A Three-echelon Multi-objective Multi-period Multi-product Supply Chain Network Design Problem: A Goal Programming Approach

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Abstract

In this paper, a multi-objective multi-period multi-product supply chain network design problem is introduced. This problem is modeled using a multi-objective mixed integer mathematical programming. The objectives are: maximizing the total profit of logistics, maximizing service level, and minimizing inconsistency of operations. Several sets of constraints are considered to handle the real situations of three-echelon supply chains. As the optimum value of conflicting objective functions of the proposed model cannot be met concurrently, a goal programming approach is used for that matter. An illustrative numerical example is provided to show the mechanism of the proposed model and the solution procedure. In a numerical example, 1 manufacture, 2 warehouses, 2 distribution centers (DCs), and 2 types of final products are considered in a planning horizon consisting of 3 time periods. Products are shipped from the manufacturer to warehouses, and then are shipped from the two warehouses to two distribution centers. The distribution centers are the points from which products are shipped to final consumers. The Model is coded using GAMS software on a Core i7 CPU, using 8GB of RAM with MS-Windows 8.0. The optimum design of supply chain, inventory level for warehouses and distributors, and amount of shipments between echelons are determined.

Keywords: Supply chain network design, Goal programming, Back order, Multi-Period Planning.

1. Introduction

Supply Chain (SC) is defined as a collaborative and integrated approach in which different firms, including suppliers, producers, distributors, and retailers, work together to develop goods and deliver services to the end user (Beamon, 1998). As the number of firms in a chain may be large, the management of these firms, which usually have conflicting objectives, is essential to enhance the performance of SC. Supply chain management (SCM) is concerned with the coordination of material, information, and financial flows within and across legally separated organizational units. Stadtler (2009) defined collaborative planning as a joint decision-making process for aligning plans of individual SC members with the aim of achieving coordination in light of information asymmetry. Supply chain network design (SCND) and supply chain network planning (SCNP) are laid among the most important problems in SCM.

SCND problems are usually complicated according to uncertain parameters of design and planning. The cost of chain and demand of customers are usually mixed with uncertainty. A large number of mathematical models have been proposed for SCND and SCNP. To our knowledge, there is no unique model which addresses

probabilistic SC while designing and planning in a multi-echelon environment through multi products. In this paper, a multi-objective multi-period model for SCND and SCNP is introduced. The problem aims to minimize logistic costs and maximize service level in a three-echelon multi-product SC with regard to back orders. The layers of chain include suppliers, manufacturers, and distribution centers. The parts of logistic costs are discussed and modeled while service level is also interpreted as low level of backorder and shortening the delivery time of products to customers. This problem is modeled using a multi-objective mixed integer mathematical programming. Several constraints due to real-world conditions are also considered in the proposed model. As the objective functions, i.e., logistic costs and satisfaction levels, are conflicting, a posteriori multi-objective mathematical approach, called efficient epsilon-constraint, is proposed to generate several non-dominated solutions on Pareto front of the problem.

As mentioned, we are going to develop a new multi-objective multi-echelon SC logistic design and planning problem considering both cost and service level objectives. There is no unique optimum solution, in which

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all objectives are optimized, for a multi-objective problem, so several multi-objective procedures were proposed (Hwang and Yoon, 1981; Hwang and Lin, 1987). Hwang and Masud, (1979) proposed the multi-objective procedures classified into four groups based on type and time of gathering preference of Decision Makers (DMs) on priority of conflicting objective functions. These classes were: 1) no preference articulation; 2) prior preference articulation; 3) interactive preference articulation; 4) posterior preference articulation. In this paper, we are going to propose a posterior preference method, which yields sets of non-dominated solutions on Pareto front of the problem. In posterior preference articulation methods, the preferences of DM on the priority of objective functions are asked after finishing the solution procedure. On the other hand, a set of non-dominated solutions is generated, and the preferred solution among them is selected by DM based on his/her knowledge and experience (Hwang and Masud, 1979).

The remainder of this paper is organized as follows. Section 2 gives a brief literature of recent research studies; Section 3 presents the proposed model. We discuss the multi-objective solution methodology in Section 4. The numerical examples and results are presented in Section 5. Eventually, the paper concludes in Section 6 with some directions for future studies.

2. Literature of Past Works

There are some research studies that have considered multi-objective decision making for SCM problems. For instance, multi-objective stochastic model was proposed by Sabri and Beamon (2000) for strategic and operative planning of production and distribution problem in SCs. On the other hand, Chen et al. (2003) developed the traditional formulation of SC planning models for considering multiple objectives such as maximizing the level of service, the benefits for each participant, and safety inventories. Also, they considered a multi-product, multi-period, and multi-plant environment in the model and solved it by applying two-phase method. Chen and Lee (2004) suggested a multi-objective mixed integer nonlinear programming model which considered uncertainty for market demands and product prices, and the fuzzy sets were used for describing the sellers and buyers' incompatible preferences on product prices. Altiparmak et al. (2006) proposed a new solution procedure based on genetic algorithms to find the set of Pareto-optimal solutions for multi-objective SCND problem. Chern and Hsieh (2007) employed a heuristic algorithm to solve master planning problems for a SCNP with three objectives including delay penalties, outsourcing capacity usage, and total cost.

Roghanian et al. (2007) used fuzzy programming technique to obtain a compromise solution to enterprise-wide SC planning problem where market demand, production capacity of each plant, and resource available to all plants for each product are random variables. Selim et al. (2008) developed a multi-objective mixed-integer linear programming (MILP) model for collaborative production-distribution planning problem using fuzzy goal programming approach. Torabi and Hassini (2008) suggested multi-objective optimization for a multi-echelon SC planning problem and solved the problem using a fuzzy goal programming-based approach.

Azaron et al. (2008) developed a multi-objective stochastic programming approach for SCND under uncertainty. Demands, supplies, processing, transportation, shortage, and capacity expansion costs were all considered as the uncertain parameters. The proposed model by Azaron et al. (2008) included the minimization of the sum of investment costs, minimization of the variance of the total cost, and minimization of the financial risk or the probability of not meeting a certain budget. Liang and Cheng (2009) developed fuzzy sets to integrate manufacturing/distribution planning decision (MDPD) problems with multi-product and multi-time periods in SCs by considering time value of money for each of the operating cost categories. The proposed fuzzy multi-objective linear programming model (FMOLP) proposed by Liang and Cheng (2009) attempted to simultaneously minimize total costs and total delivery time. Díaz-Madroñero and Peidro (2011) proposed a fuzzy goal programming approach for collaborative SC master planning. The proposed model by Madroñero and Peidro (2011) included minimization of costs and maximization of profit.

Songsong and Papageorgiou (2013) proposed a model for integrated production, distribution, and capacity planning of global SC. Songsong and Papageorgiou (2013) considered cost, responsiveness, and customer service level, simultaneously. Songsong and Papageorgiou (2013) proposed a multi-objective mixed-integer linear programming (MOMILP). The objective functions were total cost, total flow time, and total lost sales. The $\in$-constraint and lexicographic mini-max methods were used to solve the problem.

3. The Proposed Model

3.1 Problem definition

The proposed design of SC consists three echelons including one manufacturer, several warehouses, distribution centers (DC), and markets. Several products of a family are produced in this chain (i.e., it is multi-product), and the planning is accomplished during multi-periods.

The specific problem of this paper is to obtain the optimal level of the multiple products shipped from the manufacturer to warehouses, from the warehouses to distributors, and from the distributor to markets. Also, we seek to find the optimal launching strategy of warehouses

and distributors, in which we determine whether we should run a warehouse/distributor at a specific period or not. Moreover, inventory level for each of distributor/warehouse is calculated. The model has three objective functions, and some logical and technical constraints are described in detail. A schematic diagram of numerical example of the problem can be seen in Figure 1.

3.2 Problem Assumption:

Assumptions of the proposed model are as follows:

- The production and shipment can happen simultaneously at one period at a single facility, and the lead time is set equal to zero for all facilities.
- The model is of multi-period and multi-product kind, but the number of periods, products, warehouses, and markets is known and fixed.
- Fixed and variable transportation costs from supplier to warehouses, from warehouses to DC, and from DC to markets are considered.
- Transportation cost is variable based on the distance between two locations and the product type

- Demand changes based on the product type, period, and location of the market.
- The following parameters are assumed to be known, fixed, and deterministic through planning periods: capacity levels, the number of products, DCs, manufacturers, and demands.
- The locations of manufacturers, warehouses, DCs are known and fixed during planning horizon.
- Inventory shortages are allowed for suppliers and manufacturers for a period, but not for the whole periods.
- Capacity levels of distributors and warehouses are different.

3.3 Mathematical notations

A multi-objective mixed-integer linear programming (MILP) optimization model is proposed to analyze the problem of this study. The indices, parameters, decision variables, objective functions, and constraints of the proposed model are introduced in the following sub-sections.
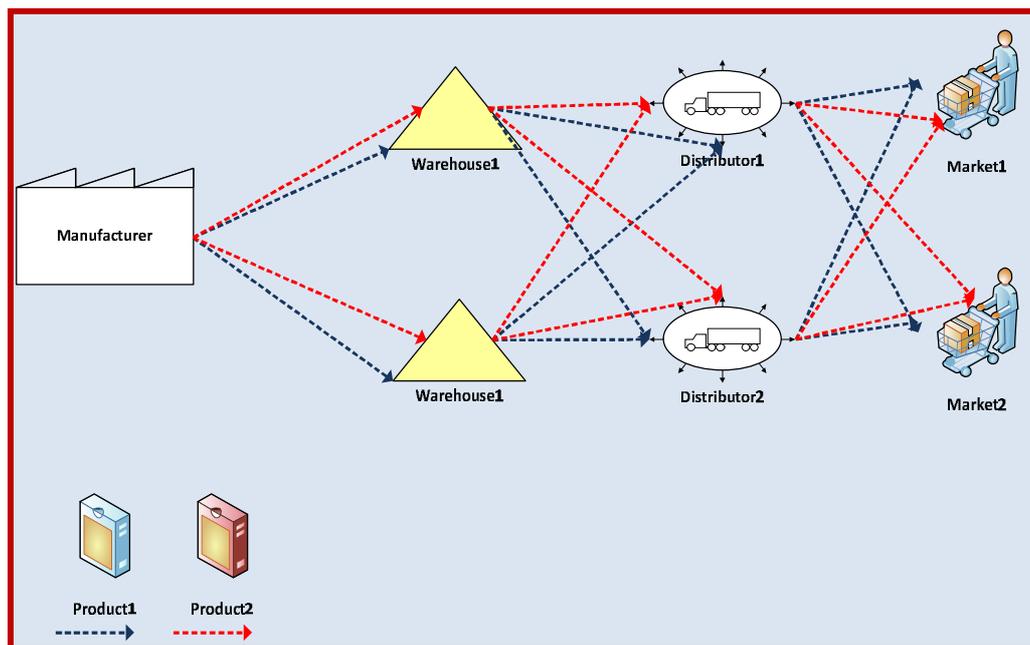

Fig. 1. Schematic View of supply chain

3.3.1 Indices

Several sets, including supplier, warehouses, distribution centers, type of final products, type of raw materials, and time periods of planning, are the main entities of the proposed model. These sets are defined using the following notations:

t	Periods
j	Distributors
i	Warehouses
k	Markets
l	products

T	Number of time periods t=1,..., T
J	Number of distributors j=1,...,J
I	Number of warehouses i=1,..., I
K	Number of markets k=1,...,K
L	Number of products l=1,...,L
N	Number of objectives n=1,...,N

3.3.2 Parameters

The associated parameters with supplier, warehouses, distribution centers, type of final products, and time periods of planning are defined as follows:

P_{kl}	Price of product l at market k
F_{it}	Fixed cost of launching warehouse i at period t
E_{jt}	Fixed cost of launching distributor j at period t
TCW_{il}	Transportation cost of each product l from manufacturer to warehouse i
TCD_{ijl}	Transportation cost of each product l from warehouse i to distributor j
TCC_{jkl}	Transportation cost of each product l from warehouse j to market k
HS_{kl}	Shortage cost of lacking each product l at market k
D_{klt}	Demand for product l at market k at period t
M	Big number
$CAPW_i$	Inventory capacity of warehouse i
$CAPD_j$	Inventory capacity of distributor j
W_k	Importance of holding service level at market k
Q_l	Volume of each product l
α	Coefficient of the first objective at objective function
β	Coefficient of the second objective at objective function
μ	Coefficient of the third objective at objective function
L_{l1}, L_{l2}, L_{l3}	Transportation capacity between supplier and warehouses(L_{l1}), warehouses and distributors(L_{l2}), and distributors and markets(L_{l3})

3.3.3 Decision variables

The proposed model for this study should determine optimal level of the multiple products shipped from a station to another and optimal launching strategy of warehouses and distributors and inventory level for each of distributor/warehouse. In this regard, the following integer and binary variables are defined.

U	objective function
TP	Total profit
SL	Service level
OC	Operations Inconsistency
x_{jkl}^t	Shipment volume of product l from distributor j to market k at period t
y_{ijl}^t	Shipment volume of product l from warehouse i to distributor j at period t
z_{il}^t	Amount of inventory of raw material *n* in manufacturer *j* at the end of time period *t*
bx_{jt}	Amount of inventory of product *l* in manufacturer *j* at the end of time period *t*

by_{it}	Amount of inventory of product l in distribution center k at the end of time period t
$invw_{ilt}$	Receiving time of raw material n from supplier i to manufacturer j in time period t
$invd_{jlt}$	Receiving time of product l from manufacturer j to distribution center k in time period t
com_{kl}^t	Binary variable with a value of 1 if raw material n to be purchased and transported from supplier i to manufacturer j in time period t; 0 otherwise
$dmins_n$	Binary variable with a value of 1 if product l to be transported from manufacturer j to distribution center k in time period t
$dplus_n$	backlog level of product l at distribution center k at the end of time period t

3.3.4 Mathematical model of the problem

The mathematical model of the problem is proposed as follows.

First Goal: Maximizing Total profit of Logistics
The total profit of logistics includes total sales revenue minus the total costs of purchasing, production, and distribution activities and could be calculated by the following equation.

$$\max TP = \sum_{t=1}^{T}\sum_{l=1}^{L}\sum_{k=1}^{K} P_{kl} * \min\{D_{kl}^t, \sum_{j=1}^{J} x_{jkl}^t\} -$$

$$(\sum_{t=1}^{T}\sum_{i=1}^{I} F_i^t by_i^t + \sum_{t=1}^{T}\sum_{j=1}^{J} E_j^t bx_j^t + \sum_{t=1}^{T}\sum_{l=1}^{L}\sum_{i=1}^{I} TCW_{il}.z_{il}^t +$$

$$\sum_{t=1}^{T}\sum_{l=1}^{L}\sum_{j=1}^{J}\sum_{i=1}^{I} TCD_{ijl}.y_{ijl}^t + \sum_{t=1}^{T}\sum_{l=1}^{L}\sum_{j=1}^{J}\sum_{k=1}^{K} TCC_{jkl}.x_{jkl}^t + \qquad (1)$$

$$\sum_{t=1}^{T}\sum_{l=1}^{L}\sum_{i=1}^{I} HW_{il}.invw_{il}^t + \sum_{t=1}^{T}\sum_{l=1}^{L}\sum_{j=1}^{J} HD_{jl}.invd_{jl}^t +$$

$$\sum_{t=1}^{T}\sum_{l=1}^{L}\sum_{k=1}^{K} HS_{kl}(D_{kl}^t - \sum_{j=1}^{J} x_{jkl}^t)) + d_1^- = Goal\,1$$

Goal 1 indicates the profit of the supply chain system. In fact, the sale revenue is subtracted by the cost of launching warehouses and distributors, cost of transportation between manufacturer, warehouses, distributors and markets, cost of inventory kept at warehouses and distributors, and cost of shortage of products at markets.

Second Goal: Maximizing Service Level
Service level is assumed as the second objective function of SC. Service level is defined as percentage of satisfied markets.

$$\max SL = \frac{1}{T.L}\sum_{k=1}^{K}\sum_{t=1}^{T}\sum_{l=1}^{L} W_k com_{kl}^t + d_2^- = Goal\,2 \qquad (2)$$

If demand of a market at a period is satisfied at that period, the corresponding variable (com_{kl}^t) is equal to 1; otherwise, it is zero. Goal 2 (2) refers to percentage of markets at which the demand of a period is satisfied at the same period. Our ideal figure for this goal is 1.

Third Goal: Operations Inconsistency
We define the last objective function as below:

$$\min OC = \sum_{t=1}^{T}\sum_{j=1}^{J}\left|bx_j^t - bx_j^{t+1}\right| + \sum_{t=1}^{T}\sum_{i=1}^{I}\left|by_i^t - by_i^{t+1}\right| \qquad (3)$$

$$-d_3^+ = Goal\,3$$

Goal 3 (3) measures the inconsistency of operations in a warehouse or distributor at succeeding periods. It means that if one warehouse is not working in one period, it is favorable that it does not work at the next period, and vice versa. We prefer that this goal becomes zero at the ideal situation.

3.3.5 Model constraints

In this sub-section, the constraints of the proposed model are defined and then discussed.

$$D_{kl}^t - \sum_{j=1}^{J} x_{jkl}^t \leq M(1 - com_{kl}^t) \quad \forall t \quad \forall k \quad \forall l \qquad (4)$$

$$invw_{il}^t = invw_{il}^{t-1} + z_{il}^t - \sum_{j=1}^{J} y_{ijl}^t \qquad (5)$$

$$invd_{jl}^t = invd_{jl}^{t-1} + \sum_{i=1}^{I} y_{ijl}^t - \sum_{k=1}^{K} x_{jkl}^t \qquad (6)$$

$$\sum_{l=1}^{L} Q_l invw_{il}^t \leq CAPW_i \quad \forall i \quad \forall t \qquad (7)$$

$$\sum_{l=1}^{L} Q_l invd_{jl}^t \leq CAPD_j \quad \forall j \quad \forall t \qquad (8)$$

$$Max\{\sum_{l=1}^{L}\sum_{i=1}^{I} y_{ijl}^t, \sum_{l=1}^{L}\sum_{k=1}^{K} x_{jkl}^t, \qquad (9)$$

$$invd_{jl}^t\} \leq Mbx_{jl}^t \quad \forall j \quad \forall t$$

$$Max \{\sum_{l=1}^{L} \sum_{j=1}^{J} y_{ijl}^{t}, \sum_{l=1}^{L} z_{il}^{t}, invw_{il}^{t} \} \quad (10)$$

$$\leq Mby_{i}^{t} \quad \forall i \quad \forall t$$

$$\sum_{i=1}^{I} \sum_{l=1}^{L} \sum_{t=1}^{T} z_{il}^{t} = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{l=1}^{L} \sum_{t=1}^{T} y_{ijl}^{t} =$$

$$\sum_{j=1}^{J} \sum_{k=1}^{K} \sum_{l=1}^{L} \sum_{t=1}^{T} x_{jkl}^{t} = \sum_{k=1}^{K} \sum_{l=1}^{L} \sum_{t=1}^{T} D_{kl}^{t} \quad (11)$$

$$\sum_{t=1}^{T} z_{il}^{t} = \sum_{j=1}^{J} \sum_{t=1}^{T} y_{ijl}^{t} \quad \forall i \quad \forall l \quad (12)$$

$$\sum_{i=1}^{I} \sum_{t=1}^{T} y_{ijl}^{t} = \sum_{k=1}^{K} \sum_{t=1}^{T} x_{jkl}^{t} \quad \forall j \quad \forall l \quad (13)$$

$$\sum_{j=1}^{J} \sum_{t=1}^{T} x_{jkl}^{t} = \sum_{t=1}^{T} D_{kl}^{t} \quad \forall k \quad \forall l \quad (14)$$

$$\sum_{j=1}^{J} x_{jkl}^{t} \leq D_{kl}^{t} \quad t = 1,...,T-1 \quad (15)$$

$$\forall k \quad \forall l$$

$$x_{jkl}^{t} \leq L_{l1} \quad \forall t \quad \forall k \quad \forall l \quad \forall j \quad (16)$$

$$y_{ijl}^{t} \leq L_{l2} \quad \forall t \quad \forall i \quad \forall j \quad \forall l \quad (17)$$

$$z_{il}^{t} \leq L_{l3} \quad \forall t \quad \forall i \quad \forall l \quad (18)$$

$$bx_{jt}, by_{it}, com_{kl}^{t} \in \{1,0\} \quad \forall n,i,j,k \quad (19)$$

$$x_{jkl}^{t} y_{ijl}^{t} z_{il}^{t}, invw_{ilt}, invd_{jlt}, dmins_{n},$$

$$dplus_{n} \geq 0, \quad \forall n,l,i,j,k \quad (20)$$

3.3.6. Constraints description:

In this part, we indicate a brief description about the set of constraints used in the proposed model.

Equation (4) determines if com_{kl}^{t} is 1 or zero. In fact, if

summation of shipment of a product to a market ($\sum_{j=1}^{J} x_{jkl}^{t}$

) is bigger than or equal to demand of that market (D_{kl}^{t}) at

a special period, then com_{kl}^{t} is 1; otherwise, it is zero.

Equations (5) and (6) indicate inventory level for each product at period t for warehouse i and distributor j, respectively, equaling inventory level at period t-1 plus summation of all of inputs of the product to that warehouse/distributor subtracted by summation of all outputs (shipment) of the product from that warehouse/distributor.

Equations (7) and (8) point out that the capacity of warehouses/distributors in which inventory level is limited.

Equations (9) and (10) indicate that a warehouse/distributor only launches its operations at period t if it has inventory or it ships or receives any product at that period; otherwise, the warehouse/distributor is passive.

Equation (11) shows that the total shipment from station 1 (manufacturer) to station 2 (all warehouses) should be equal to the total shipment from station 2 (all warehouses) to station 3 (all distributors) and equals the total shipment from station 3 (all distributors) to station 4 (all markets) for all periods and all products. It means that there are no defected and returned products, and all of the products should be sold to the market by the end of last period. As a result, there must not be any product left at the system .

Equations (12), (13), (14) generally show that there is no product created, unless it is consumed by the customer at that period or other periods. So, the total shipment from each station to the next one should be equal to the total market demand. Equation (12) indicates that total shipment from manufacturer to all of the warehouses at all periods has to be equal to the total shipment of products from all warehouses to all of the distributors at all of the periods. In equation (13), we indicate that the total shipment of products from all warehouses to all of the distributors at all periods is equal to the total shipment from all of the warehouses to all of the distributors at all periods and that is equal to the total shipment quantities from all of the distributors to the total number of the markets at all periods shown in equation (14).

Equation (15) shows that shipment quantities from distributors to a market at a specific period cannot be more than the demand of that market at that period for all of the periods except the last one. The reason for this constraint is that we do not have any storage in the markets, so we cannot store products. At the last period, we eliminate the probable cumulative shortage of products at a specific market which could not or should not be fulfilled at the last periods .

In equations (16), (17), (18), we set a limit for maximum quantity of product that can be transported between stations at each period for each kind of product.

4. Solution Procedure: Goal Programming

Using goal programming, simultaneous movement toward several conflicting objectives can be made possible. Principles of modeling in goal programming do not differ significantly from linear planning model. The main difference is in the type of description and the formulation of objectives, goals, priorities of goals, and constraints of goals. The aim of this section is show the possible applications of goal programming. Since achieving this objective involves familiarity with some principal concepts in linear goal programming, these concepts are

briefly reviewed. Then, different types of linear goal programming are explained.

The main aim of goal programming is to achieve a set of objectives simultaneously (Charnes and Cooper, 1955). This method was initially used by Charnes and Cooper (1961). Then, a number of other researchers such as Lee (1972), Ignizio (1976), Romero (1991), and Ignizio and Cavalier (1994) employed this method. It has been proven that goal programming is consistent with the concept of Pareto optimization. For more information, the readers can see Jones and Tamiz (2010).

4.1 Goal programming by the minimization of weighted sum of deviations

In this method, a certain value is selected as the goal for every objective. Then, the related objective function is formulated. The aim is to find an answer which minimizes the weighted sum of deviations of each objective relative to the goal that has been selected for that objective. In order to express the problem in mathematical terms, we assume that $x_1, x_2, x_3, \dots, x_n$ are decision variables, K is the number of intended objectives, C_{jk} ($j = \{1, 2, \dots, n\}$) is the coefficient of decision variables in the objective function No. K ($K = \{1, 2, \dots, K\}$), and g_k is the selected goal for objective k. In this way, we intend to find an answer which makes it as much as possible to achieve the following goals:

$$\sum_{j=1}^{n} c_{j1} x_j = g_1 \qquad \text{Goal } 1 \qquad (21)$$

$$\sum_{j=1}^{n} c_{j2} x_j = g_2 \qquad \text{Goal } 2 \qquad (22)$$

$$\sum_{j=1}^{n} c_{jk} x_j = g_k \qquad \text{Goal } k \qquad (23)$$

Since simultaneous satisfaction of all goals is not possible, it is necessary to define the expression as much as possible. In the simplest case (when deviations from selected goals in both directions have similar significance), the additive objective function of goals can be formulated in the following way in which the objective is to minimize the sum of deviations from goals.

$$Z = \sum_{k=1}^{K} \left| \left(\sum_{j=1}^{n} c_{jk} x_j - g_k \right) \right| \qquad (24)$$

Z can simply be formulated as follows. The first step is to define new (auxiliary) variables.

$$y_k = \sum_{j=1}^{n} c_{jk} x_j - g_k \qquad (k = 1, 2, \dots, K) \qquad (25)$$

$$Z = \sum_{k=1}^{n} | y_k | \qquad (26)$$

Since y_k can take positive and negative values, their positive and negative elements (y_k+, y_k-) can be defined as follows:

$$y_k = y_{k^+} - y_{k^-}, \quad y_{k^+} \geq 0, \quad y_{k^-} \geq 0, \quad \forall k \qquad (27)$$

So, the goal programming model can be written as follows:

$$Min \quad Z = \sum_{k=1}^{K} (y_{k^+} - y_{k^-}) \qquad (28)$$

Subject to:

$$\sum_{j=1}^{n} c_{jk} x_j - (y_{k^+} - y_{k^-}) = g_k \qquad (29)$$

$$(k = 1, 2, \dots, K)$$

$$y_{k^+} \geq 0, \, y_{k^-} \geq 0, \, x_j \geq 0 \qquad (30)$$

$$(j = 1, 2, \dots, n)$$

Now, we can obtain optimal answers for all variables (including x_j).

Usually, some objectives have a higher significance compared to the others. In addition, in a particular case, deviation from ideal in one direction might be more significant compared to another direction. These differences can be included in the formulation by the help of weighted coefficients (W_k+, W_k-), which are related to variables y_k- and y_k+, respectively. These weighted coefficients measure the relative significance of deviations. Therefore, goal programming will be as follows:

$$Min \, Z = \sum_{k=1}^{K} (W_{k^+} y_{k^+} + W_{k^-} y_{k^-}) \qquad (31)$$

5. Illustrative Example and Results

In order to illustrate the performance of the proposed approach, a numerical example is discussed. In the considered chain, there are 1 manufactures, 2 warehouses, 2 distribution centers (DCs), and 2 types of final products. The planning horizon consists of 3 time periods. Products are shipped from the manufacturer to warehouses, and then are shipped from the two warehouses to two distribution centers. The distribution centers, in this SC, are the point from which the products are shipped to final consumers (markets). Demand for the products is currently less than the total capacities of plants. The

detailed data of numerical example are presented in Appendix 1.

5.1 Software implementation

The proposed multi-objective mathematical model was handled using goal programming and was coded using GAMS software on a Core i7 CPU, using 8GB of RAM with MS-Windows 8.0.

5.2 Discussion of results

To analyze the model, we require to monitor the trends of each objective while the other objective functions change. In this paper, the model has three objective functions; it is difficult to interpret them using one chart. As a result, a graph is illustrated for each pair of objectives while considering the other objective fixed. It is notable that the weights of all objectives have been set equally.

In the first case, we set Operations Inconsistency (the third objective) at 5 and consider the total profit as the objective function. Then, based on different service levels as a constraint, the model is solved using the proposed goal programming. Figure 2 shows service level versus total profit illustrated.

As shown in Figure 2, there is no linear relation between Total Profit and Service Level. Points i and j are dominant within the points. In other words, they are preferred compared to the rest as they have greater total profit and service. However, there is a debate in which the manager should choose higher service level or higher total profit which may depend on strategic vision of a company.

The second case fixes the second objective at a specific level, say 0.6. We consider Total Profit as the objective function and gradually increase the goal of Operation Consistency objective within its range from 3 to 8. The results are illustrated in Figure 3.
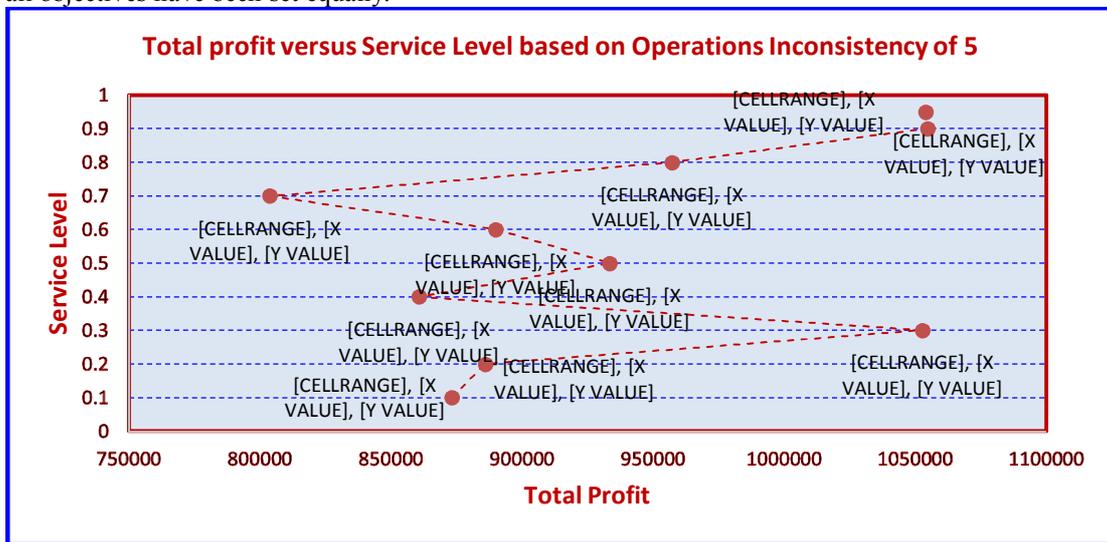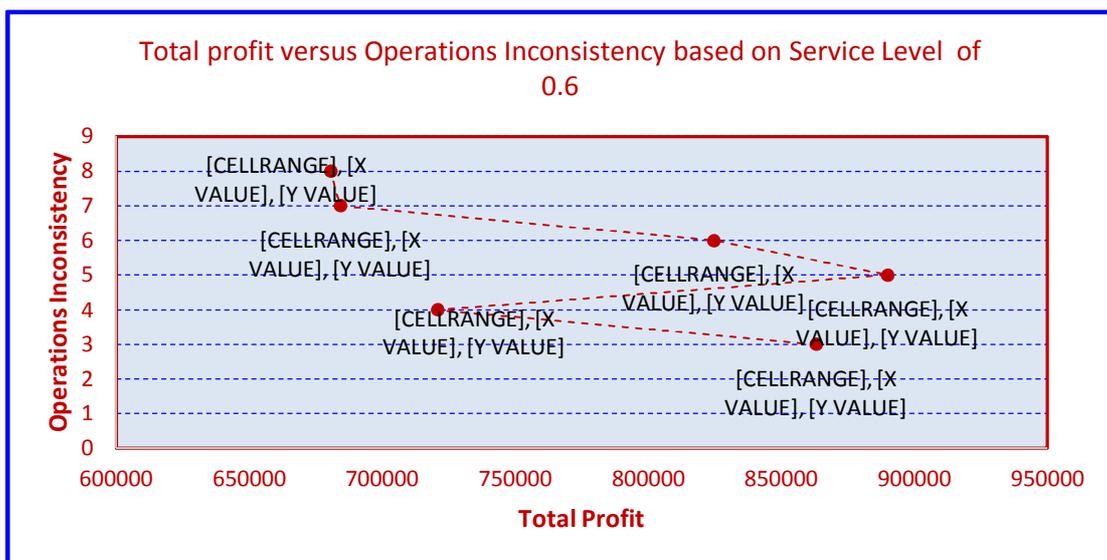

Fig. 2. Total profit versus Service Level

Fig. 3. Total profit versus Operations Inconsistency based on Service Level of 0.6

As it is shown in Figure 3, points *a* and *c* are dominant points, as point *a* has higher Total Profit than the other points except point *c*, and also it has the least operations inconsistency among all of the points. But, as it is mentioned, point *c* has bigger Total Profit and it raises the debate whether Total profit is applied to the company's strategy vision or Operations Consistency.

To clarify a typical software's run, Figure 4 shows the schematic result of relation between the variables' levels obtained after solving the numerical example.

In Figure 4, the numbers shown at arrows indicate the level of shipment level from a facility. The numbers inside the boxes in warehouses and distributors are the inventory level at that period for each of the products. The numbers inside the box for the markets indicate how many products have been shipped to the market at that period from each product. Finally, at the last column, the demand of each product for each market at each period is shown.

6. Conclusions and Future Research Directions

In this paper, a multi-objective mixed-integer linear programming model was developed for the supply chain network design problem. Three objectives were considered as maximizing the total profit of logistics, maximizing service level, and minimizing operations inconsistency. Several sets of constraints were proposed to handle the situations of real-world three-echelon supply chains. The goal programming was adopted in order to solve the proposed multi-objective mixed-integer mathematical programming. An illustrative numerical example was provided to show the mechanism of the proposed model and the solution procedure.

As the proposed model is NP-Hard, meta-heuristic algorithms can be proposed in the future research studies to solve the large-scale instances efficiently. Customization of the proposed model for perishable goods and consideration of
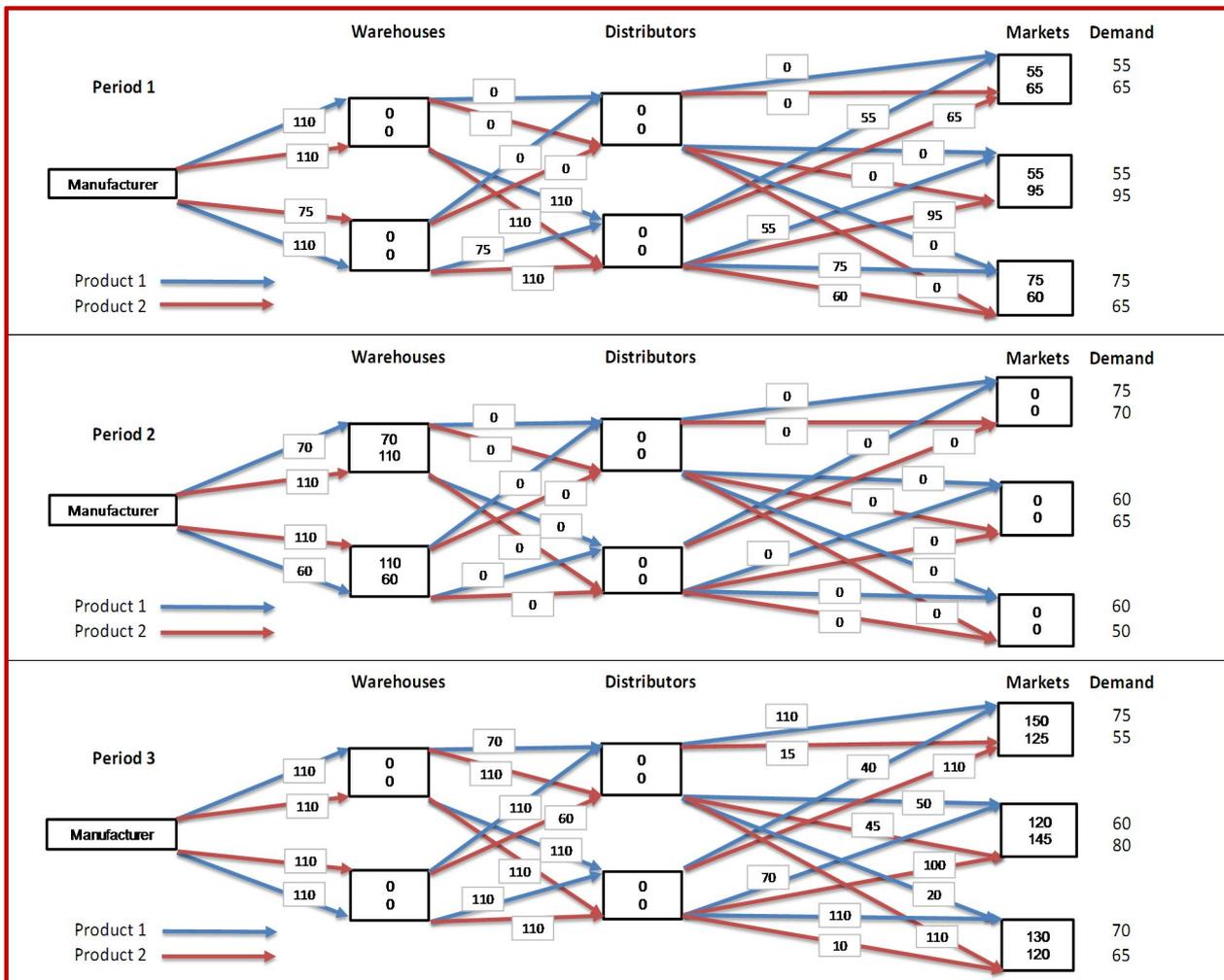

Fig. 4. Designed Supply Networks

Discounts and inflations are also assumed to be interesting subjects for future studies. Investigation of the proposed model in presence of uncertainty can be another interesting future research direction.

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Appendix 1: Tables of numerical example

Table 1

P(k, l) price of product l at market k			HS(k, l) shortage cost		
	Product 1	Product 2		Product 1	Product 2
Market 1	1000	1300	Market 1	40	40
Market 2	800	1150	Market 2	50	60

Table 2

HW(i, l) maintenance cost for product l at warehouse i			HD(j, l) maintenance cost for product l at distributor j		
	Product 1	Product 2		Product 1	Product 2
Warehouse 1	6	5	Distributor 1	7	9
Warehouse 2	8	9	Distributor 2	10	8

Table 3

F(i, t) fixed setup cost for warehouse i at the beginning of period t			E(j, t) fixed setup cost for distributor j at the beginning of period t		
	Period 1	Period 2		Period 1	Period 2
Warehouse 1	6000	10000	Distributor 1	4000	5000
Warehouse 2	8000	14000	Distributor 2	6000	7000

Table 4

TCD(i, j, l) Transportation cost from warehouse to distributor for each product			TCC(j, k, l) Transportation cost from Distributor to market for each product			TCW(i, l) Transportation cost from manufacturer to warehouse for each product		
	Product 1	Product 2		Product 1	Product 2		Product 1	Product 2
warehouse 1 to distributor 1	25	5	Distributor 1 to market 1	15	32	Warehouse 1	5	3
warehouse 2 to distributor 1	10	7	Distributor 2 to market 1	25	8	Warehouse 2	15	7
warehouse 1 to distributor 2	13	8	Distributor 1 to market 2	7	22			
warehouse 2 to distributor 2	5	10	Distributor 2 to market 2	12	4			

Table 5

D(k, l, t) Market demand at market k at period t for product l		
	Period 1	Period 2
Market 1. Product 1	55	75
Market 2. Product1	55	60
Market 1. Product2	65	70
Market 2. Product2	95	65