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AN ANALYSIS OF RETAIL SUPPLY CHAINS: TIME BASED SIMULATION IN NEURAL NETWORKS AND MAXIMUM FLOW NETWORKS

ABSTRACT

Contemporary supply chain management systems need not only be adaptive to changing needs of the consumers but also to the varying terms amongst the members of the supply chain. Moreover, the on-time availability of services and goods is imperative for retaining customers. Hence, irrespective of a new supplier becoming a partner of the supply chain or an old supplier exiting the business, the demand must be met keeping cost constraints into account. Supply chain management is a cross-functional approach that involves managing the movement of raw materials into an organization, processing of materials into finished goods and finally providing finished goods to the end consumers. In this paper, the concept of SCM has been perused with the approach of network flows applying maximum flow network algorithm of graph theory with changing count of the supply chain players and their supplying capabilities. We have discussed cases of increasing count of Suppliers, Manufacturer, Distributors and Retailers from 8 to 88 players of an apparel retail chain. This variability is then analyzed for time using MATLAB Simulation tool. The same variability is assessed using feed forward neural networks for modifying the number of neurons within the various layers.

This study emphasize on the analysis of the performance of the two approaches which calculate the material flows across several alternate supply sub-chains from suppliers to the destined retail stores. The algorithms are simulated with varying data to compute actual supply chain logistics and then, the running time of the algorithm is compared in a dynamic node scenario. The results of the two approaches have been compared using mean squared error of the difference between actual demand and expected demand as well as running time of these two approaches. Simulation of supply chains has been performed using weighted graphs with non-negative edges and employing iterative Ford Fulkerson algorithm and multilayer feed forward network using inbuilt MATLAB functions.

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INTRODUCTION

In today's era, every enterprise needs complete visibility into its end-to end supply chain and seamless integration between internal system and external parties. A business looking to enter a global market must assess its supply chain to address the perfect region for the product. Ability to tap new local supplier is to raise the stiffness of the competition in a market from incumbent firms as well as new and emerging players. While competition can benefit consumers by optimizing cost, it keeps enterprises vying for innovative ideas and supply chain models – that can help them stay in this tight race. Supply chain is a network of suppliers, manufacturers, distributors and retailers who are collectively concerned with the conversion of raw materials into goods that can be delivered to the customer. It is a dynamic, stochastic and complex system.

The objective of the supply chain is to enhance the operational efficiency, profitability and competitive position of a firm and its supply chain partners. Supply chain stages include procurement, production, inventory and distribution. Supply chain management involves handling logistics at these different stages as shown in Figure 1.1. Production distribution planning is one of the most important activities in supply chain management. The main decisions involved are plant location, capacity allocation and market (demand) allocation. These decisions influence both cost and customer experience. Customer demand is not a static factor in real world situation and this has been modeled using various methodologies.

This study is concerned with changing number of suppliers, vendors or distributors and corresponding capacity allocation while demand is assumed to be accurately estimated well before it has to be fulfilled. The following sections include the description of the existing work and an insight into how supply chain dynamics are being modeled so far. Then the methodology and reference algorithms used in the study have been discussed. We, then, present a modified algorithm that works with varying nodes and changing capacities. The implementation of the approaches for certain scenarios and the running time analysis are finally put forward.

LITERATURE REVIEW

OVERVIEW OF INVESTIGATION STUDIES ON SUPPLY CHAIN

Keith Oliver, a consultant at Booz Allen Hamilton recognized the concept of Supply chain management in 1982. He popularized the terms like supplier, distributor, retailer, customer and defined the flow of information which intact the different entities in one relationship while maintaining the upstream and downstream of business to fulfill the proportion of supply and demand. Supply chain management provides an integrated environment where systems like production, storage, distribution, and material control are integrated in one plan i.e. ERP. The purpose of supply chain management is to improvise the factors of trust and collaboration among supply chain partners to further improve inventory visibility and the velocity of inventory movement. There have been many issues that have been addressed in achieving goals of SCM such as determination of inventory levels and forecasting demand accurately. These are critical design factors of supply chains with the uncertainty aspects modulated according to the supplier and the customer. The paper is focusing to the variability in the size of supply chain partners can be assessed using graph theory as well as neural networks for effective risk mitigation and better logistic flows.

METHODOLOGIES OF ANALYZING SUPPLY CHAINS

There are different ways to create strategies for a total systems view of the links in the chain that work together efficiently and to create customer satisfaction at the end point of delivery to the consumer. As a consequence, costs must be lowered throughout the chain by driving out unnecessary expenses, movements, and handling. The main focus is turned to efficiency and added value, or the end-user's perception of value. Efficiency must be increased, and bottlenecks removed. The measurement of performance focuses on total system efficiency and the equitable monetary reward distribution to those within the supply chain. The supply chain system must be responsive to customer requirements. The impact of number of changing terms among the supply chain partners is mentioned in different parameters of the literature survey.

Benita M.Beamon [4] hasperformed the investigation of various processes within manufacturing supply chains. The paper focused on the performance, design and analysis of the supply chains. Several models were described which enhance the performance and design by implementing heuristic model and spread sheet based inventory model. These models maximize system flexibility measured by the time-based sum of differences between the capacities and utilizations of the inventory resources and activity resources. Another purpose of their work was to determine the location of distribution centre and assign the selected Distribution Centers (DCs) to customer zones. The design and analysis of supply chain

Figure 1.1: Supply Chain Logistics

determined the efficiency and/or effectiveness of an existing system or to compare competing alternative systems.

Abbas Tolie Eshlaghy and Maryam Razvai [1] have described the uncertainty in supply chain management which can be overcome through an emergency inventory. The idea of the paper was to integrate all the activities throughout the chain which reduced the inventory to be supplied to customers. The linear control method and transfer functions analysis for modeling the supply chain were used to control the negative effect of changes in demand on order rate. The system focuses on the structures and behaviors of combined systems comprising of mutual feedback loops by the customer. If feedback loop changes an amount of a variable opposite to the direction of the original deviation, then the loop is considered as a negative feedback else considered as positive feedback. The continuous-time condition calculates the best situation for exchanging order rate and inventory using Vensim Software.

Jefrey W. Herrmann et.al. [8]have discussed about the novel supply chain simulation framework that includes the Supply Chain Operations Reference (SCOR) which integrates discrete event simulation and spreadsheets. SCOR was developed to depict the business activities correlation with all phases of satisfying a customer's demand. They have further described the three levels of supply chain simulation model which designate the implementation of the framework using Arena and Microsoft Excel. The simulation models were hierarchical in nature and used sub-models that capture activities specific to supply chains. The approach of paper was to integrate the libraries of reusable sub-models to build unified supply chain models with less effort within the specified time available for evaluating the system. The focus was to improve the performance of entire supply chain model.

Barnett and Miller [3] explained specialized supply chain simulation software that applies SCOR. The goal was to perform supply chain simulation models using the SCOR model with reusable components from discrete-event simulation software to facilitate model construction. The dynamic system analyzed and defined the perspective of the evolutionary process of supply chain collaboration with the SCOR usability.

S.D. Chandrasekaran [13] described the crystallized concepts about integrated business planning that have been supported by logistics experts, strategists and operation research practitioners to compute the quality and desirability of a product which was further conceptualized in terms of optimization along with the genetic algorithms. The genetic algorithm frame in supply chain networks identified the multi point search technique that further examined a set of solution which can be extracted to find the solution of complex supply chain network. Various constraints were considered for optimization of the supply chain network of an organization with the aim to reduce the total operating cost and maximize the profit of industry with the help of mathematical modeling. The modeling was done using genetic algorithm in MATLAB. Genetic algorithms have found applications in bioinformatics, phylogenetics, computational science, engineering, economics, mathematics, chemistry and other fields. The effectiveness of the algorithm was tested through computer simulation for various real life problems and found to be very effective. The GA approach not only satisfied the customer's requirements but also defined a near minimum cost.

C. Edward Wang et.al. [5] explained how supply chains are affected by the production and inventory strategies, which influence the amount of information needed by the chains. The lack of precise market demand and reliable supplier's stock level makes it inappropriate to use the statistically based inventory model to extract inventory strategies for the new product supply chain. This paper demonstrated a fuzzy neural network model to determine the uncertain market demand and reliability in supply products to the customer. The paper also explained the long term effect of supply and customer's demand in the multi –echelon acyclic network supply chain. The study considered the shortage, backordering costs and applied a fuzzy neural network model to crystallize the capacity at each production facility in order to improve the entire supply chain. The algorithm was derived to estimate minimal inventory costs under given capacity range.

Stephan M. Wagner and Nikrouz Neshat [11] described about the susceptibility caused by the frequent natural and manmade disaster in supply chain. They have explained an approach which quantify and mitigate supply chain using graph theory. The purpose was to assess the vulnerability of the supply chain and provided the effective strategies of risk mitigation. The proportion of vulnerability drivers in supply chain structure stem to a large degree from the disintegration and the globalization of value added activities. The supply chain vulnerable dependency affected both the supply side and demand side if errors in inventory planning were made. Therefore, graph modeling used an appropriate method to quantify the vulnerability and tap the interdependencies. The vulnerability drivers acted as a nodes and interdependencies acted as edges or links in graphs. Graph modeling measured the vulnerability assists in converting supply chain vulnerability to an index. The further use of index has allowed managers to better manage the vulnerability and defined the interaction among the drivers which considered as direction dependent. These interactions and the intensities were represented by a weighted directed edge which determined the value associated with each edge and can be mapped in adjacency matrix provided the allocation of an information in the prescribed path. The strategies which can be implemented were augmented by three parameters like graph size, graph order and graph permanent values were used to reduce the risk in supply chain and subsequently improve financial performance of the firm.

Yisheng Wu [12] explained about the closed loop supply chain by determining the information flow like forward supply chain or reverse supply chain with effect from the fuzzy graph theory. The paper had eleven constituents which described about the information and fund flow direction from supplier to consumer. The primary coverage of fuzzy graph theory was generalized fuzzy matrix and multi level direction fuzzy graph and their principles were based on many valued logics. The fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic has been expressed to handle the concept of partial truth, where the truth value may range between completely true and completely false. When linguistic variables are used, these degrees may be managed by specific functions.

PROBLEM DEFINITION AND STUDY METHODOLOGY

A supply chain model must be able to keep into account all characteristics of the system, including dynamic specifications such as demand fluctuations, delays in lead time and variable system components. It is of interest to analyze how the change in the tally of supply chain players affects the logistics. The impact of varying the player counts is also dependent on the strategy of finding out optimum flows. A case of an ABC apparel retail chain is thereby taken to represent scenarios of how an increase in the number of suppliers will affect the time to compute material flows across the supply chain to meet the demand. Similarly, a change in number of the manufacturers or distributors will impact the material supplies and is, therefore, studied. The supply chain of ABC retail group initially considered in the analysis has the following topology having a supplier to provide raw materials to two manufacturers, and two intermediary distributors who furnish demands of three retail branches, each. Hence, flow of materials is directed from left to right in the Figure 3.1.

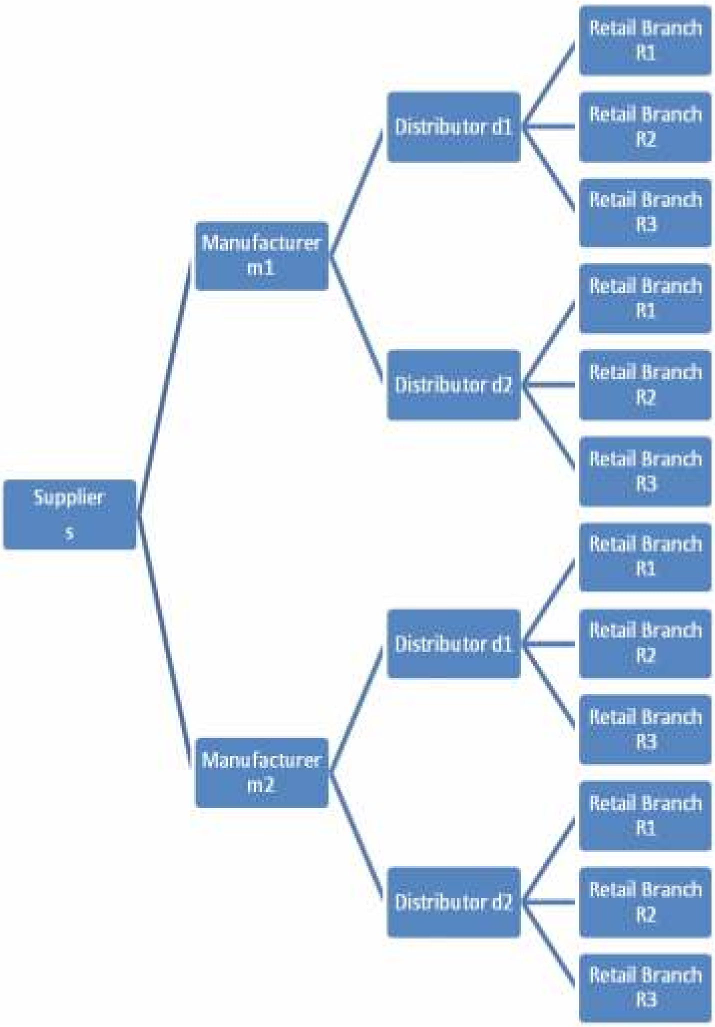


Figure 3.1: Basic supply chain

There are numerous methodsthat can be deployed to model supply chains. These include deterministic, stochastic, game theory models, and simulation based models. This paper is exercising simulation of the supply chain using network graph modeling as well as neural networks in MATLAB. A network flow graph is a weighted directed graph with two extraordinary vertices, the source vertex, and the sink vertex, with no incoming edge and outgoing edge respectively. Corresponding to the supply chain network, suppliers are the source nodes and retailers are the sink nodes. Each pair of supplier node and retail store node forms the end points of flow networks. The edges represent logistics between the two player nodes, and edge weights, here, are the capacity of channels between any two players. The capacity of the channel is determined based on the processing capabilities of the receiving player and is negotiated whenever a deal occurs between two players. This capacity is considered to be a function of time and retail demand is factored in this value. Therefore capacity can be updated from time to time. The supply chain management system should be able to compute the maximum flow possible and the corresponding conceptual augmented path from every supplier to the retailer to not exceed the capacity of the network. The procedure makes an iterative use of an old strategy by Ford and Fulkerson (http://www.geeksforgeeks.org/ford-fulkerson-algorithm-for-maximum-flow-problem/). Ford Fulkerson algorithm takes as input a digraph with its vertex set and edge set, the source and sink nodes, and non negative edge capacities. The flow conservation is maintained between the nodes, that is, the sum of flows of all outgoing edges of a vertex cannot exceed the sum of flows of all incoming edges of this vertex. Also, edge capacity obviously is the upper limit for edge flow. Ford and Fulkerson computed residual paths to finally reach at the maximum flow. G(V, E) is the given directed graph with V vertex set and E edge set, and for any two vertices u, v, c(u,v) defines the capacity of the edge from u to v, and f(u, v) denotes the flow from u to v. A residual network $G_r(V, E_r)$ is the network with capacity $c_r(u, v) = c(u, v) - f(u, v)$ and no flow. An augmented path from s to t is found using Edmonds-Karp breadth first search method or depth first search method. The algorithm is as follows:

Ford Fulkerson Algorithm:

Inputs Graph G with flow capacity c, a source node s, and a sink node t

Output Maximum flow f from s to t

Steps:

1. Initialise f (u, v) as zero for all edges (u, v)

2. While there is an augmented path p from s to t in residual graph Gr with positive edge capacities $c_r(u, v) > 0$ for all edges (u, v), do the following

1. Find $c_r(p)$ = minimum {cr(u,v) : (u, v) in p}

2. For each edge (u, v) in p

a. $f(u,v) = f(u,v) + c_r(p)$

b. $f(v,u) = f(v,u) - c_r(p)$

Hence, the maximum flow has been attainted when the residual graph has no more augmenting paths. MATLAB will be used in order to implement the algorithm using graph maxflow function. An instance of such a network with 1 supply node, 2 manufacturing nodes, 2 distributors and 3 retail branches with their augmented paths is shown in the diagram in Figure 3.2 generated in MATLAB.

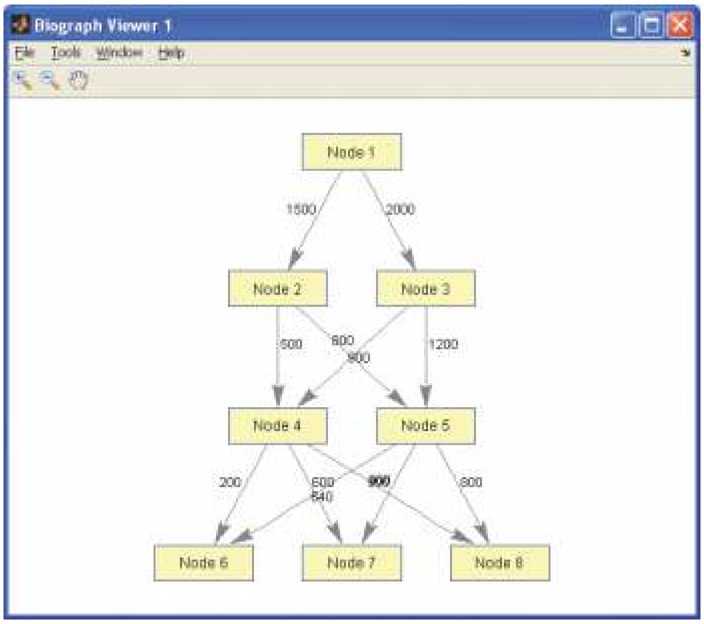


Figure 3.2: A Network Flow Biograph of 8 nodes generated in MATLAB

Besides using max flow algorithm, another approach was taken as a means to capture the structure of interconnection of the supply chain components and flows among them. Feed-forward back-propagation neural networks are popular neural network architectures [6].To apply a feed-forward NN to supply chain, allowable flows to a player from its provider will be provided as inputs and demand to be met at the retail stores will be taken as anticipated outputs of the network. Then based on the actual outputs produced and error between desired flow and actual flow, the weights of the connections will be adjusted. Since there is layered architecture of the supply chain where each player category forms an echelon in the chain, the same can be modeled using a multi layer feed forward network as shown in the below instance diagram in Figure 3.3 of the neural network with seven suppliers furnishing supplies at the input layer and meeting targeted demand of twelve instances of retailers forming output layer. The five manufacturers and eight distributors are the two hidden layers.

The neurons are performing weighted sums of the incoming flows and the activation function is simply a sigmoid function to represent convergence to the targeted demand from uplinked layer. Output nodes yield the actual demand met based on the current initial weights of the interconnections. Then based on the difference between the desired demand to be met and actual output demand, the weights are readjusted. This learning process is useful to fine tune the flows from the suppliers all the way through to the retail branches. These weights can be analogously compared to the flows in the network flow graphs used in the previous methodology. Both the strategies are examined in the paper using MATLAB toolboxes.

The algorithm for a generalized feed-forward back-propagation method is as follows:

Inputs A neural network with multiple sets of input values as training patterns; weights of connections initialized as small random numbers, between -1 and 1; desired outputs from the output layer; Threshold values for each connection.

Output A neural network with all weights assigned such that error between desired and actual output vector is minimum

Steps:

1 For each given training pattern, do the following: Initialise the network with the pattern;

While there are layers in the network, do the following: For every node in the layer, do:

a. Calculate the weightsum of the inputs to the node

b. Add the threshold to the sum

c. Calculate the activation for the node end

For every node in the output layer, do:

Compute the error between desired output and actual output generatedend

For all hidden layers, do the following as back-propagation:

For every node in the layer, do:

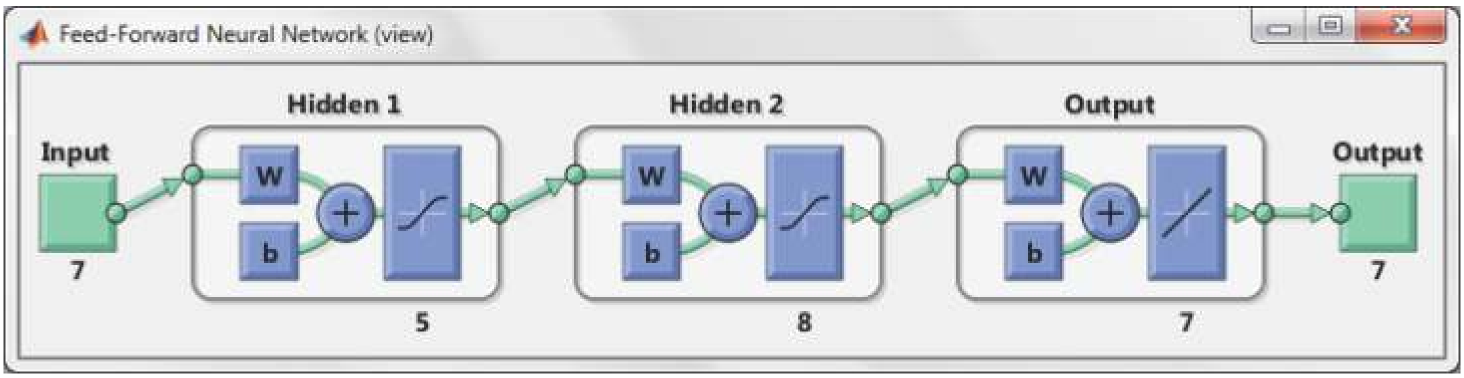


Figure 3.3: Multi-layer Feed-forward Network with an input layer, an output layer and two hidden layers

a. Compute the node's error

b. Update the node's weight

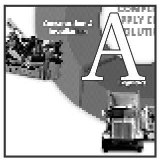
end

end

end

2 Repeat step 1 while the error exceeds the minimum error permissible.

The implementation of this algorithm is directly performed using MATLAB functions and sigmoid function is taken as the activation function for the neurons since it generated non negative derivatives showing a natural convergence to the desired value attainable.



DAPTED NETWORK FLOW ALGORITHM FOR MAXIMUM MATERIAL MOVEMENT

The supply chain network has node count changing every unit of time. It is assumed that the number of suppliers and consumers are changing and recorded at regular discrete intervals of time t1, t2, t3, t4 and so on. The demand (capacity) of each supply player has been predetermined and is assumed to be constant during a time unit. The algorithm will assume that there is only one good type and there is a one to one correspondence between one unit of good and one unit of raw material, i.e. one unit of raw material replenishes one unit of demand of the good. The algorithm may be extended to over multiple good types and multiple raw material components. Following are the variables used in the procedure to record observed and computed data.

S	set of suppliers = {si: i = 1 to Smax}
M	set of manufacturers = {mj: j = 1 to Mmax}
A	set of distributers = {ak: k = 1 to Amax}
R	set of retail branches = {rl: l = 1 to Rmax}
Dr(tL)	Estimated demand or capacity by rth player at time tL
δSt	Change in number of suppliers at time t
δMt	Change in number of manufactures at time t
δAt	Change in number of distributers at time t
δRt	Change in number of retail branches at time t
L	Maximum Lead time from demand ordered to replenishment
Xijt	number of goods furnished by ith player to jth player at time t

Capacities of the supply channels are available based on the predicted demand for time t.

The algorithm is as follows:

Input:

A graph Ginitial with initial supply chain topology at time t1, with number of vertices = |S|+|M|+|A|+|R| and edges from each supplier si, to each manufacturer mj to each distributor ak to each retail branch rl

A graph Gnew1 with updated supply chain topology at time t2>t1, with vertices count |S|+ δS_{t2} +|M|+ |A| +|R| and edges from each supplier, to each manufacturer to each distributor to each retail branch

A graph Gnew2 with updated supply chain topology at time t3>t1, with vertices count |S|+ |M|+ δM_{t2} + |A| +|R| and edges from each supplier, to each manufacturer to each distributor to each retail branch

A graph Gnew3 with updated supply chain topology at time t4>t1, with vertices count |S|+ |M|+ |A| + δA_{t2} +|R| and edges from each supplier, to each manufacturer to each distributor to each retail branch

A graph Gnew4 with updated supply chain topology at time t5>t1, with vertices count |S|+ |M|+ |A| +|R| + δR_{t2} and edges from each supplier, to each manufacturer to each distributor to each retail branch

Output:

Maximum flow values from each si to each rl via each manufacturer and distributor

Time taken to run the algorithm at time t1 and t2

Steps:

1. Initialise time t = t1 and G = Ginitial;

2. For time t, do the following:

For each supplier si in G as source node do:

for each retailer rl as sink node:do:

Compute the maximum flow and corresponding path using Ford Fulkerson algorithm and record time taken to compute the same

end;

end;

3: Update time t = tx and G= Gnewx where x = 2, 3, 4, 5 and repeat step 2.

4: Compare the computational costs for a unit change in each of the supply chain player

This algorithm models the changing dynamics of the flow due to changing count of players. The iterative Ford Fulkerson algorithm is being analysed for this model. Step 4 implements step 2 repeatedly for each of the following scenarios:

Updating number of suppliers.

Updating number of manufacturers.

Table 5.1: Data Set Size for Experimentation for two approaches

Player Matrix Size	# of Suppliers	# of Manufacturers	# of Distributors	# of Retailers	Source Node	Sink Node
8 × 8	1	2	2	3	Supplier Node s1	Retail Nodes r1 to r3
32 × 32	7	5	8	12	Supplier Node s1 to s7	Retail Nodes r1 to r12
44 × 44	12	6	12	14	Supplier Node s1 to s12	Retail Nodes r1 to r14
80 × 80	16	18	26	20	Supplier Node s1 to s16	Retail Nodes r1 to r20

Updating number of distributors.

Updating number of retail branches.

The algorithm works with changing nodes of the network flow graph.

IMPLEMENTATION

MATLAB by MathWorks is a powerful computational and modeling tool that is quite often used in engineering and information technology research. We have also deployed the tool in order to compute the flows in the supply chain under dynamic demographical conditions over time.

The BioInformatatics Toolbox provides several graph theory functions for network analysis and visualization. graphmaxflow(*G, SNode, TNode*) function accepts a sparse matrix representing a directed graph *G* with a source node *SNode* and a sink node *TNode* and outputs the maximum flow *MaxFlow, FlowMatrix,* a sparse matrix with all the flow values for every edge, and Cut, an optional row vector indicating the nodes connected to *SNode* after calculating the minimum cut between *SNode* and *TNode*. Since we don't require the cut matrix for our computations, it's not taken as an output parameter [14].

This function was iteratively called with varying input parameters. Table 5.1 shows below the inputs to the function: matrix of capacity of movement from suppliers to manufacturers, from manufacturers to distributors, as well as from distributors to retail branches; the suppliers as source nodes and retail branches as the sink nodes. The output generated by running the code is specified in the results section for each input data set. The time taken by the algorithm has been also recorded.

Neural network designing for the supply chains for these varying supply chain sizes has been done by:

1. First setting up the multilayer neural network with an input (supplier) layer, an output (retail store) layer, and two intermediate hidden layers (manufacturer and distributor),

2. Then configuring the network with the same input data sets as above altering the number of perceptrons at each layer,

3. Then initializing the weights and biases and training the network using a training algorithm (*trainlm* is used here with mean square error performance function which uses Levenberg-Marquardt algorithm)

4. Finally validating and using the network

The *feed forward net(hidden Sizes, trainFcn)* function in the Neural Network toolbox accepts as inputs a row vector of one or more hidden layer sizes and a training function trainFcn default of which is trainlm.

RESULTS

When run for the data sets for varying number of supply chain members, the following measurements were taken.

Approach	Matrix Size	MSE of Target Demand & Supply	Time Taken (in sec)
Iterative Fold Fulkerson	8 × 8	69525	0.0312
Feed-forward back-propagation Neural Net	8 × 8	8.9E-23	0.59

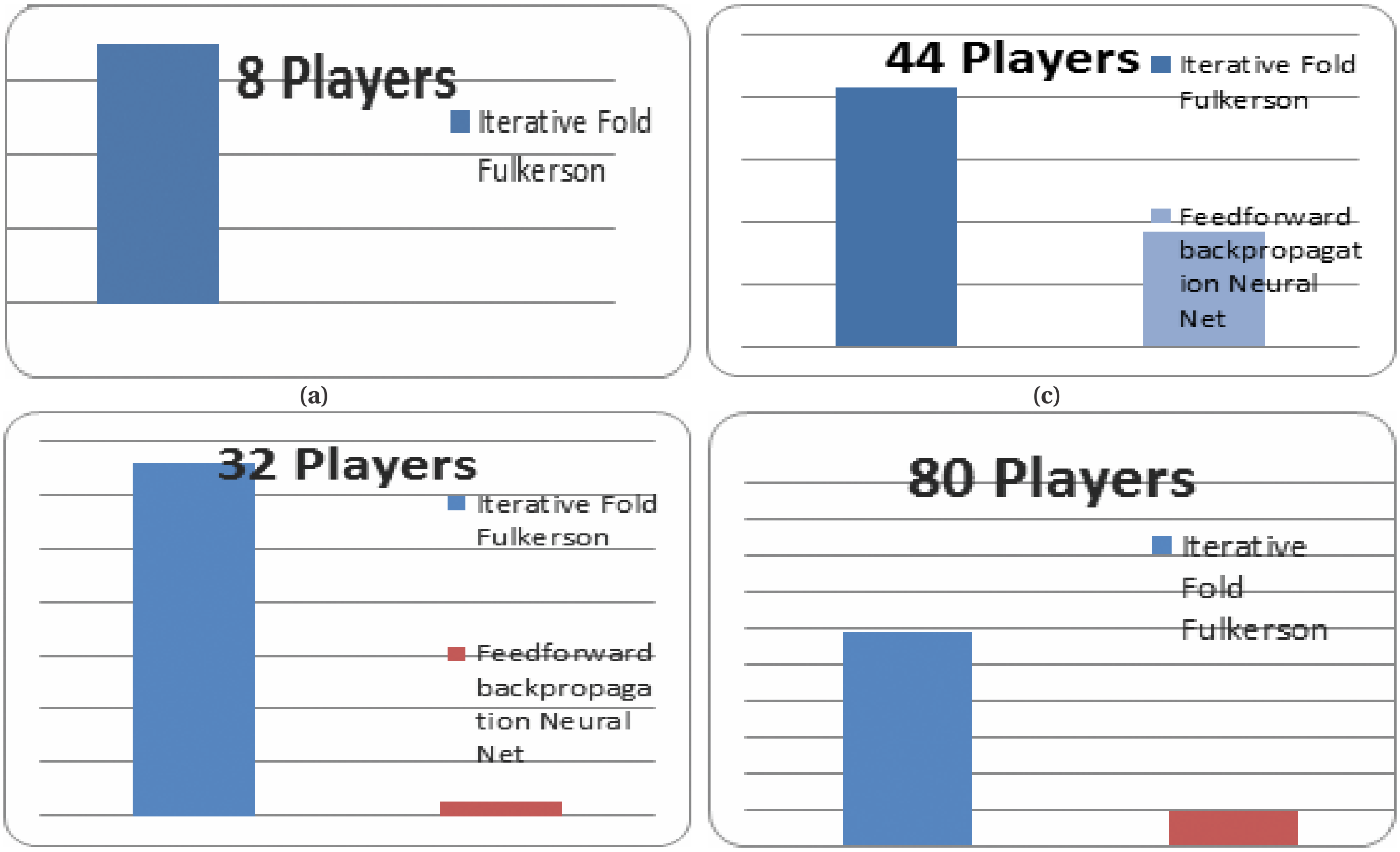
Approach	Matrix Size	MSE of Target Demand & Supply	Time Taken (in sec)
Iterative Fold Fulkerson	32 × 32	66138.84	0.0468
Feed-forward back-propagation Neural Net	32 × 32	2732	0.962

Approach	Matrix Size	MSE of Target Demand & Supply	Time Taken (in sec)
Iterative Fold Fulkerson	44 × 44	82878.04	0.0936
Feed-forward back-propagation Neural Net	44 × 44	3700	1.138

Approach	Matrix Size	MSE of Target Demand & Supply	Time Taken (in sec)
Iterative Fold Fulkerson	80 × 80	58516.2	0.1
Feed-forward back-propagation Neural Net	80 × 80	9210	2.66

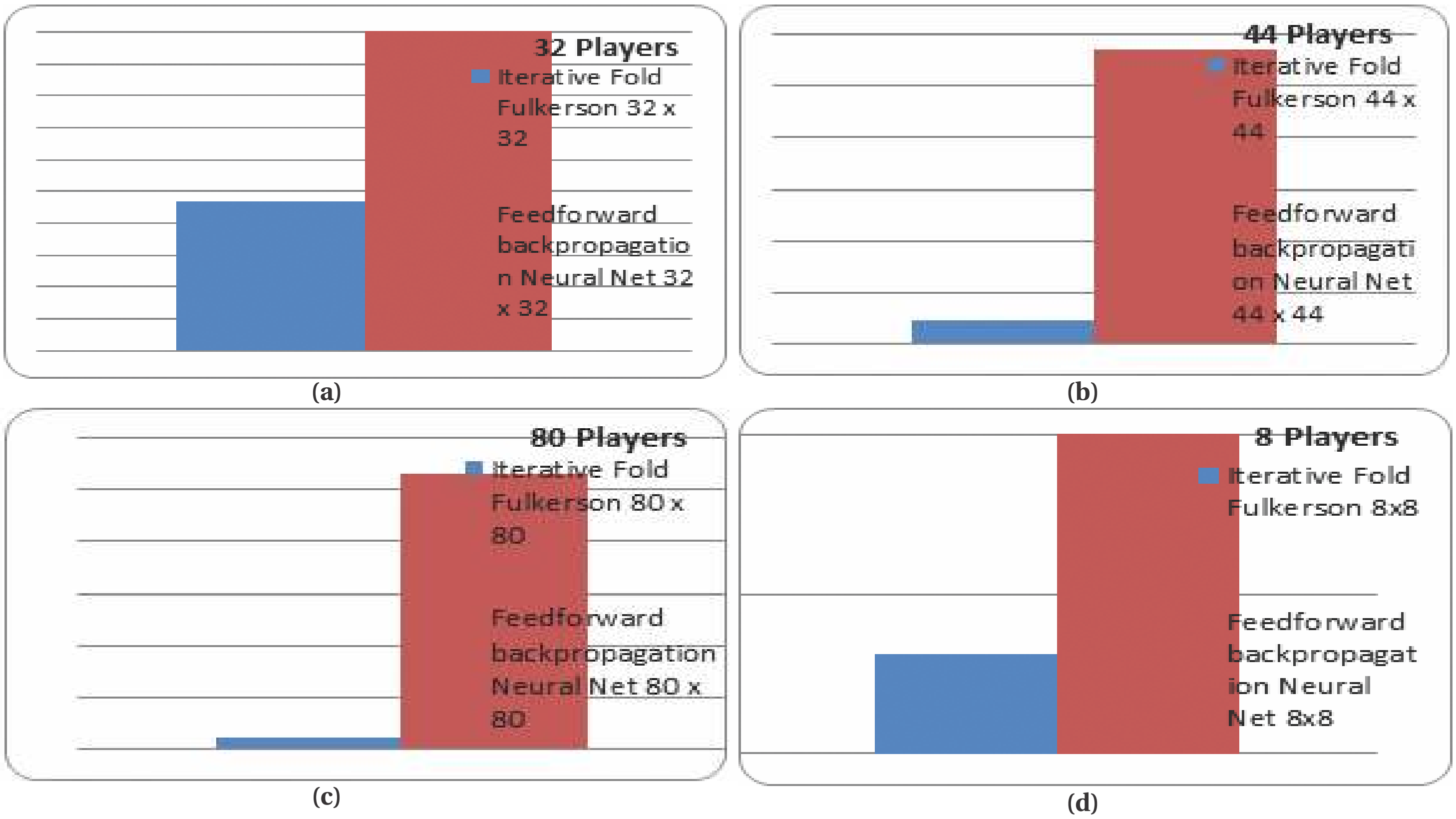
The comparative study between the two approaches using histograms is shown in figures 6.1 and 6.2.

In all scenarios, it was found that using Feed forward back propagation Neural Network strategy to model dynamic supply chain leads to better results in terms of meeting the demand more accurately than Iterative Fold Fulkerson strategy (Figures 6.1(a) to 6.1(d)). However the time taken by



(a) (c) (b) (d)

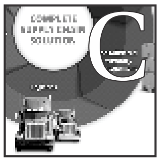
Figure 6.1 MSE comparison of two strategies for computing flows of supply chain with varying number of players



(a) (b) (c) (d)

Figure 6.2 MSE comparison of two strategies for computing flows of supply chain with 8 players

Iterative Fold Fulkerson methodology is less as compared to Feedforward backpropagation Neural Net strategy (Figure 6.2(a) to 6.2(d)).



ONCLUSION

Balancing the growing needs for better customer satisfaction with changeability of supply chain size in terms of number of material suppliers, growing manufacturing units and distributors is a crucial factor for the success of the business operations. A highly dynamic supply chain in terms of variable number of players requires a quick as well as an efficient means to reflect the changes in the flows in order to meet the required demand of the end customers.

Using one of the two proposed methods for computing the material flows under dynamic supply conditions is a managerial decision and is based on the tradeoff between speed v/s accuracy. Our case study justified through the analysis that time sensitive systems that can tolerate some unmet demand may use maximum network flow graphs and apply Ford Fulkerson algorithm iteratively. Most supply chain management systems however are considered reliable if they meet target demand requirements more precisely. Neural network modeling therefore has been a better strategy with lower mean squared errors between desired and actual supplies according to the experiment results. To mathematically compute the performance difference between the two approaches is left for further research.

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