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Productivity Improvement in a Steel Industry using Supply Chain Management Technique

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Abstract

Cost reduction is one of the methods applied for improving the productivity of organizations. In productivity literature, particularly in nonparametric methods, cost reduction related methods are regarded as input oriented models. This paper presents a Supply Chain Management (SCM) model in which purchasing iron ore and coke from different resources, along with production and distribution of steel products were investigated to improve the productivity of a steel making plant in Iran. The model was designed based on a single objective concept with a focus on total cost minimization. The constraints of the model consisted principal restriction concerning mines, coke plant and products. The model was implemented in steel factories (blast furnace) affiliated with Iranian Mines and Mining Industries Development and Renovation Organization (IMIDRO).The results showed that the priority for providing iron ore should be given to Iran Central Iron Ore Company (ICIOC) which has enough production capacity to satisfy the required ores. The results further suggested that at the best productivity condition, Isfahan steel plant should focus on the beam and bar production. The other plants, i.e. Zagros plant, should focus on L-beam and slab and finally Meibod steel plant should concentrate on slab production. It was also showed that the coke production plants cannot supply the required tonnage of the steel plants. Therefore, some new plants should be established to achieve self-sufficiency in this industry. This model can be used as a support tool for decision-makers at strategic and tactical decision levels.

Keywords: productivity, supply chain management, linear programming, steel industry.

1. Introduction

Based on the definition from the National Efficiency Organization of Iran, productivity is the ratio of the obtained desirability in a production process (outputs) to the amount of resources (inputs) which is consumed. In general, productivity is the ratio of outputs to inputs; thus, if an industrial firm is able to produce and present more products or products with higher quality, its finished cost will become less and its profit will rise, thereby the firm will achieve economic growth.

Many business managers engage in periodic cost reduction drivers in order to make their company's operation more efficient and to boost profits. A cost reduction is entirely within the control of a company, where as revenue increase is not [1].

Organizations today are looking for opportunities to improve operational efficiencies and reduce cost without having a negative effect on customer service levels. Production and supply chain management can help reduce costs by connecting every unit in the supply chain partners, and offer visibility into the demand and supply side of the chain. Production and supply chain management involves a number of drivers through which acquired raw materials are converted into finished goods for sale to customers. In turn, these drivers involve several processes that offer opportunities for cost reduction. Common drivers include procurement, design of the supply chain, distribution, transportation, warehousing, and collaboration. Cost reduction requires timely and improved decision making for common processes under each driver.

There are two different approaches in order to measure and analyze efficiency: input-oriented and output-oriented. In the former approach, it is assumed that production and income are fixed, and then it is tried to minimize the entities such as production factors and their related cost and supply, transportation and distribution cost. However, in the latter approach, we try to maximize the output and income, assuming that the amounts of entities are fixed [2].

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The steel industry is often referred to as a 'key' and 'strategies' industry. This is not only because of its importance for development but also because of the characteristics of the production process. The steel industry has distinct characteristics, such as highly capital intensive, long life of products, and its contributors in the global market, that differentiate it from other industries. This means that low cost production is, in general, a prerequisite to become a market winner and companies cannot rely on increased prices to ensure their profitability [3]. Therefore, the supply chain and logistics system in this industry appear to be complex. In this study, steel industry supply chain in Iran – including raw material supply, steel production and finish product distribution- is modeled, assessed and evaluated in order to improve efficiency with input-oriented approach using mathematical linear programming.

2. Supply chain management

A supply chain consists of all stages that play a role in satisfying customer's request, both directly and indirectly. It includes not only the manufacturers and suppliers, but also transporters, warehouses, retailers, and customers themselves [4]. Considering the extent of domain of a supply chain, no model can cover all the aspects of supply chain's processes. In order to compromise between a model's complexities and the real world situation, a designer should define the model's extent and scope in a way that not only recognizes the real world situation but also is capable of providing solutions to problems [5]. Supply chain management's objective is to put more efficiency and effectiveness into costs along the chain, in such manner that it minimizes the total costs of transportation, distribution and inventory [6]. In supply chain modeling, various constraints, which represent limits of decision variables and their feasibility, are taken into account [7]. Some of these constraints, depending on the nature and type of the problem, are location variables, amount of allocation from distribution points to costumers, network structure, quantities of facilities and equipments, number of the levels in the chain supply, service sequence, optimum amount of purchase, production and transportation, inventory level, and amount of labor force.

In this study, a linear programming model has been presented in order to undertake the Supply Chain Management (SCM) in steel industries that use blast method furnace (BF). This model has been implemented in BF steel factories affiliated with the Iranian Mines & Mining Industries Development & Renovation (IMIDRO). The model includes procurement and blending of different types of iron ore and procurement of coke, to provide various types of rolled steel products and to fulfill customer and distributor demand. The optimum solution is obtained based upon minimizing the costs.

In the 1960s and 1970s, the dominant idea in order to increase a company's competitive power focused on standardizing and improving initial processes and consequently producing products with higher quality and lower production cost. In the 1980s, due to the increase in number of product varieties demanded by costumers, more flexible and versatile production lines as well as new products were developed in order to satisfy costumers' demands. In the 1990s, along with improvement in production processes and application of reengineering patterns, the necessity of providing products with higher quality and less production cost as well as building a close connection between distributors and development policies of production market were taken into account. As such, supply chain methods and its management approaches came to existence [8].

Such studies vary due to the nature of the studied industry, goals of the study (expenses and time minimization, profit maximization and etc.), improvement techniques being used (single or multi-objective, deterministic or non-deterministic models and etc.

One of the first efforts in order to develop an integrated model in supply chain was taken by Glover *et al*. (1979) who concentrated on production, distribution and inventory for three areas of supply, warehouse, site selection, and planning for costumers demand [9]. Williams (1983) studied several heuristic algorithms for scheduling distribution operations in an assembly supply chain network [10]. Benjamin (1990) studied the choice of transportation mode in the supply chain with multiple supply, demand points, and single product [11]. Tzafestas and Kapsiotis (1994) used a deterministic Linear Programming (LP) model in order to optimize a supply chain and then analyzed the optimized model by simulation techniques and through a numeral example [12]. Voudouris (1996) developed a mathematical model designed to improve efficiency and responsiveness in a supply chain [13].

In a similar vein, Ghodsypour and O'Brien (1998) employed LP techniques to structuralize the supply chain [14]. Shih (1999) used LP models to determine the best scheduling and optimized usage for transportation structure, and to add uncertainty to the problem, he implied fuzzy LP [15]. In another research, Li and O'Brien (1999) used dynamic programming methods in modeling supply chain [16]. Sabri and Beamon (2000) focused on deterministic supply chain and stochastic supply chain [17]. Chandra and Kumar (2001) proposed two single objective linear models for supply chain network design [18]. Lakhal *et al*. (2001) and Cakravastia, *et al*. (2002) also used mixed-integer programming methods in their researches [19, 20].

Zhou *et al*. (2002) studied the balanced allocation of costumers to multiple distribution centers in the supply chain network using genetic algorithm (GA) [21]. Lee and Kim (2002) studied the production-distribution problem in the supply chain, considering capacity constraints [22]. Wang *et al*. (2004) considered a distribution network consisting of multiple factories' warehouses and multiple retailers [23]. Chan and Chung (2004) developed a multi-criteria GA for solving distribution network problem supply chain management [24]. Wang *et al*. (2004) used goal programming [25]. Huang *et al*. (2005) used GA and Graves and Willems (2005) focused on dynamic programming in supply chain modeling [27, 28]. Spitter *et al*. (2005) developed an LP model for supply chain operation planning with capacity constraints for assembly [29]. Gunnarsson *et al*. (2006) studied supply chain planning for wood industry focusing on minimizing transportation, production and distribution costs considering fulfillment of product's demand [30].

Bilgen and Ozkarahan (2007) modeled the problem of production and transportation, using mixed-integer programming in which the objective function includes minimization of the total cost of production, loading, transportation and inventory [31]. Farahani and Elahipanah (2008) devised a dual objective model for just-in-time distribution in the context of supply chain management for distribution network of a three-level supply chain [32]. Hamedi *et al*. (2009) presented an integrated multi-period optimization model for the distribution planning in different stages of natural gas supply chain [33].

In certain papers, the steel industry has been studied with the aim of implementing improvements in the sector. Potter *et al*. (2004) studied the evolution of a case study steel supply chain within the UK over the past decade [34]. It has been proposed that supply chains evolve from a traditional (uncoordinated, disparate, sub-optimal) to an integrated supply chain structure. Xiong and Helo (2008) discussed certain challenges to the supply chain in today's steel industry [35]. They emphasized that optimizing the supply chain is one of the most important technologies in the world steel industry. Suthikarnnarunai (2009) studied the economic factors influencing logistics cost of steel industry in Thailand [36]. He concluded that the logistics cost of the steel industry was according to the principle of supply chain and logistics management theory and also relied on other economic factors. Gutierrez-Franco *et al*. (2009) presented an LP approach for modeling the supply chain in the semi-integrated steel industry in Colombia [37]. The production is based on waste management (recycled iron and steel scrap). Some of the previous researches related to supply chain management of steel industry are given in Table 1.

The review of the literature shows that several techniques and methods have been presented for supply chain management. Some of the optimization techniques used for supply-chain configuration include LP, mixed integer programming, dynamic programming, goal programming and GA.

3. Modeling

Steel can be produced using different methods such as blast furnace (BF) and direct reduction (DR). BF represents more than 66% of global steel production. Figure1 represents the general BF steel supply chain. Principal raw materials consist of iron ore and coke. Several types of iron ore can be provided; i.e. iron ore is mined and prepared as concentrate which are sold as separate products. Steel products can be also produced in different qualities and various rolling types (beam and bar and so on) upon users' request.

In this research, LP is used to model supply chain planning and its management in the BF steel industry. The model consists of problem definition, assumptions, decision variables, parameters and indices, objective function, and constraints. Below is a description of each section.

Int J Min & Geo-Eng (IJMGE), Vol. 47, No. 1, Jun. 2013, pp. 41-60

Table 1. Applications of supply chain management in steel industries

Roy & Guin	1999	Conceptual model for just in time produce at a steel plant in India [38]
Gielen & Moriguchi	2001	Statistical analysis and value chain analysis in a supply chain of steel [39]
Jiang	2005	A decision support model for selecting the appropriate component supplier and contractor in the steel industry [40]
Zapfel & Wasner	2006	warehouse layout management in steel supply chain in order to optimize use of space and timely access to products [41]
Marley	2006	Study on defeat factors of supply chain [42]
Karl	2008	Models to improve the environmental performance of steel factories and steel melting process optimization [43]
Peng et al.	2009	a mathematical model for optimization the supply chain process of China's coal mines[44]
Liu & Dong	2010	A qualitative and conceptual model for supply chain of a steel company [45]
Xiaozhen et al.	2010	A conceptual – operational framework for the steel company's supply chain [46]
Helle et al	2010	Optimization of work condition and production of blast furnace [47]
Seifbarghy et al.	2010	Supply chain performance assessment in Mobarakeh Steel Company based on supply chain operations reference model [48]

3.1. Problem definition

The problem consists of purchasing and providing principal raw materials (iron ore and coke) for a steel company, transforming them into various types of steel products, and transporting them to different destinations, such that minimizes the total cost. Constraints applied to this model include constraints on resources, production and selling the steel products.

3.2. Problem assumptions

A steel company needs to satisfy its customers' demand for different types of products. It should buy raw materials including various types of iron ore from nearby mines, and coke from coke-producing plants.

3.3. Decision variables

The decision variables are defined as below:

M_{nmh}: The tonnage of type m iron ore which will be transported from mine n to factory h.

M_{fh}: The tonnage of coke that is transported from coke plant f to steel factory h

F_{ht}: The tonnage of steel with rolled type of t that is produced in factory h

D_{htr}: The tonnage of steel with rolled type of t that is transported from factory h to costumer r

M^{t}_{nmh}: The tonnage of iron ore with type of m that is transported from mine n to factory h and is consumed in production process of steel with rolled type of t

3.4. Parameters

- Procurement costs of iron ore

PO_m: Price, per ton of type m iron ore

TO_{nh}: Transportation cost per ton of iron ore from mine n to factory h.

- Procurement cost of coke

PC_f: Price per ton of coke from coke plant f

TC_{fh}: Transportation cost per ton of coke from coke plant f to steel factory h

- Production and transportation cost of steel

C_{ht}: Production cost per ton of steel with rolled type of t in factory h

TS_{htr}: Transportation cost of each ton of steel with type of t from factory h to costumer r

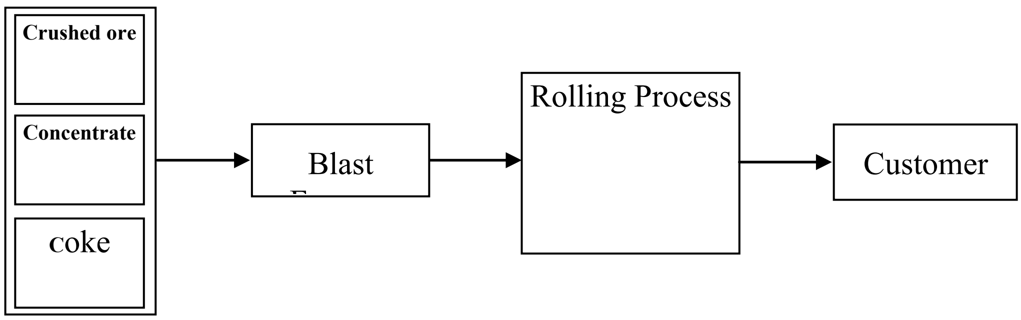

Figure 1. The steel supply chain

3.5. Indices

$n \in \{1, 2, 3, \ldots, N\}$, N: maximum number of mines

$m \in \{1, 2, 3, \ldots, M\}$, M: maximum number of ore types

$h \in \{1, 2, 3, \ldots, H\}$, H: maximum number of steel factories

$f \in \{1, 2, 3, \ldots, F\}$, F: maximum number of coke plants

$t \in \{1, 2, 3, \ldots, T\}$, T: maximum number of rolled steel product types

$r \in \{1, 2, 3, \ldots, R\}$, R: maximum number of customers

3.6. Objective function

The objective of the model is to minimize the total cost in supply chain. Total cost equals to sum of the purchasing price of raw materials, transporting cost to the steel factory, cost of producing various types of rolled steel products and their delivery cost to customers.

Purchasing and transportation costs of iron ore =

$$\sum_{n=1}^{N}\sum_{m=1}^{M}\sum_{h=1}^{H}(PO_m + TO_{nh})M_{nmh} \quad (1)$$

Purchasing and transportation costs of coke

$$= \sum_{f=1}^{F}\sum_{h=1}^{H}(PC_f + TC_{fh})M_{fh} \quad (2)$$

Producing costs of steel products

$$= \sum_{h=1}^{H}\sum_{t=1}^{T}C_{ht}F_{ht} \quad (3)$$

Transportation costs of steel products to customers

$$= \sum_{h=1}^{H}\sum_{t=1}^{T}\sum_{r=1}^{R}TS_{htr}D_{htr} \quad (4)$$

Therefore, objective function is defined as it follows:

$$MinZ = \sum_{n=1}^{N}\sum_{m=1}^{M}\sum_{h=1}^{H}(PO_m + TO_{nh})M_{nmh} + \sum_{f=1}^{F}\sum_{h=1}^{H}(PC_f + TC_{fh})M_{fh} + \sum_{h=1}^{H}\sum_{t=1}^{T}C_{ht}F_{ht} + \sum_{h=1}^{H}\sum_{t=1}^{T}\sum_{r=1}^{R}TS_{htr}D_{htr} \quad (5)$$

3.7. Constraints related to

- Exploitation capacity of different mines

$$\sum_{h=1}^{H} M_{nmh} \le A_{nm} \quad (6)$$

A_{nm}: Exploitation capacity of type m iron ore from mine n

- Production capacity of different coke plants

$$\sum_{h=1}^{H} M_{fh} \le A_f \quad (7)$$

A_f: Production capacity of coke plant f

- Steel production capacity

$$\sum_{t=1}^{T} F_{ht} \le L_h \quad (8)$$

L_h : Production capacity of steel factory h

- Amount of consumed iron ore ($\sum_{t=1}^{T} M_{nmh}^{t}$) comparing to the amount of purchased iron ore (M_{nmh})

$$\sum_{t=1}^{T} M_{nmh}^{t} \le M_{nmh} \quad (9)$$

- Blending ratio of different types of iron ore

$$\frac{\sum_{n=1}^{N} M_{nmh}^{t}}{\sum_{n=1}^{N} M_{nm'h}^{t}} = \frac{i_{mh}^{t}}{i_{m'h}^{t}}$$

$m \neq m'$ or it can be said

$$i_{m'h}^{t} \sum_{n=1}^{N} M_{nmh}^{t} \quad i_{mh}^{t} \sum_{n=1}^{N} M_{nm'h}^{t} = 0 \quad (10)$$

$\frac{i_{mh}^{t}}{i_{m'h}^{t}}$: The blending ratio of type m to type m' iron ore in order to produce rolled type steel of t in factory of h. $m, m' \in \{1,2,3,\ldots M\}, m \neq m'$

- Amount of various quality of iron ore that are consumed

$$\sum_{m=1}^{M}\sum_{n=1}^{N} M_{nmh}^{t} = \alpha_{ht} F_{ht} \quad (11)$$

α_{ht}: Total iron ore tonnage consumption for production of 1 ton of rolled type steel in of t in factory h

- Amount of consumed coke

$$\sum_{h=1}^{H} M_{fh} = \beta_h \sum_{t=1}^{T} F_{ht} \quad (12)$$

β_h: Total consumed coke tonnage for production of 1 ton of steel in factory h

- Steel supply

$$\sum_{r=1}^{R} D_{htr} \le F_{ht} \tag{13}$$

- Steel demand

$$\sum_{h=1}^{H} D_{htr} \ge E_{tr} \tag{14}$$

E_{tr} : The amount of customer's demand of *r* for steel with rolling type of *t*.

3.8. Final model

Adding up what's been said before; LP model is as below:

$$MinZ = \sum_{n=1}^{N}\sum_{m=1}^{M}\sum_{h=1}^{H}(PO_m + TO_{nh})M_{nmh}$$

$$+ \sum_{f=1}^{F}\sum_{h=1}^{H}(PC_f + TC_{fh})M_{fh} + \sum_{h=1}^{H}\sum_{t=1}^{T} C_{ht} F_{ht}$$

$$+ \sum_{h=1}^{H}\sum_{t=1}^{T}\sum_{r=1}^{R} TS_{htr} D_{htr}$$

S.t:

$$\sum_{h=1}^{H} M_{nmh} \le A_{nm}$$

$$\sum_{t=1}^{T} M^t_{nmh} \le M_{nmh}$$

$$i^t_{m'h} \sum_{n=1}^{N} M^t_{nmh} \quad i^t_{mh} \sum_{n=1}^{N} M^t_{nm'h} = 0$$

$$\sum_{m=1}^{M}\sum_{n=1}^{N} M^t_{nmh} - \alpha_{ht} F_{ht} = 0$$

$$\sum_{h=1}^{H} M_{fh} \le A_f$$

$$\sum_{h=1}^{H} M_{fh} - \beta_h \sum_{t=1}^{T} F_{ht} = 0$$

$$\sum_{t=1}^{T} F_{ht} \le L_h$$

$$\sum_{r=1}^{R} D_{htr} - F_{ht} \le 0$$

$$\sum_{h=1}^{H} D_{htr} \ge E_{tr}$$

$$M_{nmh}\ , F_{ht}\ , D_{htr}, M^t_{nmh}\ , M^t_{nm'h} \ \ge 0$$

4. Case study

In 2010, Iran produced approximately 33 million tons of iron ore (concentrate) and exported about 10 million metric tons, mainly to China [49]. The country produced about 12 million tons of crude steel and was ranked 17th in the world and second in the Middle East in 2010 (World Steel Association). Eight steel factories are currently working, whose main shareholder is IMIDRO. About 25% of steel production is achieved by using the BF method.

In this study, the supply chain of three steel production units affiliated with the IMIDRO, which are using the blast furnace method, was studied. These units purchase two types of iron ore (fractionized and concentrate) from five available mines and also purchase the coke from one plant.

It sells four steel product types to four whole sellers. The names of mines, steel and coke making plant and the related index are presented in Table 2.

Results obtained by using LINDO are similar to those achieved by LINGO software packages (with respectively 72 and 65 iterations). Optimum values of decision variables are categorized in Table 3. The optimum value of objective function (minimum value of total cost) is about $127 million per month.

5. Results and discussion

The model yielded cost reduction in supply chain elements, including supplying raw materials, manufacturing steel products and distribution. Because the capacity of supplying iron ore mines is far more than that of steel factories' production, all the factories operate at full capacity. This suggests that producer surplus is used for the direct reduction plant and export. All products of the Central Iron Ore Mine are shipped to factories but the purchase of GolGohar and Jalalabad mines is not efficient.

Table 2. Case study specification

Iron mines		Cock plants		Steel units		Customers	
Name	Index	Name	Index	Name	Index	Name	Index
Gol-gohar	n=1	Zarand	f = 1	Isfahan	h =1	Tehran	r =1
Chadormalu	n=2			Zagros	h =2	Mashhad	r =2
Mishdovan	n=3			Meybod	h =3	Bandarabas	r = 3
Jalal abad	n= 4						
Choghart	n= 5						

Table 3. Results of problem

Variable	Value	Variable	Value
M_{221}	430000	D_{111}	1200000
M_{311}	80000	D_{112}	500000
M_{511}	2920000	D_{113}	500000
M_{512}	346666	D_{121}	1000000
M_{513}	533333	D_{122}	300000
M_{521}	1700000	D_{123}	800000
M_{13}	400000	D_{131}	500000
M_{22}	455000	D_{132}	36666
M_{23}	300000	D_{141}	163333
F_{11}	2200000	D_{232}	83333
F_{12}	2100000	D_{233}	350000
F_{13}	536666	D_{242}	80000
F_{14}	163333	D_{243}	136666
F_{23}	433333	D_{341}	136667
F_{24}	216666	D_{343}	863333
F_{34}	1000000		

Only 20% of the concentrate capacity of Chadormalu mine is shipped to steel plant in Isfahan. Mishdovan mine could carry only about 12% of graded product to steel plant in Isfahan. As mentioned, steel factories operate at full capacity. The steel factory of Isfahan can allocate 86% of its capacity to produce the beam and the bar. In Zagros steel plant only producing L-beam and slab (with a ratio of 2 to 1) is economically efficient. The steel factory of Meybod should allocate all of its manufacturing capacity to produce the slab. Since Isfahan plant meets its required tonnage of coke, the model prediction will be validated. Whole production of Zarand coke plant only provides 57% of Meybod steel plant need. Therefore the remaining 43% of its need should be provided by other local producers. It is also concluded that the total demand of Zagros plant should be provided through local coke producers as well.

6. Conclusion

In this paper, with the purpose of productivity improvement, a supply chain management model for the steel industry blast furnace method was presented. The supply chain was formulated as a LP model, single-objective, multi raw materials, multi-suppliers, and multi-products. The objective of this model was to minimize all costs related to ore and coke, their transportation, steel production and distribution cost as to enhance productivity. In fact input oriented and cost reduction of supply, product and distribution was aimed. Major features of the model included forming a relation among decision variables and considering diversity and amount of provided ore from different mines, consumed coke and diversity among steel products.

Since end product pricing is not in control of manufacturers, if we plan supplying, manufacturing and distribution according to the model result, productivity may increase through cost reduction. The validity of the model and its solution approach has been measured for the selected blast furnace steel factories in Iran, using LINGO and LINDO software packages.

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