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Optimization of Transportation and logistics costs to maximize revenue and efficiency of supply chain

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Abstract - Supply chain operations are perceived as total business operations for revenue generation. Various objectives like minimization of total operating costs, minimization of logistics & transportation costs, maximization of revenue etc forms the necessary pre-requisites for effective and efficient strategies in supply chain practices. But these are conflicting objectives if total efficiency and effectiveness of supply chain performance is to be achieved. Adhering to one strategy does not ensure perceived/improved performance of the supply chain. Therefore, all of such conflicting objectives are to be considered set wise to arrive at the total effectiveness of SCM practices. Supply chain optimization is the optimization using mathematical methods to ensure that the optimal operation of supply chains. Supply chain operations are optimized to minimize operating costs, minimization of inventories, minimization of operating expenses like inventory, transportation, manufacturing, distribution etc. and maximizing gross margin, maximization of revenue, maximization of return on investment. Supply chain operations are optimized to minimize operating costs, inventories, operating expenses like inventory, transportation, manufacturing, distribution, information sharing etc. and maximizing gross margin, revenue return on investment. These costs primarily vary from up-stream side to down-stream side as the supply chain entities use customized information sharing facilities and technology. Supply chain optimization may include refinements at various stages of product lifecycle. Supply chain optimization problem is supply chain general problem, i.e. providing products and services to customers at the highest profit, but at the lowest price possible. In this paper, multi-objective optimization of logistics and transportation costs, operating costs and revenue is carried out with the application of Non-Dominating Sorting Genetic Algorithm (NSGA-II). These optimization results are used in decision making & strategy formulation to develop a cost effective operation of supply chain.

Key Words: SCM, Multi-objective optimization, Logistics & Transportation costs, NSGA-I, Revenue, Objective function sets.

I. INTRODUCTION

Optimization in general involve usage of appropriate computer software tools with proper parameter settings. Several customized software is also available to perform optimization with ease. Supply chain problems are complex and difficult due to the number of entities in the supply chains, the lead times at each node of the supply chain, complex inventory management practices at each entity, stochastic demand nature, diversified logistic options etc. Many independent entities in the supply chain each of which try to maximize their own objective functions or interests in business transactions and many of their interests are conflicting when entire supply chain is considered. Thus, for a specific supply chain, giving an optimal design configuration is very difficult. Any optimization solution to an independent entity does not guarantee a optimal solution to the entire supply chain.

II. BACKGROUND AND REVIEW

Supply chain operations are perceived as total business operations for revenue generation. Various objectives like minimization of total operating costs, minimization of Logistics & Transportation costs, maximization of revenue etc forms the necessary pre-requisites for effective and efficient strategies in supply chain practices. But these are conflicting objectives if total efficiency and effectiveness of

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supply chain performance is to be achieved. Adhering to one strategy does not ensure perceived/improved performance of the supply chain. Therefore, all of such conflicting objectives are to be considered set wise to arrive at the total effectiveness of SCM practices.

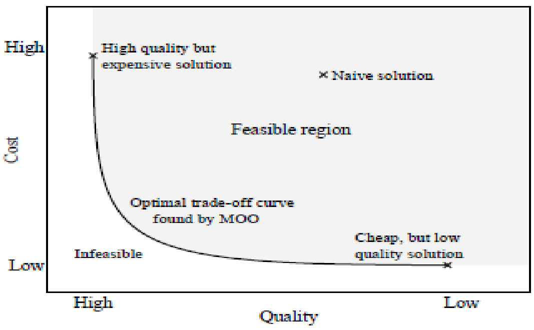
Thus the main objective of the supply chain is to maximize the profitability of not just a single entity but rather all the entities taking part in the supply chain. This can only be done if all the entities wish to optimize performance of the supply chain as a whole (system optimization) and do not place their individual preferences (individual optimization) above that of the system. There must also be a complete integration among all the entities so that information can be shared in real-time in order to meet the highly fluctuating demand of the customers. Therefore, to maximize the profitability of the entire supply chain it is definitely not enough to optimize these individual drivers separately. Objective functions capturing these drivers have to be optimized simultaneously.

III. METHODOLOGY

In this work, multi-objective optimization using Non-dominating Sorting Genetic Algorithm (NSGA-II) algorithm is used to generate pareto-frontier.

3.1. Multi-Objective Optimization (MOO)

Given an optimization problem with two or more objectives, MOO will give an optimal trade-off curve between those objectives. All points on this curve are optimal in the sense that it is not possible to improve one objective without worsening at least one other. Note that the trade-off curve is the result of a search in parameter space, and that most solutions will lie behind the Pareto-optimal curve—and may well be of worse quality than the cheapest found by MOO, and more expensive than the best quality solution.



With these results, the decision-maker can make a design choice from among the points on the optimal trade-off curve. Budgetary constraints, quality limits, emission limits can all be taken into account easily by studying the graph. Furthermore the decision-maker can see the shape of the entire curve, and see, for example, for only a small extension of the budget, a large quality gain can be made, or, that if a slightly lower quality than specified is acceptable, large savings can be made.

3.2 Non-dominated Sorting Genetic Algorithm (NSGA-II)

A Methodology & Algorithm presented by **Kalyanmoy Deb** is used to Optimize the Supply chain Total operating costs, information sharing costs using NSGA-II[16]. A small initial population size is used in the beginning and the population size is increased where at each step the percentage increase in the number of non-dominated solutions with respect to the previous step is noted. If this percentage increase falls below a certain pre-specified amount, then further increase in population size is not necessary.

Srinivas and Deb presented NSGA (Non-dominated Sorting Genetic Algorithm) [23] which was based exactly on MOGA except for a few changes in fitness assignment leaving the rest of MOGA unchanged. NSGA-II is the second version of the famous “Non-dominated Sorting Genetic Algorithm” based on the work of Prof. Kalyanmoy Deb. NSGA-II is a fast and elitist multi-objective evolutionary algorithm. The most recent implementation of multi-objective genetic algorithm is Non-dominated Sorting Genetic Algorithm-II or NSGA-II that is known as one of the best methods for generating the Pareto-frontier. The NSGA-II algorithm ranks the individuals based on dominance. It also calculates the crowding distance for each individual in the new population. Crowding distance gives the GA the ability to distinguish individuals that have the same rank (i.e. those that reside in the same frontier set). Individuals that are in a lower frontier set are considered better than those in higher sets. If they are in the same frontier, then individuals which is the farthest from other individuals is considered better. [90]. The NSGA-II is one of the most competitive multi-objective evolutionary algorithms available today and it’s often used as a reference to determine the performance of new approaches [17].

A brief explanation of the steps involved in NSGA-II is presented below:

1. A parent population called Pt is randomly generated and an offspring population Qt is created from it.
2. Both populations Pt and Qt and combined into population of size $2N$ where N is the population size. This new population is called Rt.
3. The population Rt undergoes non-dominated sorting where all members are classified and put into fronts.
4. The *best* N individuals from Rt are selected using the crowding tournament selection operator and from the parent population of the next generation $Pt+1$.

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5. The steps 1-4 are repeated until the termination criteria have been satisfied.

The source code for NSGA-II is freely available for research purposes at the KanGal (Kanpur Genetic Algorithms Laboratory) website. The code is implemented in the C programming language. The motivation for using NSGA-II in this paper is because it's performance has been tested on several test functions and has given accurate results in generating the Pareto front as can be seen in Deb et al, 2002 and it is well supported by literature having been used in many real-world applications.

4. SUPPLY CHAIN OPTIMIZATION - PROBLEM DEFINITION

A generic supply chain with usual entities is considered Optimization problem to arrive at strategies that help the decision making on effective operation of supply chain. The entities in consideration are five suppliers, three manufacturing plants and four customer zones. In a more general formulation of this problem, the three different components can be supplied by any of the five suppliers. These components can be shipped to any of the three plants where the product is made. Then they are shipped to the customer zones based on the demand.

To mimic a realistic supply chain; some suppliers would be preferred over others depending on their policies which impact their previous performance, quality and timeliness of goods delivered. This argument is also valid in the case of the plants. Similarly depending on the amount of importance that is placed on a certain customer zone it would be beneficial to ensure that supply never falls short of demand at important customer zones, but to an extent it can fall short at less important ones. In this situation however a scenario is considered where only certain suppliers can supply certain plants. Thus they are predetermined and the algorithm required to provide solution does not need to choose suppliers to optimize the supply chain. Instead of a single objective function that is used in most traditional approaches this formulation has conflicting objectives.

A short description of the data values (constants) and variables are presented in this section. The principal set of indices used to denote the entities and the interactions between entities in the supply chain is given in Table 1.

Index	Meaning	Total indices
i	Component	3
j	Supplier	5
k	Plant	3
l	Retailer Point	4
m	Information Sharing	2

Table: 1. Indices

Using indices, we can derive sets which elicit the interactions between the different entities in the supply chain. These sets are a) Component-Supplier which is represented by (i,j), b) Component-Supplier-Plant represented by (i,j,k) c) Plant-Retailer Point represented by(k,l) and d) Information Sharing-supplier-Retailer Point represented by (m,i,j).

The Following representations for data are used in this formulation. The data used in this model applied to suppliers, plants, retailer points and information sharing among them.

Supplier Entity:	
Capacity of Supplier 'j' for component 'i'	L(i , j)
Cost of making a component 'i' by the supplier 'j'	CS(i , j)
Transportation cost of a component 'i' from supplier 'j' to plant 'k'/unit	STC (i, j, k)
Plant Entity:	
Capacity of plant 'k'	U (k)
Labor cost of plant 'k'/unit	LC (k)
Manufacturing cost of plant 'k'/unit	MC (k)
Plant transportation cost from plant 'k' to customer zone 'l'/unit	IC (k)
Customer Zone Entity:	
Demand at customer zone 'l'	D (l)
Selling price at customer zone 'l'/unit	SP (l)
Logistics and Transportation Costs:	
Logistics & Transportation costs between suppliers and plant	TOC(j)
Logistics & Transportation costs between plant and retail points	TOC(k)
A binary variable to represent whether the plant 'k' gets the component 'i' form the supplier 'j' or not and this value is fixed	S(i, j)
Total Revenue	T_R

Table: 2. Data representations.

4.1 Variables

There are three kind of variables used in this formulation: they are vendor shipment variables, plant shipment variable, inventory variables and information sharing variables.

Variable	Meaning
$X_{i, j, k}$:	Amount of component 'i' from supplier 'j' to plant 'k'
$Y_{k,l}$:	Amount of product shipped from plant 'k' to customer zone 'l'
$I_{i,k}$:	Inventory of component 'i' at plant 'k'
$M_{i, j, k}$:	Cost of Information sharing as a constituent of Total Operating Cost in supplying component 'i' from supplier 'j' to plant 'k' and there to the retailer point

Table: 3. Variables

4.2 Optimization Problem Formulations

The optimization problem is formulated as a two set of two objective function and different sets of constraints depending on which set of objective function is used to represent equalities and inequalities. Various parameter selected for the purpose of Optimization are profit, revenue,

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total operating costs and information sharing costs. The Profit in SC operations refers to the overall efficiency of the supply chain. In order to increase the profit, operating costs have to be minimized to the extent where variable costs are brought to the minimum possible. Revenue, on the other hand refers the ability of the supply chain to ensure effectiveness in business operations and outcomes. A company's performance is measured to the extent to which its asset inflows (revenues) compare with its asset outflows (expenses). While coming to information sharing costs, it refers to the costs associated with the infrastructure, tools and service cost in information sharing practices of a company. Usually, data pertaining to the business entities have to be shared and used for necessary decision making regarding business operations. The up-stream side and down-stream side of the supply chain needs a supportive infrastructure and tools for proper information transfer and sharing.

The following are the expressions for various cost elements.

Logistics & Transportation Costs from Suppliers to Plants and Plants to Customer Zones;

TC =
$$\sum_i \sum_j \sum_k (X_{i,j,k} S_{i,j} STC(i,j,k)) + \sum_k \sum_l Y_{k,l} PTC(k,l)$$

Total Manufacturing Costs; Which Include Plant labor, Inventory (IC) and Manufacturing Costs

TMC = $$\sum_k (LC(k) + MC(k) + IC(k))$$

Supplier Costs;

SC = $$\sum_i \sum_j (CS(i,j) S_{i,j} X_{i,j,k})$$

Total Cost of Logistics & Transportation costs of Suppliers to plants and between plants to Customer Zones (as a constituent of Total Operating Cost)

TISC = ∑ ∑ ∑ (ISCj,k + ISCk,l)

Then, Total Operating Costs (TOC) = TC + TMC + SC

Profit (T_P) = T_R - TOC

4.3 Objective Function Sets

The following sets of objective function combinations were selected to help the decision maker/manager on effective operation of a supply chain. Objective functions are paired to enable the selection of suitable strategy to optimize the supply chain. The most considerable key performance indicators for Supply chain efficiency are Profit, Manufacturing costs, Logistics & Transportation Costs, operating costs and Revenue. An effective and efficient supply chain ensures maximization of revenue and profit and minimization of all costs in business operations. Therefore, it is mandatory to establish set of objective functions that supports the decision making meaningful.

The paper considered two set of objectives for optimize the supply chain and is as follows.

Set 1:	Objective Function 1: **Maximize Profit** Maximize Profit = T_p Objective Function 2: **Minimize Manufacturing Cost** Minimize TMC = $\sum_k (LC(k) + MC(k) + IC(k))$
Set 2:	Objective Function 1: **Maximize Revenue** Maximize T_R Objective Function 2: **Minimize Logistics & Transportation Costs** Minimize TC= $\sum_i \sum_j \sum_k (X_{i,j,k} S_{i,j} STC(i,j,k)) + \sum_k \sum_l Y_{k,l} PTC(k,l)$

Subjected to

Constraints

a) Supplier and Plant Capacity constraints;

$$\sum_l Y_{k,l} \le U_k \qquad \forall k \qquad (1)$$

$$\sum_k S_{i,j} X_{i,j,k} = L(i,j) \qquad \forall \text{ i, j} \qquad (2)$$

b) Inventory balancing constraints;

$$\sum_j S_{1,j} X_{1\,j,k} = \sum_l Y_{k,i} + I_{1,k} \quad \forall \text{ k} \qquad (3)$$

$$\sum_j S_{2,j} X_{2\,j,k} = \sum_l Y_{k,i} + I_{2,k} \quad \forall \text{ k} \qquad (4)$$

$$\sum_j S_{3,j} X_{3\,j,k} = \sum_l Y_{k,i} + I_{3,k} \quad \forall \text{ k} \qquad (5)$$

4.4 NSGA-II

Non-dominated Sorting Genetic Algorithm is used to optimize the supply chain costs. In order to obtain the idea on stochastic nature of the results obtained through evolutionary computation, a random seed analysis was performed on the objective function in each set. The generation size of 500 and 700 with a population size of 100 is presumed to be the best combination to obtain the trade-off curve. NSGA-II Parameter Settings: Parameter setting for NSGA-II is presented in the following table 4

GA Settings	
Population size	100
Number of Generations	500 and 700
Cross over Probability	0.9
Mutation Probability	0.05
Selection type	Binary tournament selection
Crossover type	Simulated binary crossover
Mutation type	Polynomial mutation

Table 4: NSGA-II parameter setting

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4.5 NSGA-II OUTPUT

The following sections deals with the obtained results of multi-objective optimization results through NSGA-II for each of the objective set functions. Total number of seeds used for each set is 57.

4.5.1 Objective function Set 1: Manufacturing costs Vs Profit :

Random seeds generated for objective functions of manufacturing costs and profit were fed to NSGA-II to obtain the results. Random Seed Analysis is performed for both the objective functions in the objective function sets. For set 3 the table 5 gives the Random Seed Analysis.

	OBJECTIVE FUNCTION	CORRESPONDING VALUE
Statistic	Manufacturing Cost	Profit
Maximum	132178.4578	26492.8891
Minimum	41542.21473	75610.3701
Mean	82998.10303	
Standard Deviation	29096.65754	
Confidence Level (95.0%)	7720.382379	
	Profit	Manufacturing Cost
Maximum	27414.4817	136590.8994
Minimum	7563.7858	41553.9033
Mean	170400.8606	
Standard Deviation	57690.4351	
Confidence Level (95.0%)	15168.9265	

Table 5 : Random Seed analysis for set 1

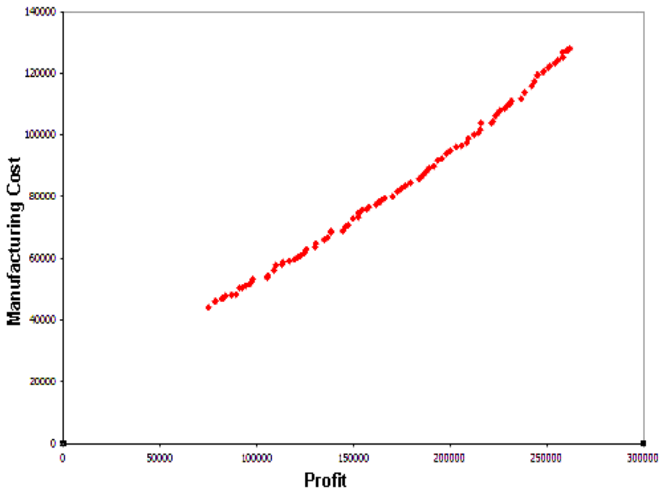

Fig: 1. Trade-off Curve between Manufacturing costs and Profit for Population size 100 & 500 Generations

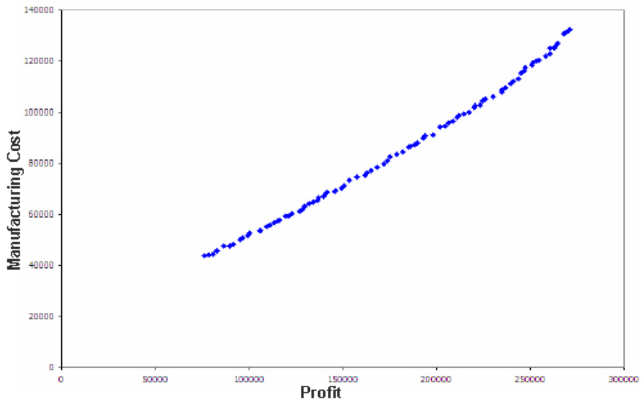

Fig: 2. Trade-off Curve between revenue and logistics and transportation costs for Population size 100 & 700 Generations.

It is evident that the Patero front of efficient solution given by NSGA-II output is well populated for generations 500 and 700. The Values for manufacturing cost varies between 40000 and 235000 and the values for profit vary between 75000 and 280000. Fixed Costs in the Manufacturing costs leads to the huge threshold value, therefore, the cost assumed here is reflecting the actual scenario in many organizations.

4.5.2 Objective function Set 2: Revenue and Logistics and transportation costs:

Random seeds generated for objective functions of Logistics and transportation cost and revenue were fed to NSGA-II to obtain the results. Random Seed Analysis is performed for both the objective functions in the objective function sets. For set 1 the table 6.6 gives the Random Seed Analysis.

	OBJECTIVE FUNCTION	CORRESPONDING VALUE
Statistic	Logistics & Transportation Cost	Revenue
Maximum	60753.9689	413244.6669
Minimum	58008.8504	399045.7778
Mean	59277.9656	
Standard Deviation	879.5506	
Confidence Level (95.0%)	231.2660	
	Revenue	Logistics & Transportation Cost
Maximum	413935.9111	60887.6095
Minimum	399047.6089	58009.2044
Mean	406155.0645	
Standard Deviation	4326.7826	
Confidence Level (95.0%)	1137.6695	

Table 6: Random Seed analysis for set 2

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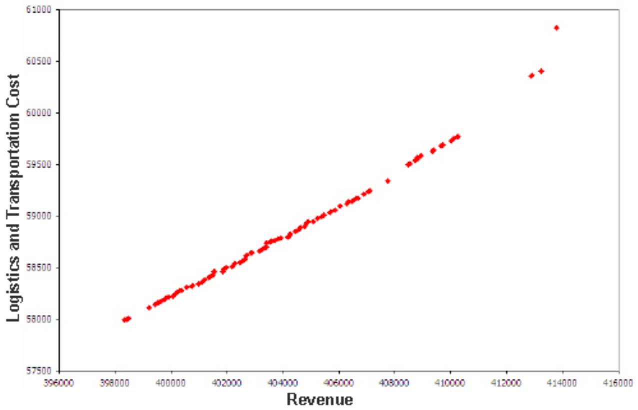

Fig: 6.4. Trade-off Curve between Logistics & Transportation Cost and Revenue for Population size 100 & 500 Generations

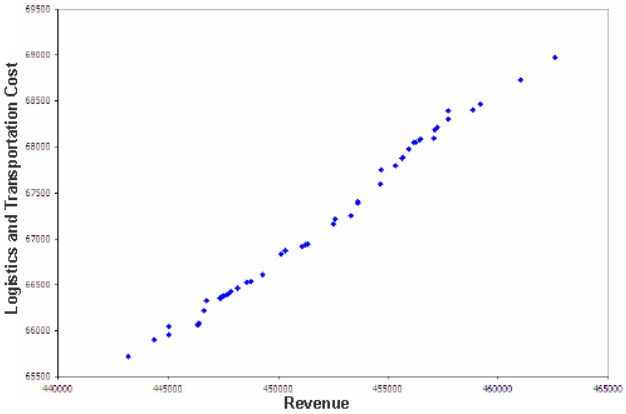

Fig: 6.5 . Trade-off Curve between Logistics & Transportation Cost and Revenue for Population size 100 & 700 Generations

It is evident from the figures that the Patero front of efficient solution given by NSGA-II output is well populated for generations 500 and 700. Logistics costs are the costs associated with the scheduling and execution of transportation both in-bound and out-bound logistic activities. There exists a strong relation between the logistics and transportation costs and the revenue because of its criticality in the entire supply chain. Any mismatches will readily affect the revenue generation from the business operations. These mismatches may be due to change in transportation schedules, order delivery etc.,

V. CONCLUSIONS

NSGA-II gave good results and provided for a well populated Pareto front which a decision making analysis in choosing the solution that best embodies with each objective function set. The results are presented for generation sizes of 500 and 700. A brief conclusions drawn from the output of NSGA-II is as follows. There exists a strong relation between the logistics and transportation costs (costs in both in-bound and out-bound logistic activities) and the revenue generated because of its criticality in the entire supply chain. Any mismatches will readily affect the revenue generation from the business operations. These mismatches may be due to change in transportation schedules, order delivery etc. However due to decrement of logistics & transportation costs, efficiency of the supply chain improve.

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