GUIDELINES FOR SUPPLY CHAIN NETWORK DESIGN: A PRACTICAL APPROACH

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ABSTRACT

The purpose of this paper is: (1) to identify and classify supply chain network design models addressed in literature based on model objective, decision variables and the issues that the models address (2) to highlight the assumptions and limitations of the existing models (3) to introduce a framework for designing global supply chain networks in practical settings to address both quantitative and qualitative factors and incorporate the dynamic behavior of real life cases, using a combination of optimization methods and simulation analysis.

Keywords: Supply Chain, Network design, Practical Framework, Optimization, Simulation

INTRODUCTION

Supply Chain is an integrated network of business players that are involved in the transformation process that makes it possible to provide a desired product or service to the customer (Christopher, 1992; Min & Zhou, 2002). Since a numbers of players are involved in this transformation process it becomes necessary to coordinate and efficiently manage the supply chain to deliver customer requirements at minimum cost. Supply chain therefore involves the flow of material from source to consumer with value additions along the way and flow of information from consumer to source to make the value addition as per customer demand (Beamon, 1998). Supply chain management includes all functions that make this transformation process possible. The functions are planning, sourcing, making, distributing, returns management as well as control policies that dictate the transformation process.

Since customers are becoming demanding in their requirements and markets are becoming competitive it is getting necessary to manage the supply chain such that desired level of customer satisfaction is provided at minimum cost. Since it has become possible to disaggregate the transformation process to achieve benefits of global competencies, many organizations are selecting their suppliers and moving their processes such that they could get that maximum value for minimum cost. Hence supply chain can become a source of competitive advantage for many organizations (Meepetchdee & Shah, 2008; Chase et al., 2001).

The importance of supply chain management has compelled a number of organizations to align the supply chain to achieve the benefits. Both researchers and practitioners are showing increased interest on the performance, design and analysis of the supply chain as a whole. Optimization models have been developed to find the best possible design for a supply chain.

Anyhow, supply chain design decisions are complex. Since no model can capture all aspects of the complex processes that exist in real life, a model builder should define the scope of the supply chain model in such a way that is reflective of key real-world dimensions, yet not too complicated to solve (Min & Zhou, 2002). One way of classifying SCM problem is to divide the area into strategic, tactical and operational level (Chopra & Meindl, 2001; Talluri et al., 2002). Since strategic planning is at the top of the hierarchy and demand major capital investment, it is critical to any organization and should be looked at first. We, in this paper, address the supply chain network design problem which falls under the realm of strategic supply chain design decision.

Supply chain network design allows supply chain managers to pick the optimal number, location, and size of warehouses and/or plants; to determine optimal sourcing strategies, and to determine the best distribution channels, that is, which warehouses should service which customers (Meepetchdee & Shah, 2008).

The network design problem has been extensively addressed in literature (Beamon, 1998; Meixell et al., 2005). The models developed can be broadly classified into optimization and simulation models. There are numerous variations of optimization models that have been developed given a specific scenario and constraints. These models have their limitations as they address the real life problem (Persson & Araldi, 2007). Simulation models, on the other hand, can account for the dynamic and stochastic behavior of many real life problems but they not necessarily provide an optimal solution. Simulation models have been used where the number of alternatives are known and can be tested using simulation modeling. Anyhow, no general guidelines are available for managers approaching the network design problem in practical settings. The objectives of this paper are 1. To identify the various types of supply chain network design models addressed in literature and understand their limitations 2. To develop a framework for designing global supply chain networks in practical settings to address both quantitative and qualitative factors and incorporate the dynamic behavior of real life cases, using a combination of optimization methods and simulation analysis.

SUPPLY CHAIN NETWORK DESIGN MODELS

SCM involves three planning phases: strategic level planning, tactical level planning, operational level planning (Ingalls & Kasales, 1999; Talluri et al., 2002). Strategic level planning involves SC design which involves configuration of the supply chain network i.e. determining the location, size, suppliers, plants, and distributors to be used in the network (Azaron et al., 2008). It also to some extent includes sourcing and deployment plans and actions for all plants, distributors, and customers. This phase can be summarized as determining the nodes and arcs of the SCN and their relationships.

Tactical level planning involves supply and demand planning, inventory planning etc. which are typically performed on a monthly basis (Talluri et al., 2002). Operational level includes more daily planning activities e.g. daily scheduling of production.

Though all the stages of supply chain present avenues for improvement, we will focus on supply chain network design. Supply Chain network design involves supplier selection, selection of manufacturing sites and distribution centers, allocations and capacities, relationships and network control policies.

Network design problem has been extensively addressed in literature. Anyhow, most of the papers target specific scenarios and make simplifying assumptions to real life cases. Most network design models are quantitative models that target optimization based on Mixed Integer Programming (Beamon, 1998; Meixell et al., 2005). One of the initial location problem papers is written by Hakimi (1964).

Geoffrion and Graves (1974) first included production function to derive the capacitated production location models while Wagner and Falkson (1975) gave the first location-production-allocation problem with price-sensitive demands (Korpela et al., 2001).

Majority of literature in logistical network design uses network efficiency, which is either cost minimisation (Jung et al., 2004; Cohen and Moon, 1990; Tsiakis et al., 2001) or profit maximisation (Cohen and Lee, 1989; Gjerdrum et al., 2001), as network design objective. Most multi-objective SC approaches are either deterministic (Chen et al., 2003) or only demand is considered as the source of uncertainty (Guillen et al., 2005). Fig. 1 shows the increasing level of complexity that can occur in a supply chain network design problem, thereby making it difficult to incorporate all aspects of real life system in mathematical models.

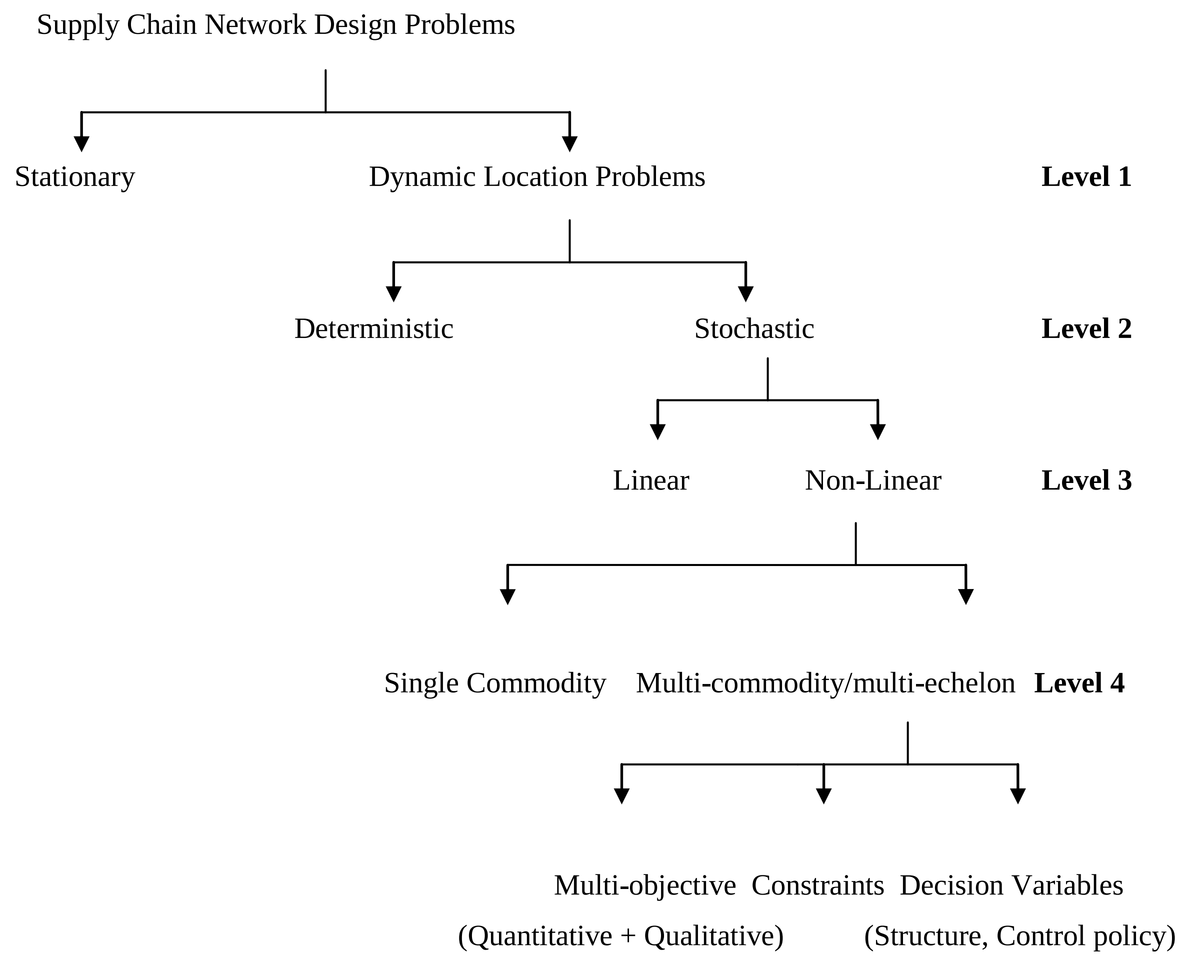


Fig 1 – Level of complexity in a Supply Chain Network Design Problem

The simplest case would be stationary, deterministic, linear, single commodity, single echelon, with cost minimization objective and location points as decision variables. Researchers have developed various types of models that apply to specific scenarios. These can be broadly classified into optimization and simulation models. Optimization models find the decision variable values to optimize the objective function whereas simulation models simulate the behavior of the model to determine how a given model will perform over time. Beamon (1998) has classified the models into following categories.

1. Deterministic
2. Stochastic
3. Economic
4. Simulation

Deterministic models assume that the values of the parameters used in the model can be determined with certainty. Out of 24 studies reported by Beamon (1998) 11 are deterministic. Anyhow, in real world scenarios there is little that is certain. Stochastic models try to capture the inherent uncertainty in the process. 9 models reported by Beamon have done stochastic analysis. One study reports an economic model and 3 simulation.

Deterministic Models

Non-linear

Cohen and Lee (1989) proposed a mixed-integer, non-linear, value added chain model with the objective to maximize total after-tax profit for the manufacturing facilities and distribution centers. Cohen & Moon (1990) extended Cohen & Lee (1989) to develop a constrained optimization model called PILOT in which the objective was to minimize fixed and variable production and transportation costs.

Multiple products/ multiple stages

There are also a few works reported in the literature to address multi-objective multi-stage decision problems (Cheng et al., 2003). Arntzen, Brown, Harrison, and Trafton (1995) used MIP to develop what they called GSCM (Global Supply Chain model). The model was formulated for multiple products and multiple supply chain stages, the objective was to minimize operations costs and activity days.

Dynamic Deterministic

Phuong et al. (2008) propose a mixed integer linear program (MILP) for the design and planning of a production–distribution system. Their study aims to help strategic and tactical decisions: opening, closing or enlargement of facilities, supplier selection, flows along the supply chain. The decisions considered are dynamic, i.e. the value of the decision variables may change within the planning horizon. The model considers a multi-echelon, multi-commodity production–distribution network with deterministic demands.

Objective Function with Qualitative Factor

Voudouris (1996) formulated a model to maximize system flexibility, measured by time-based sum of instantaneous differences between the capacities and utilizations of two types of resources (inventory and activity). The decision variables in the model were production, shipping and delivery schedule for each product and target inventory levels.

Multiple periods

Canel and Khumawala (1997) extended the international facility location problem (IFLP) model developed by them in 1996, by including multiple periods so that timing of location changes can be more carefully evaluated. Canel and Das (2002) extend this by a model that integrates manufacturing and marketing decisions in a global context.

Stochastic Models

Single Product/ 3 Stages

Pyke and Cohen (1994) consider an integrated supply chain with one manufacturing facility, one warehouse, and one retailer, but multiple product types. This is in extension to their previous model that considers single commodity. The model yields similar outputs; however, it determines the key decision variables for each product type. More specifically this model yields the approximate economic (min cost) reorder interval (for each product type), replenishment batch sizes (for each product type), and the order-up-to product levels (for the retailer, for each product type) for a particular supply chain network.

Tsiakis, Shah & Pantelides (2001) propose a design of multi-echelon supply chain networks under demand uncertainty.

Multi-objective Stochastic

Li (1990) considers a general separable class of stochastic programming multi-objective optimization with perfect state information. A generating approach using a stochastic multi-objective dynamic programming method finds the set of Pareto optimal solutions.

Azaron et al. (2008) develop a multi-objective stochastic programming approach for supply chain design under uncertainty. Their work formulates the SC design problem as a multi-objective stochastic mixed-integer nonlinear programming problem, which is solved by using the goal attainment technique.

Service level Objective function

Hwang, Heung-Suk (2002) developed a logistics system model that optimizes the performance of logistics system subject to required service levels both in the number of warehouse or distribution centers and vehicle routing schedule. The logistics system included plants, warehouses and customers. The model is formulated using stochastic set-covering problem and determines the minimum number of distribution centers among a discrete set of location sites so that the probability of each customer to be covered is not less than a critical service level.

Simulation

Towill (1991) and Towill et al. (1992) use simulation techniques to evaluate the effects of various supply chain strategies on demand amplification. One of the strategies involved elimination of the distribution echelon of the supply chain, by including the distribution function in the manufacturing echelon.

THE SUPPLY CHAIN NETWORK DESIGN FRAMEWORK

The studies have attempted to cover the complex nature of real life design problems. Anyhow there is no standard method of approaching the network design problem. Korpela et al. (2001) has proposed a framework to design outbound logistics in order to meet customer service requirements within the constraints of the supply chain. They have used AHP to decide customers' preferences for three alternate logistics services based on customers' strategic importance and then presented Mixed Integer Programming objective function to maximize these preferences which in turn determines the optimum service level. Anyhow the benefit of providing the desired customer service is not evaluated versus the added cost of providing this service.

Van der Vorst et al. (2000) has presented a method for modeling the dynamic behavior of food supply chains and evaluating alternative designs of the supply chain by applying discrete-event simulation. They have used time colored petri-nets to model and simulate the dynamic behavior of the supply chain. They used scenario analysis to evaluate potential benefits of alternative designs for the chilled food supply chain under consideration in terms of logistical performance. The designs, in this case, were known to the analyst before doing the analysis.

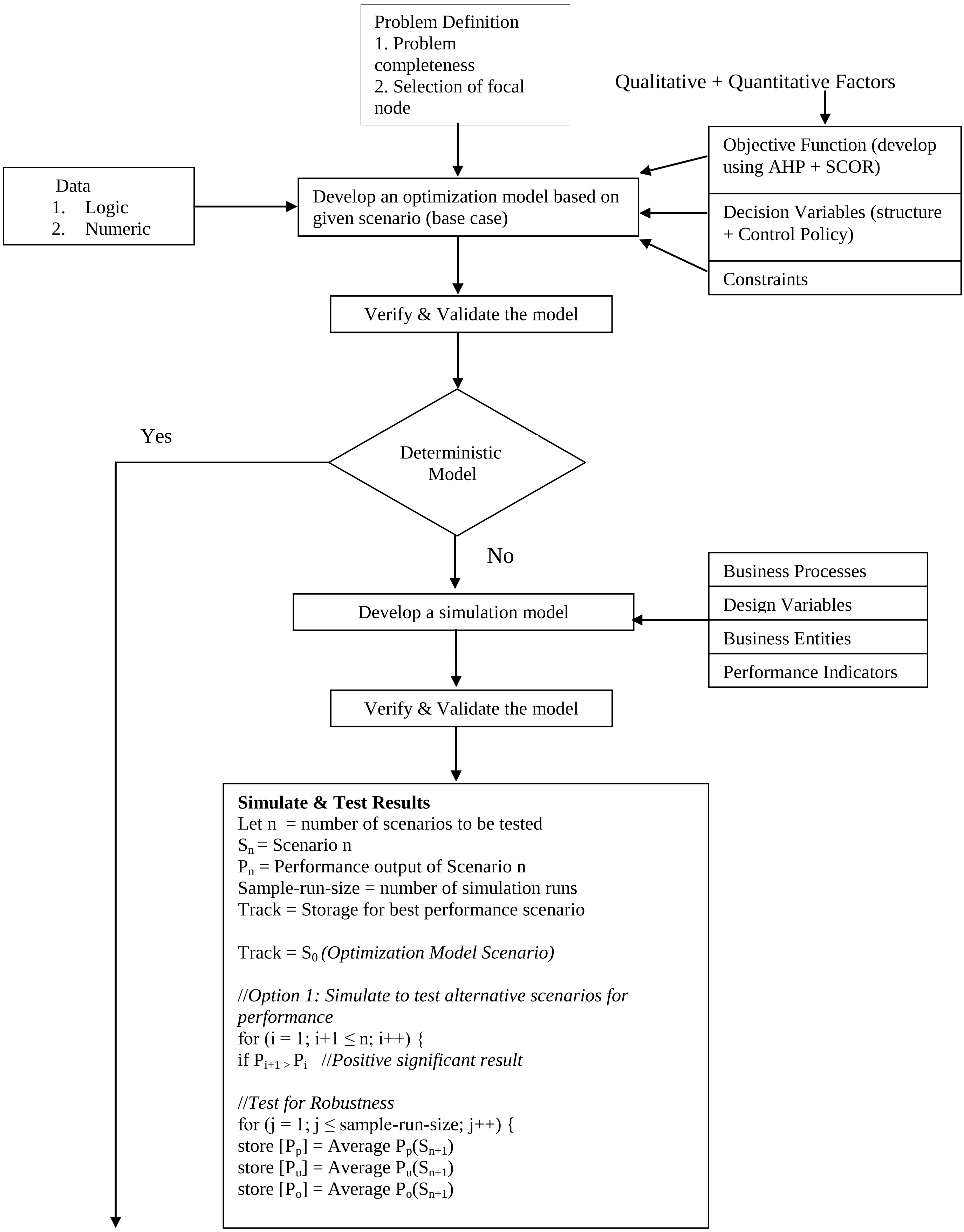
Reiner et al. (2003) has suggested a product-specific supply chain design model. Their model approaches the design of existing supply chain, again considering the various alternatives available. In this case, it is necessary to establish a target system for supply chain evaluation. They have used market winners and qualifiers as performance indicators to select the alternative that performs best on these indicators.

Persson (2006) have reported the ongoing work to integrate the SCOR methodology and discrete event simulation. Huan et al. (2004) explain how the SCOR model may be used for strategic decision making. According to them AHP can be used with SCOR metrics to arrive at an overall objective function for network optimization. Talluri et al. (2001) has presented a methodology that develops and applies a combination of multi-criteria efficiency models, based on game theory concepts, and linear and integer programming methods for effective supply chain design.

Any supply chain design problem is a combination of optimization and simulation models (Hicks, 1999). Simulation models although better at capturing the behavior of real world processes (Persson, 2006), optimization models are nevertheless required to arrive at a basic solution. Without an initial optimization solution, it will become tedious to do an exhaustive enumeration of all possible alternative designs in the network to check their effect on performance in a simulation model. Once the initial solution is available, simulation methods become necessary because of the inability of optimization models to accurately capture the complexity of the real life situation. Optimization models consider the supply chain at specific instances in time, hence lacking a dynamic view that can encompass variability of a solution in a stochastic environment. In simulation it is possible to experiment with a set of different scenarios in order to find an optimal solution (Persson, 2006). Discrete event simulation models can handle stochastic behavior throughout the SC and thereby help in studying and evaluating a phenomenon under uncertainty (Persson et al., 2002). Simulation models should therefore be developed as a second step to the network design problem.

The simulation model is developed using the solution from the optimization model while incorporating uncertainties that exist within different processes. The model is then run to test its effect on performance. Next models are changed to incorporate alternative designs and their effect of performance is then evaluated by executing simulation runs. Statistical tests (of significance) are then used to indicate if the change in performance is significant. The design offering best performance is then tested for robustness. After exhausting all the alternative options, the design offering best performance and robustness is selected.

Fig. 2 shows flow of the proposed process.


Problem Definition
1. Problem completeness
2. Selection of focal node
Qualitative + Quantitative Factors
Objective Function (develop using AHP + SCOR)
Decision Variables (structure + Control Policy)
Constraints
Data
1. Logic
2. Numeric
Develop an optimization model based on given scenario (base case)
Verify & Validate the model
Yes
Deterministic Model
No
Develop a simulation model
Business Processes
Design Variables
Business Entities
Performance Indicators
Verify & Validate the model
Simulate & Test Results
Let n = number of scenarios to be tested
S_n = Scenario n
P_n = Performance output of Scenario n
Sample-run-size = number of simulation runs
Track = Storage for best performance scenario
Track = S_0 (Optimization Model Scenario)
//Option 1: Simulate to test alternative scenarios for performance
for (i = 1; i+1 ≤ n; i++) {
if $P_{i+1} > P_i$ //Positive significant result
//Test for Robustness
for (j = 1; j ≤ sample-run-size; j++) {
store [P_p] = Average $P_p(S_{n+1})$
store [P_u] = Average $P_u(S_{n+1})$
store [P_o] = Average $P_o(S_{n+1})$

Calculate EVP(S_{i+1})
SE[EVP(S_{i+1})]

if (EVP(S_{i+1}) > EVP(S_i)) & (SE(EVP(S_{i+1})) < SE(EVP(S_i)))
Track = S_{i+1} }

else {
for (j = 1; j ≤ sample-run-size; j++)
store [P_p] = Average P_p(S_i)
store [P_u] = Average P_u(S_i)
store [P_o] = Average P_o(Si)

Calculate EVP(S_i)
SE[EVP(S_i)]

if (EVP(S_{i+1}) > EVP(S_i)) & (SE(EVP(S_{i+1})) < SE(EVP(S_i)))
Track = S_i }
}

//Option #2: Simulate until P_i = P (desired performance level)

Implement Track

Implement the model

1. Budget of the Organization
2. Organizations most pressing needs
3. Variables' impact factor

Fig 2 – Supply Chain Network Design Process

SUPPLY CHAIN NETWORK DESIGN PROCESS

1. Problem Definition

Selection of focal node:

Supply chain design should focus on a target organization. The first step is to identify a starting point. The studies in literature have focused on the major manufacturing or service concern in the chain and then built the model around that focal point to get optimum performance for the whole chain (Talluri & Baker, 2002; Thanh, Bostel & Péton, 2008). The focus is later on extended to other players in the chain, but an initial focal point serves as a basis to start the modeling and can help the modeler focus on the problem from a certain perspective, which will make his job easier.

Let's consider a manufacturing facility that produces ice-creams. Some of the suppliers supplying to this factory will not be dedicated suppliers i.e. they will be supplying to other facilities as well. Anyhow, these other facilities will not be part of the ice-cream manufacturing supply chain and will not be considered if we are modeling the supply chain for this manufacturer.

Problem completeness:

The modeler needs to make certain that the objectives and the scope of the problem have been clearly stated and all the relevant parameters with respect to the problem at hand are identified and addressed. Supply chain network design problems are context specific and the modeler needs to identify exactly the requirements of the problem at hand. Therefore the modeler needs to understand the context of the problem, policies being used, factors that need to be considered while formulating the problem. For example, risk of technology change is more obvious in the electronic industry than the consumer goods' industry, and should therefore be taken into account in case of former. Similarly preservation issue is important in fresh food supply chain whereas handling of hazardous waste may be an issue in chemical supply chains. Cost structure would appear different in the two cases.

Problem completeness also refers to level of detail that is required in the network design problem i.e. the problem should incorporate all aspects of the supply chain under review.

2. Optimization Model Formulation

Majority of the studies in network design have focused on developing optimization models for specific scenarios. The purpose of the optimization model is to find an optimal solution to satisfy a given objective given the constraints. In a network design problem the objective of most of the studies has been to minimize cost of the network (Cohen and Moon, 1990; Tsiakis et al., 2001).

We argue that supply chain network design problem should be decomposed into supplier optimization and distribution optimization problems. Since selection of suppliers (where supplier performance is determinant of the inward chain design) is not the same as defining a distribution route and control structure (where customer service and transportation cost are both critical), these two problems should be addressed separately. The focus of developing the transportation network is on maximizing customer service and reducing cost while the supplier selection problem is concerned with reducing cost of supplies and uncertainty simultaneously. These two may be combined later on to reach overall objective of the organization.

The first step in developing an optimization model is data collection.

2.1 Data Collection

There are two main types of data that should be acquired while working on a network design problem (Reiner & Trcka, 2004).

Logic Data

This includes flow charts, process maps that define the structure of the network and the existing policies at hand.

Numeric Data

Requirements like the number of suppliers, their costs, distribution centers, demand etc. are types of numeric data that need to be collected.

Next we build the optimization model using Mixed Integer Programming. The analytical optimization model comprises of the objective function, decision variables and constraints (Hillier & Lieberman, 2001).

2.2 Objective Function

Supply chain managers need decision making tools capable of investigating the effects of critical parameters on multiple performance measures (Longo et al., 2008). Relevant performance measures must then be identified in order to understand the supply chain and its characteristics (Persson et al., 2002). Attempts have been made in literature to comprehensively define supply chain performance indicators. Beamon (1998) and Min et al. (2002) provide an overview of supply chain performance indexes.

Since the objective of an organization in business is to increase shareholder wealth (Chase et al., 2001), this becomes a key overall performance indicator. Shareholder wealth is increased by sustained profits and growth. Profits are realized and sustained by increase in revenues, reduction in costs, and proper management of cash. Growth is dependant both on the investments a company makes in itself and growth in demand for its products.

In order to be strategically aligned with the goals of the organization, the supply chain should be designed to meet the objective of maximizing shareholder wealth. The objective function should be formulated using all the factors that affect wealth of firms in the chain. We here discuss the factors that affect shareholder wealth.

2.2.1 Profits

Profit maximization has been the objective of several supply chain networks present in literature (Beamon, 1998; Meixell & Gargeya, 2005). Profit maximization may be achieved by increasing revenues, reducing costs or both. Revenues are in turn derived from investments and sales. Value of investments may be increased by increase in profits or reduction in working capital and fixed capital. The value of sales is dependent on customer demand and willingness to pay (Kotler, 2006). Customer service is an important aspect of both increasing demand and customers' willingness to pay. As customers are becoming demanding and market competitive, customer service is becoming an important criterion in establishing the profitability of a firm. A number of studies have focused on meeting customer service requirements (Korpela et al., 2001; You & Grossman, 2008). Anyhow the service should be provided at minimal possible cost to generate profits for a firm. Cost minimization has been the focus of majority of the studies (Beamon, 1998; Cohen & Moon, 1990; Tsiakis et al., 2001). Although customer service and cost minimization are conflicting objectives both must be fulfilled to generate profits for the organization.

2.2.1.1 Revenues

Revenue from investments

Firms invest both in its own infrastructure for growth and in other investment avenues e.g. capital markets to generate revenues. The ability of a firm to invest capital comes from profits and decrease in both working capital and fixed capital. Where modelers consider the effect of profit on supply chain design, they should also incorporate the effect of reduction in working capital e.g. inventory, and fixed capital e.g. distribution warehouse, into the network design model. Slone et al. (2007) show how a chemical company has increased its ROA by increase in profit and reduction in assets i.e. working capital and fixed capital.

Revenue from sales

Revenue from sales is generated by market demand and customers' willingness to pay i.e. both the number of items purchased and the price paid determine the total sales value. Customer service which we define as the ability to meet customer requirements in order to satisfy the customer, determines the customers' willingness to pay and to some extent the demand for the product. Improvement in customer service may attract additional demand up to a certain level. Anyhow demand is dependent on other factors like customers' ability to pay as well as the number of customers available in a given area (Kotler, 2006; Varion, 1999). We discuss demand and growth in demand separately as their boundaries surpass the limits of customer service, and are factors important in determining overall objective of the firm.

Customer Service

Factors that are important for the customer and affect customer service have been used in designing supply chain networks (Korpela et al., 2001; Huan et al., 2004). We discuss some of the factors that have been used in literature and are important to consider for formulating a network design problem.

Flexibility & Responsiveness: Responsiveness may be defined as the ability of a supply chain to quickly respond to customer needs. The supply chain needs to be flexible to meet the changing requirements of the customer.

Delivery Reliability: It is the ability of the chain to deliver as per customer demand every time. How often can the chain deliver what the customer wants? In other words, reliability is the probability that the supply chain will respond to customer requirements. According to SCOR model, this constitutes of delivery performance, fill rate, order fulfillment lead time and perfect order fulfillment.

2.2.1.2 Factors that affect supply chain cost

Fixed Cost

These are costs that do not depend on the level of production. This includes cost of establishing a facility at a certain location, land taxes, insurance etc. These costs may be divided into quantitative and qualitative cost (Viswanadham, 1999; Chan et al., 2005) for the ease of formulation.

Quantitative

Cost that can be quantified e.g. cost of land, facility set up cost, administrative cost, cost associated with interest rates, exchange rates etc.

Qualitative

There are costs that occur because of intangible factors if a facility is located in a certain area; we call them qualitative cost factors. These include costs due to political conditions, development of infrastructure, government laws and regulations, availability of resources etc., and are important factor in international facility location problem.

Variable Cost

These costs vary as the number of units produced/ service provided increases. These may again be divided in quantitative and qualitative categories.

Quantitative

- Production cost
- warehousing and inventory cost
- total logistics cost: cost associated with transportation routes, transportation lead times, as well as mode of transportation
- corporate income tax
- freight & customs

Qualitative

Supplier and sourcing options: Overall cost of supplier selection need to be factored in the objective function, which includes cost of raw material plus the service level offered.

Cost of collecting information: The cost incurred because of incomplete information, or because of the difficulty in acquiring information regarding competitors, customer requirements, government regulations.

Supply chain risk: Supply chain risk may be quantified and expressed in terms of cost by calculating the expected value of using a risky option.

2.2.2 Cash Flows

Cash is important for the survival of business. Network node placement decisions should be made to ensure a smooth flow of cash. Players who don't have the ability and willingness to liquidate cash can cause disruptions for the whole chain. Similarly legal requirements and constraints may prohibit timely transfer of money and this should be taken into account while making a network design decision.

2.2.3 Demand Growth

Since demand volume and distance of facility from customer have a significant impact on transportation costs (Chase et al., 2001), both demand and growth of demand are important parameters to be factored in the network design problem.

Firms pursue the goal of increasing the wealth of shareholders. In order to accomplish this goal they not only target continuous profits but also ensure growth in profits. This is possible by targeting a territory where there are people who have the ability and willingness to pay.

Though the overall objective of firms remains at maximizing shareholder wealth, the process in achieving this target may be different. Since supply chain for innovative products is different from functional products (Fisher, 1997), the factors that go into the final objective function need to be carefully selected while formulating the network design problem.

AHP may then be used to incorporate the effect of various factors into the overall objective function.

There is ample justification present in literature for using AHP in network design problems and its usefulness as a procedure (Huan et al., 2004; Rabelo et al., 2007). Applications of AHP in supply chain design problem can also be found, for instance in Korpela et al. (2001) and Rabelo et. al. (2007). Korpela et al. (2001) use AHP to design a framework by which service elements and company's own strategies can be included in the cost-based design of supply chain. Huan et al. (2004) propose application of AHP with SCOR metrics to construct an overall objective function for network optimization.

The AHP is a systematic procedure proposed by Saaty (1980) for representing the elements of any problem in a hierarchal form with objectives, criteria and alternatives at various levels. The complex problem is decomposed into a hierarchy, which is then decomposed into a set of elements. The relative importance of the elements at each level is then calculated using pair-wise comparison. Priority weights at each level are calculated and integrated to allow overall evaluation of the alternatives from which the alternative with the highest overall priority weight is chosen. Saaty (1990) present the complete procedure for use of AHP.

2.3 Supply Chain Decision Variables

In a supply chain design problem main decision variables have been facility location and allocation (Arntzn et al., 1995; Camm et al., 1997; Hodder & Dincer, 1986). Some articles have attempted to include relationships and the number of echelons in the network (Lee & Feitzinger, 1995).

We divide these into two major categories:

Structural Variables

These variables define the network configuration and give as output the number of facilities, location and allocation of these facilities.

Number of facilities: These variables determine the number of suppliers, manufacturing facilities, distribution centers and warehouses should form the network.

Location: One of the answers that an analyst is looking for by running an optimization model is related to the location of a certain facility. Given the facilities under consideration the analyst wants to determine whether or not the facility should be opened. This variable is incorporated in almost all of the decision support network optimization models.

Capacity: Given it is feasible to locate a facility at a certain location, the next question is how much should this facility produce. Capacity is concerned with the size of each firm in the network

Allocation: Another question that network optimization models attempt to answer is what portion of demand should be allocated to a facility if it is selected i.e. what customers should be assigned to a certain facility if it is made operational.

Control Policy Variables

These variables define more abstract decisions regarding the control of the network. These are decisions regarding the extent of value addition at each node in the chain, customer-supplier relationships and the degree of control that lies with each member of the chain.

Extent of value added: Determining how much value should be added at each capacity. Beamon (1998) uses 'product differentiation step specification' and postponement to define the extent of value added.

Extent of outsourcing: This will also determine the number of echelons.

Customer-supplier relationships: Customers and suppliers may be categorized based on performance and their importance for the firm. Lambert, Cooper, and Pagh (1998) classified supply chain partners into two distinctive types: primary and secondary. The customer and supplier priority values thus derived may then be used to define relationship variables.

2.4 Supply Chain Constraints:

Constraints can generally be classified into functional constraints and logical consistency constraints (Hillier & Lieberman, 2001). Supply chain constraints need to be present in the formulation because of managerial limitations arising from scarce resources, regulations, customer requirements and demand. Listed below are some commonly appearing constraints in literature.

Functional Constraints

Capacity: These constraints put a restriction on to how big a certain facility can be? These restrictions are laid down because of the ability of an organization to produce the goods/ provide service at a certain facility. Since economies of scale exist along with economies of scope it will be only be viable to produce a certain limited quantity at a given location.

Demand: Demand puts an upper limit to what the supply chain is going to deliver.

Service level: The network needs to be laid out to meet a certain level of customer requirement.

Logical consistency constraints:

These constraints ensure the consistency of the structure of network design problem e.g. non-negativity constraints which ensure that the decision variables don't take any negative values. This is a logical implication of the network design problem, since a negative value of the decision variable in this case does not make sense.

3. Verification & Validation of the Optimization Model

Verification and validation of the optimization model needs to be done to make sure that there are no errors in the model and that the model is giving correct results.

The model should be checked thoroughly for internal consistency, making sure that all the relevant variables have been accounted for and that the mathematical formulations are dimensionally consistent (Hillier & Lieberman, 2001). A retrospective test may be done by using historical data and checking if the model is giving results as expected.

If the problem is deterministic in nature it can be implemented. Problems of stochastic nature should be further tested using a simulation model. It is difficult for mathematical optimization models to incorporate the complexities underlying uncertainties of real life systems (Van der Vorst, 1999; Persson & Araldi, 2007).

4. Simulation Model Development

Lee, Cho, Kim, and Kim (2002) underline the need to use modeling and simulation for analyzing and designing the whole supply chain. Simulation model of the existing system should be built first for validation purposes. Once the simulation model is validated against existing system, it should be changed to incorporate the optimal solution obtained under simplified mathematical formulation. The analytical model should be a good starting point as it would limit the choices that need to be tested using a simulation model. Simulation model is then used to test what-if scenarios and the resulting performance from these scenarios compared. Using simulation tools the quantitative performance indexes can be measured under the effects of different combinations of decision variables.

According to Longo et al (2008) the supply chain simulation model should be: (i) flexible and parametric for evaluating different scenarios; (ii) time efficient even in very complex supply chains that involve high number of supply chain stages and items; and (iii) repetitive in its architecture for easily changing the supply chain structure.

Van der Vorst (2000) has comprehensively described the following supply chain modeling parameters, which should be used while designing the simulation model.

4.1 Business processes

The supply chain comprises a set of business processes and their interrelationships. Business processes are activities that an organization does in order to add value for its customers. Processes involve resources that incur cost and consume time (Melao & Pidd, 2003). A process comprises a set of tasks to be executed in a specific order and according to a specific policy. The focus of every process is on meeting customer requirements. These processes have a specific start point, transformation time and an end point. E.g. purchase order generation, production, truck loading, transportation etc.

Business processes may be divided into two major categories i.e. value Adding and non-value adding.

Value Adding

Value adding processes are those processes that add value for the customer in the entities as they pass through the process e.g. a packaging process on a tea filling line adds value by putting lose tea grains into films or bags which are then sealed to maintain freshness of tea.

Non-value adding

Non-value adding processes are present in any system, yet they don't add value e.g. storage.

4.2. Design variables

Design variables correspond to the decision variables in the optimization framework. These variables, in the simulation model, represent the network configuration and control policies.

We have two categories of design variables for the network design problem.

1. Structural Variables: These variables determine the configuration of the supply chain network. They relate to the number of suppliers, manufacturing facilities, distribution centers, as well as the roles of each player in the network.

2. Control Variables: Control variables determine the control of network e.g. extent of value added etc., to improve performance of the supply chain.

Both design and control variables need to be identified and changed to arrive at best performance supply chain network design.

4.3 Performance indicators

It is important that the relevant performance indicators described for the optimization model be defined for the simulation model as well. These measures should be carefully linked to shareholder wealth. If the modeler is interested in the best design within existing constraints, then a maximum performance level may be sought by comparing alternative designs. Anyhow, if the purpose is to reach a preset target performance level, then design should be changed along with relaxing the constraints to achieve the target e.g. labor training may be sought or investment be made in new technology to improve the capacity constraint and then design changed to achieve the desired performance level.

4.4 Business entities

A business entity represents the flow of goods and/or information. Within a given network structure with a determined structure and control policy, the processes work to transform business entities in place, time and state to deliver the final value added product to the consumer.

Van der Vorst (2000) describes business entities as being complex and well-identified with a set of descriptive attributes as follows:

- a unique identification;
- a time stamp indicating the time at which it is released for further processing;
- descriptive attributes;
- a number of characteristic entities (a repeating group) that depend on the business entity for their existence;
- attributes that relate the business entity and/or the characteristic entities to attributes of the business entities used in processing the business entity.

They give example of a shipping list that can be identified by shipment number 7, released on Monday at 10 o’clock in week 12, is shipped from distribution centre 3 and has a delivery for retail outlet 11. The list further contains a number of shipment lines; each characteristic entity describes one part of the delivery for a product from a particular batch (attributes of such a line are batch number and quantity delivered). The batch number refers to a combination of a product number and the remaining shelf life, and is an example of a relationship of that entity to entities used to produce it. This is necessary for tracing products and for calculating performance indicators.

5. Verification & Validation of the Simulation Model

Model Verification

The model needs to be verified to check for internal consistency. This step would assure that the model is free of errors and conceptually correct i.e. all the processes are accounted for and relationships correctly defined. Manual calculations may be performed to check if the process outputs are as expected. The model should be simultaneously matched with existing system to identify loopholes. Experts from the supply chain partners can be employed to identify if the model is true description of the real system.

Model Validation

Persson et al. (2002) has highlighted three main categories of simulation model errors as follows.

1. Type I Error: Rejecting a valid simulation model
2. Type II Error: Accepting an invalid model
3. Type III Error: Solving a wrong problem

Correctly verifying the model will guard against Type III error.

In order to validate the simulation model and prevent from Type I and Type II error, the performance outcome of the model need to be compared with the real system in place. The difference in outputs of the model and the system should be analyzed to see if it is significant. A significance level α of 0.05 or 0.01 is common in statistical analysis tests. It is advisable to compare various output parameters e.g. average lead time, inventory levels, cost of supplier to check if significant difference exists. If after repeated simulation runs, the difference between the performance output of the model and the system is not significant at a given significance level, say 0.05, the model may be accepted as valid. Anyhow, there exists a possibility of committing a Type II error.

If no significant different is detected between the model and the real system, the modeler runs the chance of accepting the model as valid when it actually is not i.e. Type II error. Therefore, it is required that a guard against this is set a priori. Cohen (1977) proposes to set α to 0.05 and β to 0.2 (four times as much) to guard against false positive claims. This results in a power of 0.8 (power = $1 - \beta$), which means that the test now has 80% probability of correctly rejecting the model if it is invalid.

Baroudi & Orlikowski (1989) present three determinants of statistical power.

1. The significance criterion (α), chosen risk of a Type I error.
2. The precision of sample estimates, which is primarily influenced by the sample size n.
3. The effect size, which represents the magnitude or strength of the relationship among the variables in the population.

Since we have already set α at a specific level, and have no control over the effect size it will be best to increase simulation runs in order to increase the power of the test.

Persson & Olhager (2000) conducted an initial validity test of their model by undertaking a physical walkthrough of the existing system.

Validate the model incorporating solution from the Optimization Model

Once the model is tested against the original system, it should be changed according to the results from the optimization model. The values of the decision variables in the solution of the optimization model will correspond to design variables in the simulation model. The performance output from the simulation model should then be compared with the results from the optimization model. If the output of the optimization model fall within the range of usual values (at 95% confidence interval) of the simulation model, then the simulation model is ready for testing the effect of design changes otherwise the reason for discrepancy should be investigated and corrected.

6. Simulation & Test of Results

Once the model is accepted as valid, it may be used to test the effect of various changes in design parameters on performance. A number of scenarios that the management of the focal organization is interested in evaluating should be laid down. Each scenario will be a combination of structure and control design variables. For instance, one scenario could be that the system has four distributors instead of three in the original system and wants to have control over order delivery. The distributor in this case will be an intermediary who will be paid to deliver goods to stores as per the requirements of the manufacturer which is the focal organization in this case. It is also important to distinguish between scenario and ‘external cause factors’. Scenarios (structure and control variables) consist of variable that are under the control of the organization e.g. an organization can decide whether or not to buy from a certain supplier. We define external factors as unusual variables beyond the control of the organization that may disrupt the normal behavior of the system e.g. an unusual surge in demand, an unexpected rise in exchange rates of the country in which the organization is operating (normal behavior incorporates chance variation).

The number of runs for the simulation model should be decided depending on the time available and accuracy desired. The performance output of the model with scenario 1 is compared with solution from the previous model. The scenario is accepted if there is positive significant difference. In other words, if the desired performance output i.e. shareholder wealth increases with the new scenario it should be accepted as a valid proposal.

If, instead, the organization is interested in reaching a certain desired performance level then the model is changed until the performance level is achieved. In that case it should be ensured that the inherent reason behind the change is identified. For instance, if in the model the output of a process is increased, then it should be properly identified how the increase will actually happen; it may be because of new technology, improved labor productivity of something else.

Test Model Robustness

Robustness is the extent to which the system is able to carry out its functions despite some damage done to it, such as the removal of some of the nodes and/or edges in the network (Meepetchde & Shah, 2008). The model may be tested for unusual cases (external factors), for instance, an emergency situation (Reiner & Trcka, 2004). We propose that the model be tested for the pessimistic case, usual case and optimistic case.

If the probability of the pessimistic case is p_p, usual case p_u, optimistic case p_o and the average performance indicator value from several runs under the same scenario for the worst case PI_p, usual case PI_u optimistic case PI_o then the expected value of selecting the given model may be computed as:

$$EVP_{scenario\ 1} = p_p * PI_p + p_u * PI_u + p_o * PI_o$$

Standard deviation of the EVP is calculated as follows:

$$SE(EVP_{scenario\ 1}) = \sqrt{\{p_p*[SE(PI_p)]^2 + p_u* [SE(PI_u)]^2 + p_o* [SE(PI_o)]^2\}}$$

A robust model will have low SE(EVP), as we expect the model to give same performance output even if it is disturbed.

Examine Alternative Scenarios

If alternative scenarios are present, then changes are made to the model according to the next scenario and simulation runs executed. Design of Experiment (DOE) and Analysis of Variance (ANOVA) can be used for correctly setting parameters, number of simulation runs and replications (Longo et al., 2008).

The effect of change in model on performance parameter under review is noted. The new scenario is accepted as a valid proposal if there is positive significant effect of change on performance parameter. The model is then tested for robustness and its 'expected value of performance' calculated. If the EVP is greater than that for previous scenario, then this scenario is finally accepted.

The next scenario is similarly compared to the best alternative scenario that exists after the test. The process is repeated until all alternative scenarios have exhausted.

7. Model Implementation

Following steps are suggested for implementation of the model.

- Select the Model based on Expected Value of Performance for implementation.
- Identify all the variables that need to be changed in the existing system.
- Prioritize the variables and implement those that have highest priority first.

Major considerations (It may be wise to plan) in the implementation phase are:

1. budget of the organization
2. organization's most pressing needs
3. variables' impact factor on performance

Budget of the Organization

Organizations don't run without constraints. Budget is an important factor in deciding whether or not an organization can invest in a given alternative scenario. Investment in network design is a long term decision. For instance, building a new facility demands huge investment which then becomes a fixed asset with low liquidity characteristic. This investment would require that the organization has enough capital for operations left after the investment such that its current functioning is not affected. Budget is therefore going to be an important factor in deciding whether or not the organization can implement the scenario under consideration all at once or in pieces.

Organization's most pressing needs

Given the budget constraint, organizations want to focus on most pressing issues first. For instance, if the customers are complaining about long order lead times, then this may be an obvious issue to tackle first rather than order fill rate. Our overall objective remains increasing shareholder wealth, and the scenario selected for implementation is based on that. Considering the most pressing needs, we now determine factors from the selected scenario that will have impact on the 'most pressing need'. If therefore, lead time is the 'most pressing need' then in this case variables that most affect the lead time should be altered first to improve lead time performance.

Variables' Impact Factor

It is important to note that the variables that would be changed are dictated by the scenario been selected for implementation. Variables having greatest impact on performance are considered first. If as in our case lead time is important, then all the factors in the selected scenario that affect lead time performance will be identified. Out of these variables we further prioritize the variables based on their impact on lead time performance and select the one that has highest impact. If changing this variable is not constrained by the budget of the organization then this variable is selected as the first one to be implemented, otherwise we move on to the variable with next highest impact factor.

Research may be carried out for thorough planning of the implementation phase.

CONCLUSION

The paper identifies the methodologies used in network design problem and shortcomings of these methods. Next it proposes a framework for the network design problem, which is a strategic level issue. Anyhow, an overall supply chain design should incorporate tactical and operational level designs. Some of the tactical and operational issues that are addressed in literature are inventory policy, number and type of transportation vehicles to be employed, raw material planning. Research is required to understand if a comprehensive methodology to approach the tactical and operational level design problem is possible. Tactical level decisions should, for instance, employ the interests of individual chain partners. Strategic supply chain design decision is from a single firm (the dominant supply chain partner) perspective, as the firm has the flexibility to choose among various available suppliers and distributors to design an optimal supply chain for itself. Anyhow, tactical level decisions should, for instance, employ the interests of individual chain partners.

Acknowledgement: The authors would like to acknowledge the comments from the audience at the DSI 2009 Annual Conference, where an earlier version of this paper was presented.

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