2007178			Customer Lead Time			0.36		
Total Ordering Cost		557								
Shortage Cost		2030								

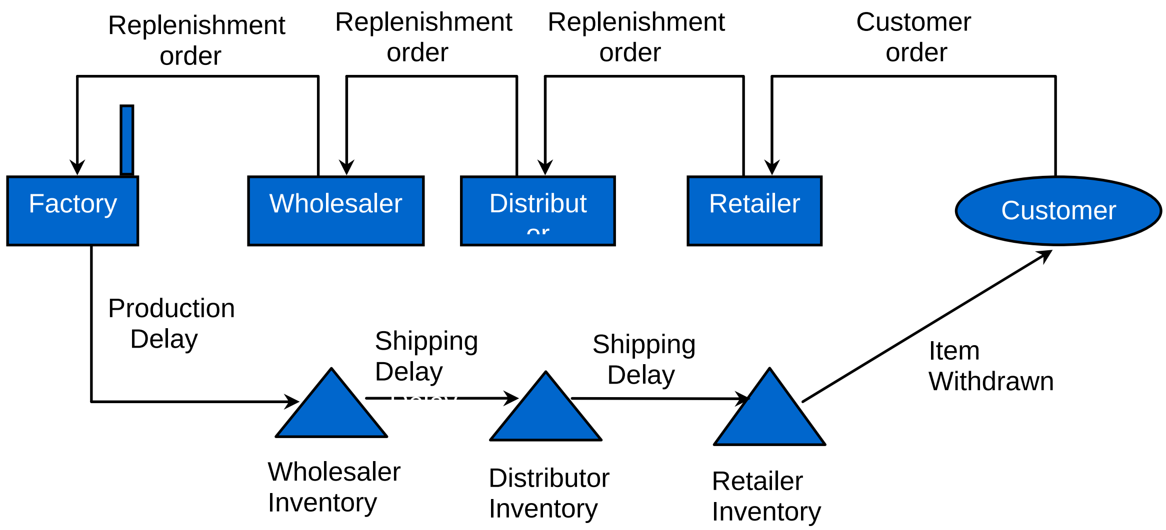

Figure 1. Simplified Supply Chain Model

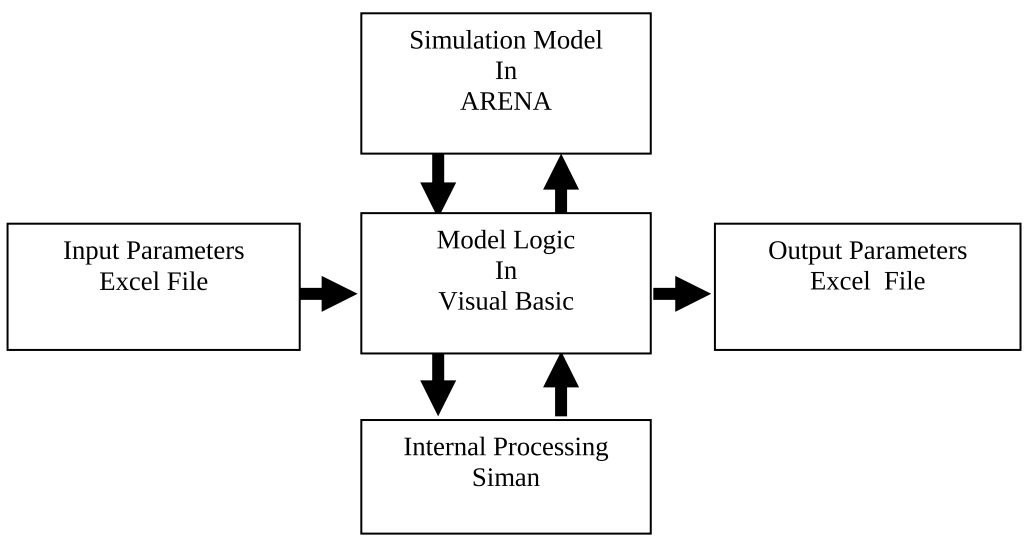

Figure 2. Logic Diagram of Simulation Model

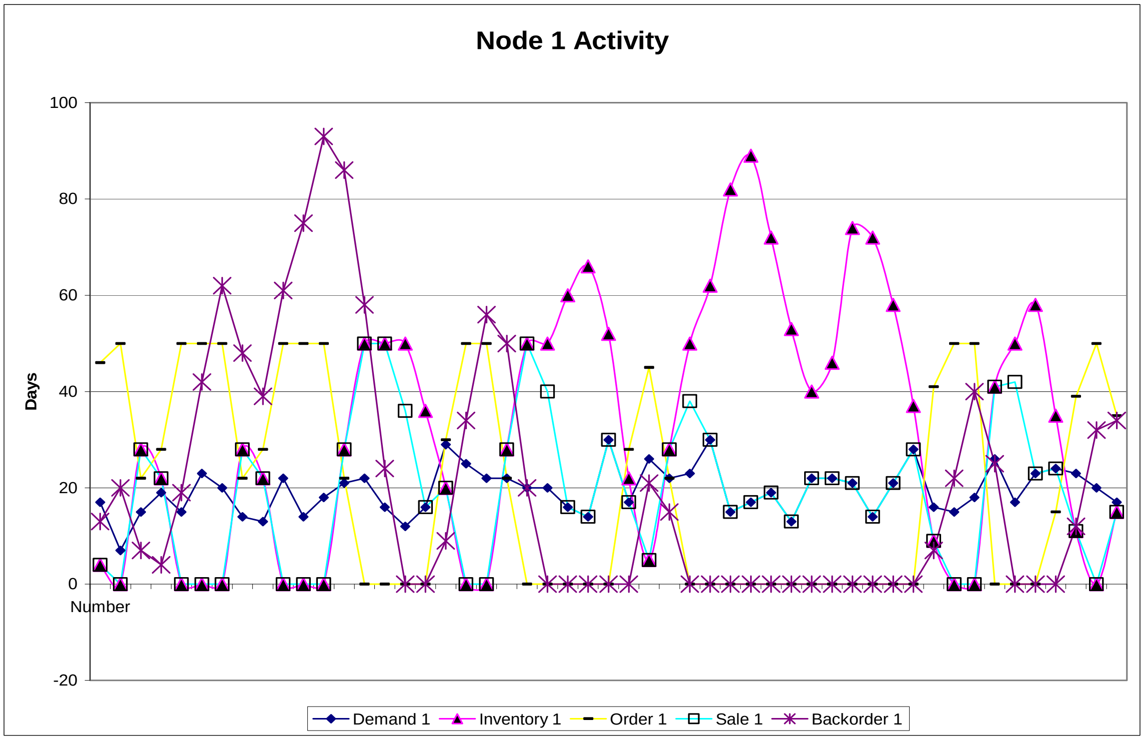

Figure 3. Activity at Node 1

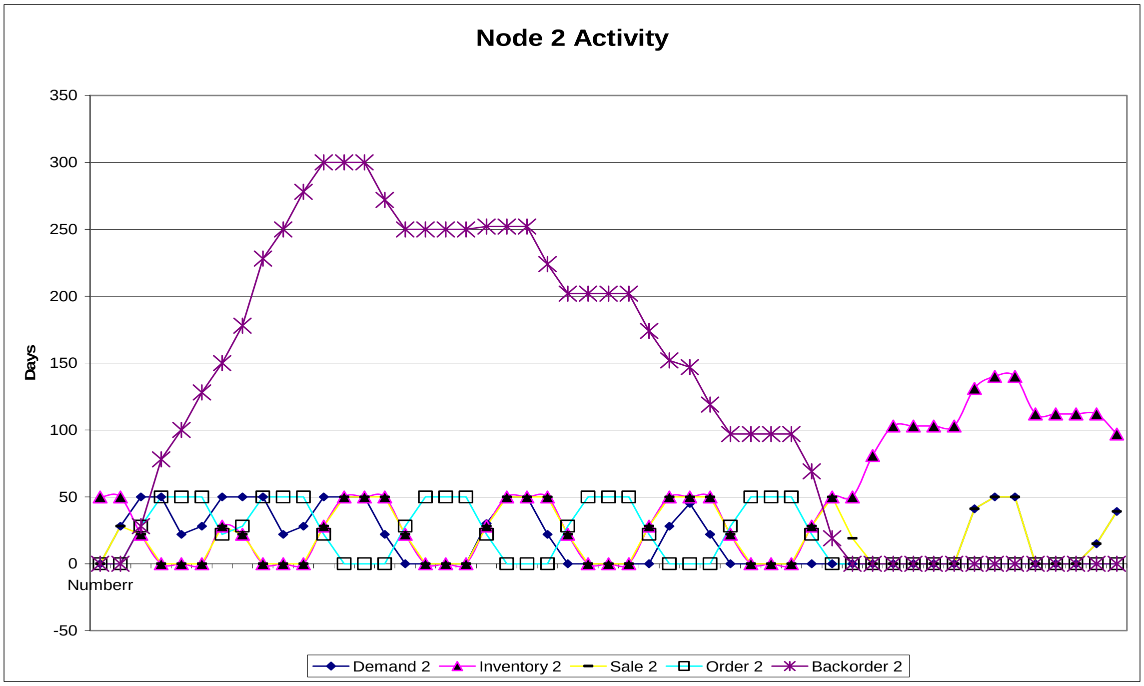

Figure 4. Activity at Node

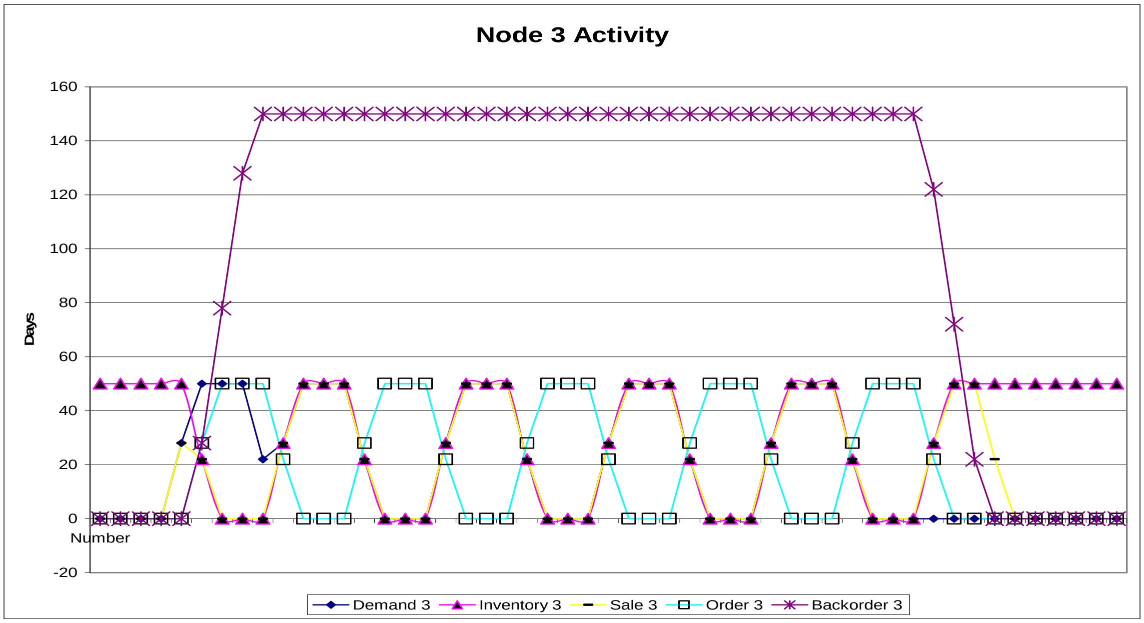

Figure 5. Activity at Node 3

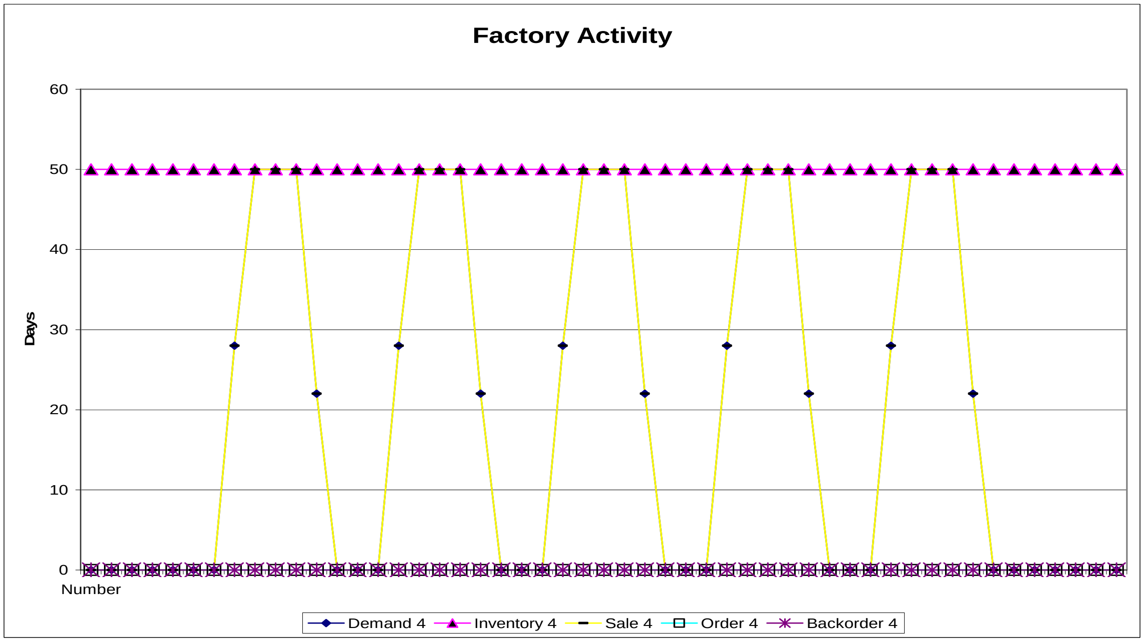

Figure 6. Activity at Factory Node

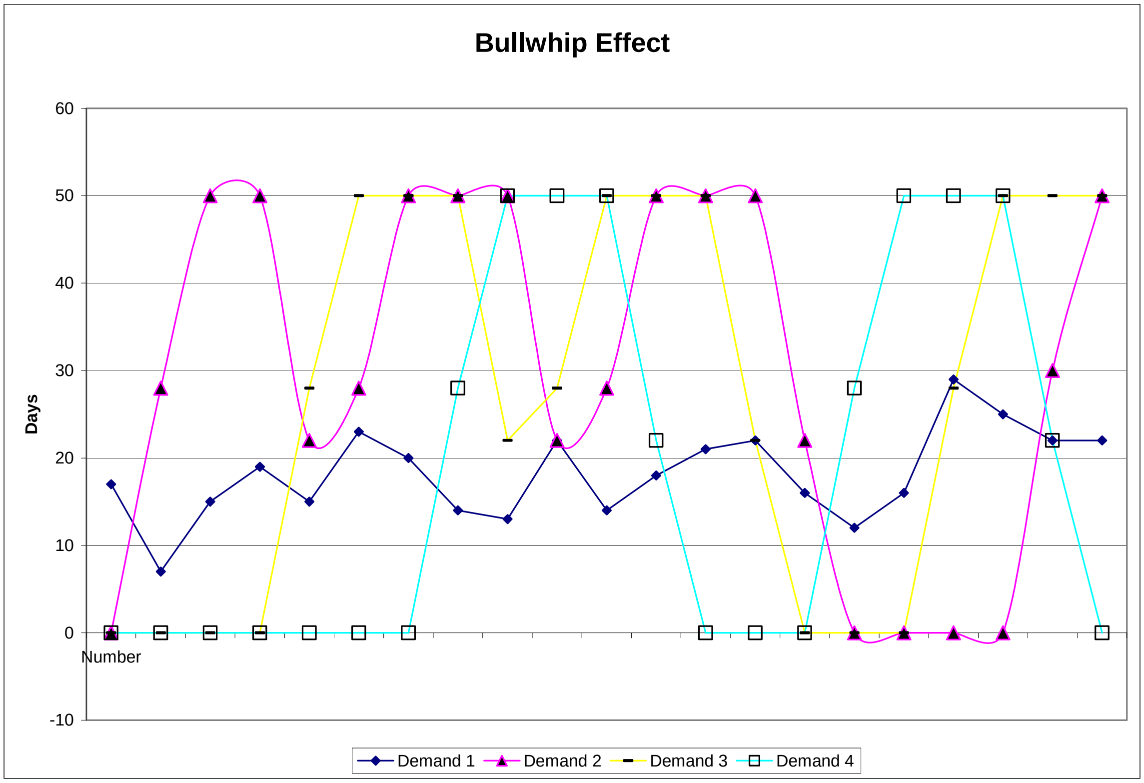

Figure 7. Bullwhip Effect