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Robust optimization Model to Minimize production Stoppage of a Five level Supply chain Network of a Car Manufacturer

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Abstract

The purpose of this study is to minimize the cost of production stoppages as well as the penalty cost caused because of delays in the delivery of the products. We consider a five-level supply chain network and customize it for a car manufacturer. To improve this system, we develop an approach which consists of two stages. In the first stage, a long-term model is developed to minimize the total cost of the supply chain. Key decisions in this model include determination of the optimal number as well as the location of cross-docks and distribution centers in the system, determination of the transportation type and amount of shipments moved between facilities in the entire chain. In the second stage, we also develop a model to minimize the tardy deliveries of products which are caused by frequent production interruptions. To achieve this goal, by analyzing the historical data first the sources of production interruptions and their effect on stoppage are identified. Then, the corrective methods to reduce the effect of each source are introduced. Due to the uncertainty in the nature of the data, robust optimization is applied to develop the model. Furthermore, to solve the model with real data which makes the scale of the problem very large, a methahurestic algorithm is developed. This approach is implemented in a real case of a car manufacturer.

Keywords: Robust optimization, supply chain management, location-allocation determination, cross- dock, tardiness reduction.

Introduction

An important criterion to evaluate a supply chain system is its ability to optimize the operation of the total chain. In this regard, to compete in this competitive market one advantage of a real world company is to be able to manage its commitments and deliver the products to customers on time and with the competitive price. Otherwise it loses its customers and the market.

The main motivation of this research stems from a case of an automotive manufacturer which incurs tremendous penalty costs caused by tardy deliveries of products. In fact, due to some system inefficiencies orders cannot be delivered on time. The sources of delay of orders are numerous factors which can be categorized as follows.

i. Delays of part delivery to production sites, ii. Production Interruptions, iii. Delay of final products (cars) to sale agents.

The first and third type of above delays can be reduced significantly by implementing a suitable planning, based to optimize the total chain. This model should optimize the configuration of facilities by determining some suitable cross-docks and distribution centers as well as well planning transportation and inventory. By implementing this model it is expected the parts and components are delivered on time to the production site and reduce the interruptions which are cause by shortage of supply. Furthermore, we develop a model to reduce production interruptions, which are the most important reasons for delivery tardiness. As mentioned before, this research initiated by investigating the case of a large car manufacturer.

Automotive industry

Generally speaking, automotive industry plays an important role in the global economy. The 52 percent growth in the production of passenger cars from 2002 to 2012 indicates the ever increasing share of automobiles in the world economy. Roughly, 5% of the global workforce is directly employed in the automotive industry and each directly related job in the field creates five indirect job opportunities. According to statistics, it is evident that the analysis of the income and expenditure of the industry plays an important role in the development of the countries which rely on this industry .The scope of this study is Iran. Among the countries that produce passenger cars, Iran was ranked 13th in 2011. Passenger car production in the country has grown 3.2 times from 2002 until 2011[1].

The share of industrial production growth in the gross domestic product (GDP) of the country was estimated at 4.2% in the year 2013. 5.6% of the country's workforce is directly employed in this industry and each direct job creates opportunities for 5 indirect jobs[2]. Increasing profits and cost reduction in this sector of industry results in the rapid and rational development of the country. On the other hand, a downturn in the automotive industry in this country, like any other country where the car has a major share of its economy, ends in a decline in public employment and in recession. Therefore, improving the management and the efficiency in the industry not only satisfies the shareholders, but also is of national interest. The automotive industry group that was chosen for this study is the largest in Iran. The number of models in term of the type of products produced in this company amounts to 36 which are categorized into 5 classes. The number of suppliers is close to 700 companies and the number of plant sites is 5. This company has 822 sales agents all around the country[3].

At the moment in the company's supply chain network, the raw materials and components from suppliers are sent directly to production sites. Similarly, the final products are sent directly from production sites to sales agents and from there delivered to the end-customers. In this article we develop a new system of supply chain to centralize the managerial control. In this system, we propose a selection of cross-docks and product distribution centers as well as suitable transportation system. The objective is to reduce the total supply chain costs, which is significant. All data used in this study are real. However, due to confidentiality agreements with the respective company, we present only output of the models in this paper.

Literature review

A supply chain is a system of facilities and activities that functions to procure, produce, and distribute goods to customers. Supply chain management is basically a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system-wide costs (or maximize profits) while satisfying service level requirements[4]. Customers place their orders at distribution centers which pass this information to the upper levels until it gets to the suppliers. Thus, a main characteristic of the supply chain is the flow of material from suppliers to customers and the counter flow of information from customers to suppliers. Benita M. Beamon provided a focused review of literature for multi-stage supply chain modeling main object and categorized the studies into four groups: Deterministic analytical models, in which the variables are known and specified, Stochastic analytical models, where at least one of the variables is unknown and is assumed to follow a particular probability distribution; economic models and simulation models[5]. Arntzen et al. developed a mixed integer programming model, called global supply chain model (GSCM), that can accommodate multiple products, facilities, stages (echelons), time periods, and transportation modes[6]. More specifically, GSCM minimizes a composite function of activity days and total cost of production (inventory, material handling, overhead, and transportation costs). Fahimnia et al. reviewed the literature based on nature of supply chain and divided the studies into seven important categories as i. Single-product models, ii. Multiple-product, single-plant models, iii. Multiple-product, multiple-plant, single or no warehouse models .iv. Multiple-product, multiple-plant, multiple-warehouse, single/no end-user models, v. Multiple-product, multiple-plant, multiple-warehouse, multiple-end user, single-transport path models, vi. Multiple-product, multiple-plant, multiple-warehouse, multiple-end user, multiple-transport path, no-time period models, vii. Multiple-product, multiple-plant, multiple-warehouse, multiple-end user, multiple-transport path, time period models[7]. The reader may also refer to some other studies[8-10].

In this paper we apply robust optimization concepts and techniques. Soyster took the very first step toward using robust optimization, proposing linear programming mode[11]. However, his approach produces a solution that is too conservative. Then, Ben-Tal and Nemirovski by introducing robust counterparts for some important problems of optimization developed robust optimization approach to address parameter uncertainty in convex programming with ellipsoidal uncertainty set[12-14]. El-Ghaoui et al. proposed a robust optimization approach to semi definite programs (SDPs)[15]. El-Ghaoui and Lebert[16] modified the original approach to handle over-conservatism. They applied robust optimization to linear programming problem with ellipsoidal uncertainty sets, thus obtaining conic quadratic programs. Bertsimas and Sim[17] presented a new approach which was specifically tailored for polyhedral uncertainty. Their approach leads to linear robust counterparts. In other words, it retains advantage of linear framework of Soyster while controlling conservativeness level of the solution. Thus, their method is also appropriate for solving discrete optimization problems and that is the reason we have adopted Bertsimas and Sim model[18].

The rest of this paper is organized as follows. In next section, we develop a mathematical model to determine the number and location of cross-docks and distribution centers as well as allocation of parts and products between facilities. Then, in Section3 we implement the model with the real data. First we aggregated data we solve the model by applying Cplex. Then, we develop another model in Section 4 to decrease the tardiness of orders. To achieve this goal we first identify and categorize the problems which cause the production stoppage and the ways to decrease their effects.

Problem Statement

Figure 1 indicates the structure of this study, namely a five level supply chain, with location-allocation focus.

The first level represents sales agents that deliver the product to costumers. The second level indicates distribution centers that receive the products and transfer them to sales agents. The plants are represented by the third level and the forth level shows cross-docks that feed the plants sites with required material.

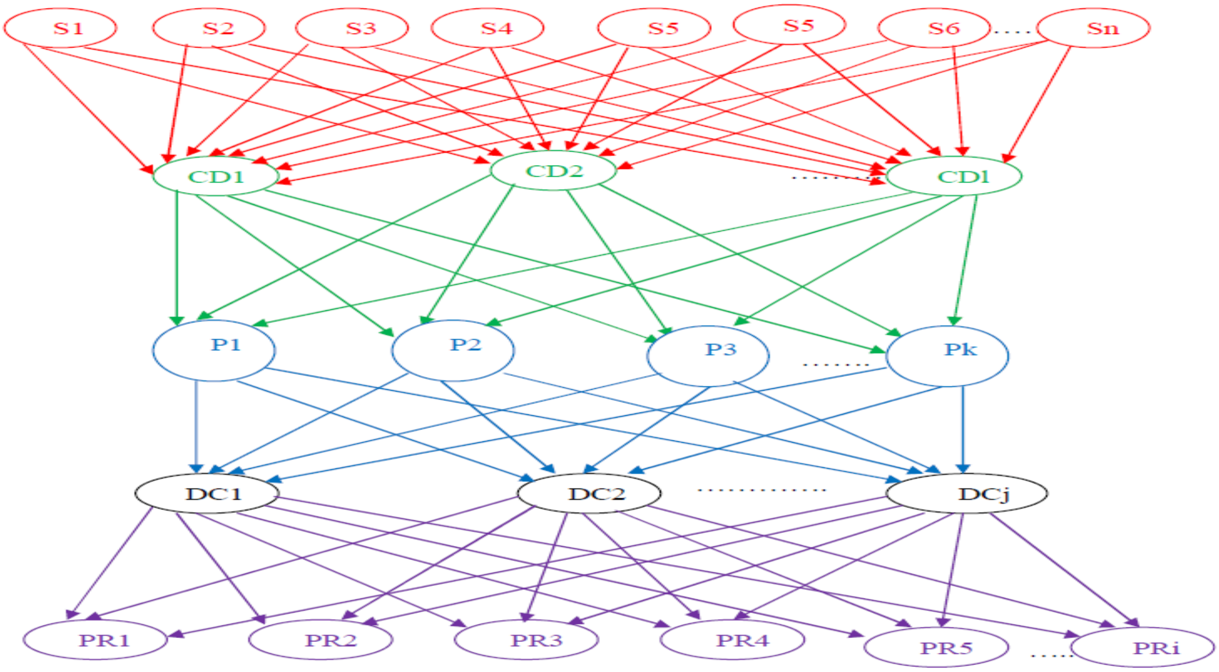

Figure-1
Five level supply chain network of a car manufacturer

Finally the fifth level indicates raw material and component suppliers. In this model the goal is to determine a number and place of cross-docks and distribution centers to establish and also a method of transferring products from distribution centers to sales agents (customers) as well as to determine the share and contribution of each supplier for each material and each sales agent in order to minimize the total cost.

Assumptions: The transferring unit for raw material and components are pre-determined and unified pallets. The capacity of each pallet for all parts and component is specified. All transportation modes (vehicle) for transporting parts and components are defined. The capacity for each vehicle is measured in terms of number of pallets. All transportation modes (vehicle) for transporting end products are defined. The capacity for each vehicle is measured in terms of number of products (cars). Due to several different factors and variables (such as poor quality of components, poor quality of maintenance and unsuitable transportation means and conditions) only 95 percent of the parts and components sent to production sites are usable for production and only 98 percent of the end products are suitable to be delivered to the costumers (In other words, 5 percent of the parts and components and 2 percent of the products are considered as wastes.), No supplier has any limit to provide the parts and component based on the previous agreement. Based on the management policies in order to create competition among suppliers, each supplier provides at least 10 percent of the associated part. Transportation costs for transferring material from suppliers to cross-docks and also from there to production sites are determined in advance based on each transportation mode. Distribution costs for transferring each product from production sites to distribution centers and from there to sales agents are defined. Construction costs for various cross-docks and distribution centers are different. Potential sites for cross-docks and distribution centers are identified. Inventory policy for keeping the components on production sites is to keep a stock for 3 days consumption. Inventory costs are the same for all cross-docks. Inventory costs are the same for all distribution centers. Mutual direct contact between suppliers, cross-docks, manufacturing sites, distribution centers and sales representatives is not be considered.

Notation: Sets, S: Set of suppliers; M: Set of potential places for establishing cross-docks; K: Set of plants; J: Set of potential places for establishing distribution centers; P: Set of products; Q: Set of parts or components; S(q): Set of suppliers of part q; V: Set of potential vehicles for transportation of parts or products; A: Set of sales agents.

Parameters: Cap(v): Capacity of vehicles type v, in terms of standard pallet for parts and in terms, of cars for products; C(v): Cost per km for vehicles type v; Co(f): Operational cost for facility f; Cd(f): Construction cost for facility f; R (q, p): Consumption coefficient of part q in product p; Dis(α, β): Distance between nodes α and β; D(p, a): Demand for product p by sales agent a; Pl(q): Number of part type q in a standard pallet; B: Total available budget for facilities construction.

Descision Variables: X(v, α,β): Number of vehicles type v transported from facility α to facility β; Y (p, α,β): Number of products type p transported from facility α to facility β; Z (q, α,β): Number of parts type q transported from facility α to facility β; F(f): is equal to 1 if facility f is selected, otherwise it is 0.

Mathematical model: Min Z =

$$\sum_{v\in V}\sum_{s\in S}\sum_{m\in M} c(v)Dis(s,m)X(v,s,m)+$$
$$\sum_{v\in V}\sum_{s\in S}\sum_{k\in K} c(v)Dis(m,k)X(v,m,k)+$$
$$\sum_{v\in V}\sum_{k\in K}\sum_{j\in J} c(v)Dis(k,j)X(u,k,j)+$$
$$\sum_{v\in V}\sum_{j\in J}\sum_{a\in A} c(v)Dis(j,a)X(u,j,a)+\sum_{m\in M} Co(m)F(m)$$
$$+\sum_{j\in J} Co(j)F(j) \tag{1}$$

Subject to:

$$\sum_{j\in J} Y(p,j,a) \geq D(p,a) \qquad \forall p,a \tag{2}$$

$$\sum_{k\in K} Y(p,k,j) = \sum_{a\in A} Y(p,j,a) \quad \forall p,j \tag{3}$$

$$0.95\sum_{m\in M} Z(q,m,k) = \sum_{p\in P} R(q,p)\sum_{j\in J} Y(p,k,j) \ \forall q,k \tag{4}$$

$$\sum_{s\in S} Z(q,s,m) = \sum_{k\in K} Z(q,m,k) \quad \forall q,m \tag{5}$$

$$\sum_{m\in M} Z(q,s,m) \geq 0.1\sum_{m\in M}\sum_{s\in S} Z(q,s,m) \quad \forall s,q \tag{6}$$

$$\sum_{p\in P}\sum_{k\in K} Y(p,k,j)+\sum_{p\in P}\sum_{a\in A} Y(p,j,a) \leq \sum_{p\in P}\sum_{a\in A} D(p,a)F(j) \quad \forall j \tag{7}$$

$$\sum_{q\in Q}\sum_{s\in S} Z(q,s,m)+\sum_{q\in Q}\sum_{k\in K} Z(q,m,k) \leq \sum_{p\in P}\sum_{a\in A} R(q,p)D(p,a)F(m) \quad \forall m \tag{8}$$

$$\sum_{q\in Q} Pl(q)Cap(v)X(v,s,m) \geq \sum_{m\in M} Z(q,s,m) \quad \forall ,q,s,m$$

$$\sum_{m\in M} Cd(m)F(m) + \in \sum_{j\in J} Cd(j)F(j) \ \leq B \ \forall m,j \tag{9}$$

$$X(v,s,m), \tag{10}$$
$$X(v,m,k), X(u,k,j),, X(u,j,a), \ \forall ,v,s,m,j,k$$
$$Y(p,k,j), Y(p,j,a), \quad \forall p,j,k,a$$
$$Z(q,s,m),$$
$$Z(q,m,k), Z(q,k,j),, X(q,m,k), \ \forall ,v,s,m,j,k$$

F(m), F(j) $\epsilon[0,1]$ $\forall\ m,j$

The objective function of this model minimizes the total transportation cost, including the transportation of parts and components from suppliers to cross-docks, from cross-docks to production sites and also the transportation cost of products from plants to distribution centers and from there to sales agents as well as the construction cost of cross-docks and distribution centers. The constraints control the relation between the subsequent levels and demands. Furthermore, they guarantee that appropriate shipments are delivered from the cross-docks to feed the production lines or from distribution centers in order to satisfy the demand.

Implementing the first model

The model is implemented with the real data. Therefore, the following data were gathered: The distance between each pair of suppliers and the potential places for cross-docks; The distance between each pair of potential cross-docks places and production sites; The distance between each pair of production sites and distribution centers candidate places; The distance between each pair of distribution centers and sales agents; Capacity of transportation vehicles (for parts) in terms of standard pallets; Capacity of transportation vehicles (for cars) ; Cost of transportation vehicles (for parts) per kilometer; Cost of transportation vehicles (for cars) per kilometer in this section.

Since the purpose of this model is to plan a strategically configuration, we run the model with aggregated data. Table 1 indicates the size of real and aggregated data.

The model happens to be a mixed integer program and can be solved by available commercial software. In this case the optimal solution is obtained by applying Cplex. The solution determines the optimal allocation of suppliers, cross- docks, plants, distribution centers and sale agents. Furthermore, the appropriate type of vehicles for shipment of parts and components as well as the number of shipments from each supplier to each cross-dock and also from there to production sites is determined. Similarly, the type of vehicles for shipment of cars as well as the number of shipments from production sites and also from there to sales agents is determined.

However, as mentioned before, for confidential reasons, we cannot reveal the details of optimal solution.

Sensitivity analysis of the solutions (aggregated data): In order to find the optimal number of cross-docks and DCs which must be located, a sensitivity analysis is done according to figures-2 and 3. Figure 2 shows the sensitivity of the objective function by changing the number of cross-docks. In figure-2, the number of DCs has been considered equal to 3. Similarly, figure-3 illustrates the sensitivity of the objective function by changing the number of DCs in which the number of cross-docks has been also considered equal to 3.

Table-1
Comparing limited case and expanded case

Title	**Aggregated data**	**Real data**
Number of suppliers	18	597
Number of parts and components	474	15750
Number of products	5	13
Number of cross-docks	3	4
Number of plants	5	6
Number of distribution centers	3	10
Number of sale agents	28	822
Number of vehicle types (parts)	8	12
Number of vehicle types (product)	4	4

It can be shown from Figure 2 that by considering three DCs in the network, all of the cross-docks (six numbers) must be located to minimize the cost. On the other hand, Figure 3 illustrates that five numbers of DCs must be located to obtain minimum cost when the number of cross-docks is equal to 3.

Minimizing penalty costs of tardy deliveries

In this section, we develop a model to minimize the tardiness OD deliveries which are caused by production interruptions. As mentioned before the delays can be categorized in general into three groups, Delays of part delivery to production sites, Production interruptions, Delay of final products (cars) to sale agents.

In the previous section, we developed a model to reduce the first and third type of above delays significantly by implementing a suitable planning. Establishing cross-docks and distribution centers as well as well-planned transportation system and inventory planning can improve the delivery tardiness of the first and third categories. In this section we develop a model to reduce production interruptions, which are the most important reasons for delivery tardiness.

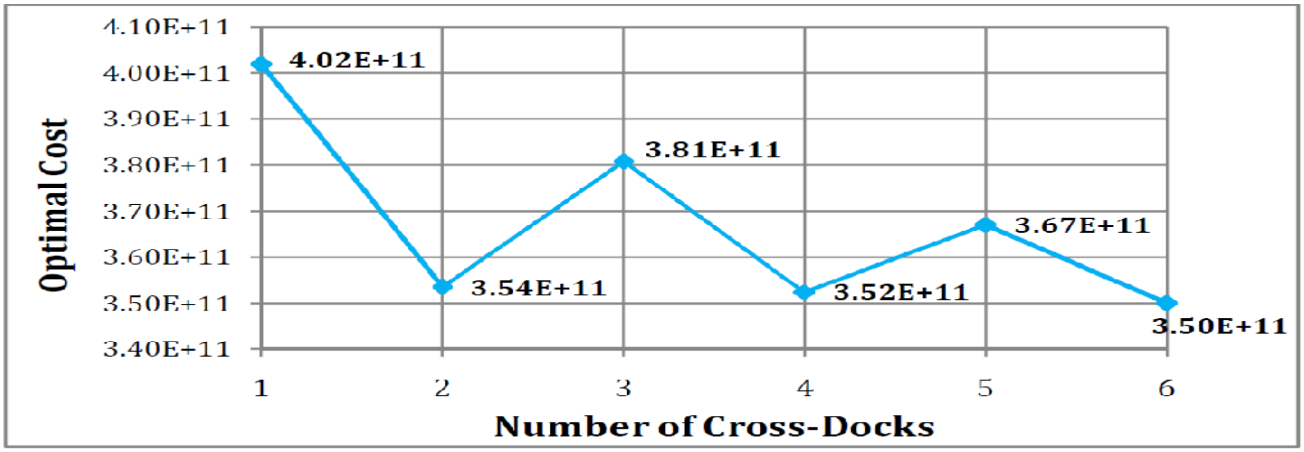

Figure-2
Optimal cost vs. number of Cross-Docks

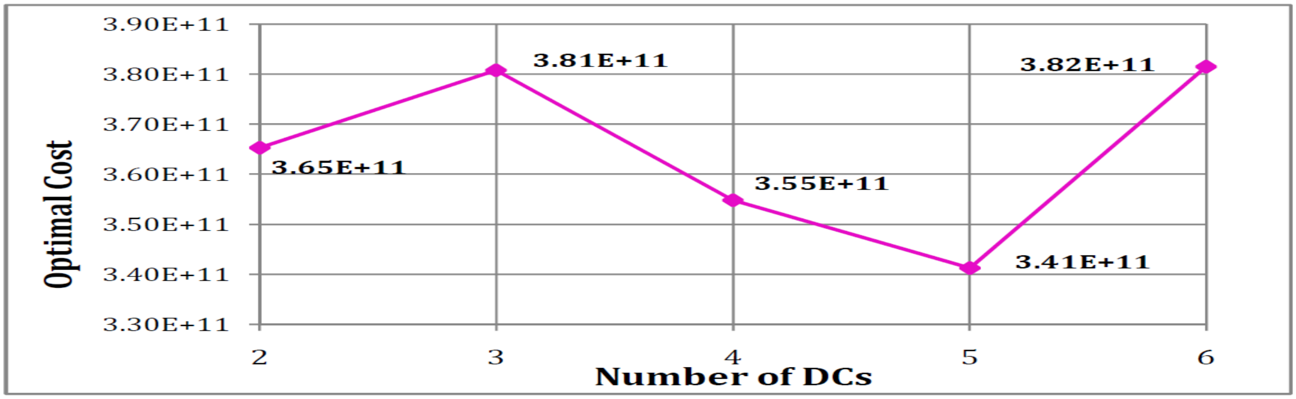

Figure-3
Optimal cost vs. number of DCs

The first step to develop the model is to identify the sources of interruptions as well as their contribution on interruptions form the historical data. In table-2 the main sources of interruptions are shown respectively. Some of these sources not only causes in a specific station, but also interrupts the succeeding stages of the production.

Table-2
Main Interruptions sources

Percentage	Main interruption
emergency maintenance	36.64
human faults	29.53
planning of process	26.53
production supports	7.30

First we develop a deterministic model for this problem. However, due to the uncertain nature of these factors, then by applying robust optimization technique, this problem is formulated again.

With the aim of minimizing the total cost of production interruption and the cost of the corrective strategies, a mathematical model is developed.

Notation Sets: I: Set of sources of production interruptions; P: Set of production lines; R: Set of corrective methods; T: Set of production stations; R(i) : Set of corrective methods for source of *i*, $i \in I$.

Parameters C_t^p: Unit cost of interruption in station *t* of product line *p*; d_{it}^p: Average interruption length in station *t* of product line *p* due to source of *i* in each period; Γ_{rt}^p: Investing cost of corrective method *r* in station *t* of product line *p*; γ_{rt}^p: Operational cost of corrective method *r* in station *t* of product line *p* per period; d_{it}^p: Average interruption length in station *t* of product line *p* due to source of *i* in each period if corrective methods are not adopted; δ_{rit}^p: Contribution of corrective method *r* in reducing the length of interruption of source of *i* in station *t* of product line *p*; $\alpha_{t\tau i}^p$: is equal to 1 if interruption of i in station *t* of product line *p* is due to the interruption in station of τ in the same product line, otherwise it is 0;

Note: Each corrective method obviously can be applied only for type of interruption source, although for different satiations and different product lines. In that case, its investing cost and operational cost is different case to case.

In some cases, for one source of *i,* more than one corrective method can be adopted, *i.e.* set R(i).

Descision Variables: X_{rt}^p: is equal to 1 if corrective method *r* is adopted in station *t* of product line *p*, otherwise it is 0; D_t^p: Interruption length (target) in station *t* of product line *p* after adopting corrective methods.

5-1-Mathematical model (deterministic):

$$\text{Min z} = \sum_{t\in T}\sum_{p\in P} C_t^p * D_t^p + \sum_{p\in P}\sum_{r\in R}\sum_{t\in T} \gamma_{rt}^p * X_{rt}^p$$

Subject to:

$$\sum_{p\in P}\sum_{r\in R}\sum_{t\in T} \Gamma_{rt}^p * X_{rt}^p \le \text{B}$$

$$D_t^p \ge d_{it}^p - \sum_{r\in R(i)} X_{rt}^p * \delta_{rit}^p + \sum_{\tau\in T} \alpha_{t\tau i}^p * d_{i\tau}^p, \qquad \forall t \in T, p \in P.$$

$$D_t^p \ge 0$$

$$X_{rt}^p \in [0,1]$$

The objective of this mode is to minimize the total cost which consists of costs of reducing operation interruptions and penalty cost of tardy orders.

The first constraint controls the budget restriction and the second set of constraints state the relation between the optimal interruption length and the length of reduction due to corrective methods. The last term of this constraint indicates that the interruption of one station may be caused by the interruption of other stations.

5-2-Mathematical model (Robust): In deterministic model, the parameters are assumed to be deterministic. There are various approaches to manage data uncertainty such as stochastic programming, robust optimization and fuzzy programming. However, we adopt robust optimization to handle uncertainties.

The main difficulties of stochastic programming approach are: i. lack of existence of distribution function of data and ii. Computational challenges.

The concept and advantages of robust approach in general, and in supply chain planning in particular can be described as follows. Deterministic approaches obtain the solution based on averaging or "good guess". In contrast, robust approach provides a solution which is "near-optimal". Although the resulting cost is more than that of deterministic approach, the solution is more reliable. In other words, taking into account the variability of parameters in a range of values, the solution is still reliable with high-confidence. Van Landeghem and Vanmaele mensioned in robust optimization approach, uncertain data takes value within an interval[19]. Although no distribution function of this random variable is available, the length of interval is given. In practice d_{it}^p, the average interruption length in station *t* of product line *p* due to source of *i* in each period is calculated on the basis of available historical data of last five years. Actually, this parameter is uncertain, by its nature. To be more realistic we apply robust optimization in formulating this problem.

We assume d_{it}^p varies within the range of $[d_{it}^p - \tilde{d}_{ip}^p\ , d_{it}^p + \tilde{d}_{ip}^p\ ]$, $\forall i \in I, t \in T, p \in P$. In fact, in this case d_{it}^p is the average of this parameter and $\tilde{d}_{ip}^{p}$ represents the variation of this parameter from the average. Both d_{it}^{p} and $\tilde{d}_{ip}^{p}$ are obtained from historical data.

We apply Bertsimas approach to develop robust model. For more information and details, the reader is referred to[18].

The robust model is as follows:

$$\text{Min z} = \sum_{\text{t}\in\text{T}} \sum_{\text{p}\in\text{P}} C_t^p * D_t^p + \sum_{\text{p}\in\text{P}} \sum_{\text{r}\in\text{R}} \sum_{\text{t}\in\text{T}} \gamma_{rt}^p * X_{rt}^p$$

Subject to:

$$\sum_{\text{p}\in\text{P}} \sum_{\text{r}\in\text{R}} \sum_{\text{t}\in\text{T}} \Gamma_{rt}^p * X_{rt}^p \le \text{B}$$

$$D_t^p \ge \ d_{it}^p - \sum_{r\in\text{R(i)}} X_{rt}^p * \delta_{rit}^p + \sum_{\tau\in T} \alpha_{t\tau i}^p * d_{i\tau}^p + Z_{pt}(\tilde{d}_{ip}^p + \sum_{\tau\in T} \alpha_{t\tau i}^p * \tilde{d}_{i\tau}^p \ ) \quad \forall t \in T, p \in P.$$

$$\sum_{\text{t}\in\text{T}} \sum_{\text{p}\in\text{P}} Z_{pt} \le \pi$$

$$Z_{pt} \le 1$$

$$D_t^p \ge 0$$

$$X_{rt}^p \in [0, 1]$$

Conclusion

In this paper, to improve the total cost as well as on-time delivery of supply chain of a car manufacturer and consequently make it competitive, we developed an approach to optimize a five level supply chain. We formulated two analytical models for the improvement the delivery tardiness problems facing this manufacturer. The first one is a location and allocation facilities problem. To overcome the problem of huge penalty costs incurred by the company, we developed another mathematical model to minimize the production interruptions and tardy deliveries the objective of the second model is to minimize the penalty cost of late delivery of cars to customers by reducing production interruptions. Furthermore, to handle the effects of uncertain parameters, robust optimization concept and technique was applied.

The models were implemented with real data gathered from historical records of the manufacturer.

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