International Journal of ISSI, Vol.7 (2010), No.1, pp.11-16

A general model for production-transportation planning in steel supply chain

A. Sabzevari Zadeh[1]* and R. Sahraeian[2]
Industrial Engineering Department, Faculty of Engineering, Shahed University, Tehran, Iran

Abstract
This paper is focused on the tactical design of steel supply chain (SSC). A general mathematical model is proposed to integrate production and transportation planning in multi-commodity SSC. The main purpose is to prepare a countrywide production and distribution plan in an SSC with three layers consisting of iron ore mines as suppliers, steel companies as producers, and subsidiary steel companies as customers. An internal supply chain consisting of melting furnaces and casting lines in each producer is also taken into account. Demand is assumed to be deterministic and known at the beginning of planning horizon. Each mine supplies iron ore with specific chemical compounds (CCs) and each producer needs a given volume of iron ore with a pre-determined range of CCs which can be provided by mixing several kinds of iron ores. Finally, a real test case in SSC is described and solved using the proposed model. Sensitivity analysis supports the decision makers with noteworthy information about tactical decisions.

Keywords: Steel Supply Chain, Production, Transportation, Blending Problem, Linear Programming.

1. Introduction
Supply chain is a network of facilities consisting of suppliers, producers, assembly lines and distribution centers. Material, information and financial flows interconnect them [1]. It can be inferred that besides production and distribution tasks, a supply chain also consists of transportation, storage and retail activities [2]. Decision making in supply chain management can be actuated in three distinct phases based on planning horizon: strategic, tactical, and operational [2]. In strategic level, an organization plans the configuration of its supply chain for several future years. Strategic decisions include: determination of the tasks to be accomplished in the organization, and tasks to be outsourced, location and capacity of production and storage facilities, assignment of products to production and storage facilities, and transportation mode selection for shipping products.

Planning horizon in tactical level is confined to some seasons or at most to one year. In this level, the organization decides about transportation and storage facilities which can be used regarding imposed restrictions in strategic framework. Finally, operational decisions concern flow shop or scheduling tasks for a special day or scarcely a week.

This paper is focused on tactical decisions in steel supply chain management. We propose a mixed integer linear programming (MILP) model to design and improve the production and transportation plan in a countrywide SSC. The proposed model determines the production levels in each producer, and transportation flows from each layer (or intra-layer) to the next one. The output of the model also consists of iron ore suppliers selection, production capacities assignment, and transportation planning for delivering products to the customers. So, the following questions would be replied through the proposed model:

- How would the producers procure their required iron ore from the mines?
- How much of each product should be produced in each producer?
- How much of each product should be transported from each producer to each customer?

This paper is organized as follows. The problem of interest and its assumptions are described in detail in section 2. Section 3 presents the proposed MILP model. A real test case in SSC and its results are discussed in section 4. Finally, section 5 summarizes the paper and reveals some promising future research issues.

2. Problem definition
We studied the dynamic multi-commodity production and transportation planning problem with deterministic demands and unlimited budget in SSC management. A supply chain network like the one depicted in Fig. 1, with three main layers comprising iron ore mines, steel producers and customers is considered. An internal supply chain with two intra-layers includes melting

* *Corresponding author:*
Tel: +98 (916) 6225761, Fax: +98 (611) 3362760
E-mail: alisabzevary@gmail.com
Address: Industrial Eng. Dept., Faculty of Eng., Shahed University, Tehran, 18155/159, Iran.
1. MSc. Industrial Engineering
2. Assistant Professor

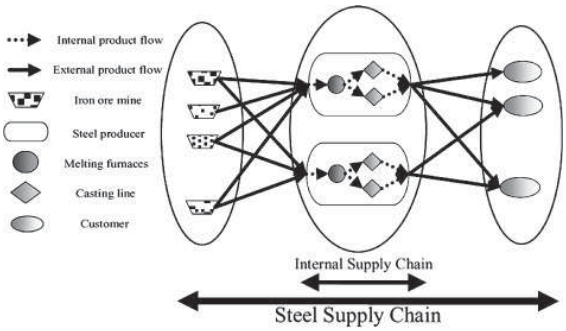

Fig.1. Example of a SSC with an internal supply chain in each producer.

furnaces (i.e., blast furnaces or electric arc furnaces) and casting lines in each steel producer is also taken into account [3].

The problem of interest consists of making decisions on production levels in producers' layer, efficient allocation of production capacities to the customers and product flows from each layer (or intra-layer) to the consequence one.

Each mine supplies iron ore with a specific amount of CCs including Fe, Fe_3O_4, SiO_2, Al_2O_3, S, P, CaO, and MgO. Moreover, each producer requires iron ore with a given range of CCs to be able to continue its robust process. In other words, each producer has a predefined standard to determine the admissible range of CCs of iron ore, empirically. It is important to note that the amount of each CC in iron ore affects process costs. As an example, sulfur (S) in any form is a temporary poison to reforming catalysts in direct reduction plants. Sulfur is present in iron ore and natural gas. Studies show when the amount of sulfur in iron ore increases, the reformer capacity will decrease. Therefore, the process costs increase by enhancing the amount of sulfur in iron ore. On the other hand, the iron ore price depends on its quality, so if a steel producer wants to supply iron ore with low sulfur, he has to pay much money. Admissible range of CCs in each producer is referred to the process technology and is specified by process experts empirically. Hence, each producer has to procure its required iron ore from several mines and mix them together to satisfy its CCs' range.

The steel making process in each steel producer consists of three stages: smelting (i.e., blast furnace (BF) or electric arc furnace (EAF)), refining (i.e., ladle furnace (LF)) and continuous casting. In this paper, both smelting and refining stages are considered as one intra-layer in the steel producers. Moreover, there is an individual continuous casting line to produce each product. Due to flexibility in steel making processes, the production capacity of melting furnaces is assumed less than total capacity of the casting lines. For more detailed information about steel making process, interested readers should refer to Atighechian et al. [4] and Zanoni and Zavanella [5].

Steel products can be imported by customers and can be exported by producers. In other words, each customer is allowed to purchase steel products from an outside producer and each producer is allowed to sell some products to an outside customer. But, total volume of imported (exported) products by all customers (producers) at each time period has been limited. A lower bound on the ratio of production volume to the production capacity is defined as minimal acceptable utilization rate to guarantee the minimum level of benefit in each producer regarding its investment size.

It is supposed that there are some steel producers in the SSC. Moreover, producers are crude steel companies, and customers are subsidiary steel companies. At the beginning of planning horizon, each producer has an initial capacity in smelting stage and casting lines. The planning horizon is divided into a set of consecutive and integer time periods which have equal lengths.

3. Problem formulation

To formulate the problem as an MILP model, the following notations are introduced in advance. Using these notations, a mathematical programming model can be formulated to solve the problem. It is also supposed that prior to model design; all relevant data were collected using e.g. appropriate forecasting methods and company-specific business analysis.

3.1. Notations

Sets:

I: set of iron ore mines

J: set of steel producers

K: set of customers

P: set of products

T: set of time periods

H: set of CCs of iron ore

Parameters:

$\overline{CS}_i^t$: maximal supply capacity of iron ore by mine i in time period t.

$\overline{CP}_j^t$: capacity of molten steel production in producer *j* in time period *t*.

$\overline{CC}_{jp}^t$ **:** casting line capacity of product *p* in producer *j* in time period *t*.

$\underline{U}_j$: minimal acceptable percentage of utilization of producer *j*.

$\overline{I}^t$: maximal acceptable ratio of import to the total production volume in time period *t*.

$\underline{E}^t$: minimal acceptable ratio of export to the total production volume in time period *t*.

Qs^t_{ih} : percent amount of compound *h* in iron ore of mine *i* in time period *t*.

Qp^t_{jh} : percent acceptable amount of compound *h* in required iron ore of producer *j* in period *t*.

PY^t_i :production yield) iron ore to steel products (for iron ore of mine *i* in time period *t*.

SC_{ij} : cost of purchasing and shipping per unit of iron ore from mine *i* to producer *j*.

PC_{jp} : unit production cost of product p made by producer j.

TC_{jkp} : cost of shipping per unit of product p from producer j to customer k.

D^t_{kp} : demand of customer k for product p in time period t.

Ci_{kp} : total cost for importing and shipping per unit of product p to customer k.

Ce_{jp} : net income for exporting per unit of product p by producer j.

$$I_h = \begin{cases} +1 & \text{if h indicate compound of Fe in iron ore,} \\ -1 & \text{otherwise.} \end{cases}$$

Decision Variables:

x^t_{ij} : volume of iron ore purchased and shipped from mine i to producer j in time period t.

y^t_{jp} : volume of product p produced by producer j in time period t.

z^t_{jkp} : volume of product p shipped from producer j to customer k in time period t.

imp^t_{kp} : volume of product p imported by customer k in time period t.

$\exp^t_{jp}$: volume of product p exported by producer j in time period t.

3.2. Linear programming model

In terms of the above notations, formulation of the problem is as follows.

(M_1) *Minimize*

$$\begin{aligned} &\sum_t\sum_i\sum_j SC_{ij}.x^t_{ij} \\ &+\sum_t\sum_j\sum_p PC_{jp}.y^t_{jp} \\ &-\sum_t\sum_j\sum_p Ce_{jp}.\exp^t_{jp} \\ &+\sum_t\sum_k\sum_p Ci_{kp}.imp^t_{kp} \\ &+\sum_t\sum_j\sum_k\sum_p TC_{jkp}.z^t_{jkp} \end{aligned} \tag{1}$$

Subject to

$$\sum_j z^t_{jkp} + imp^t_{kp} \geq D^t_{kp} \qquad \forall t, k, p \tag{2}$$

$$\sum_i \frac{x^t_{ij}}{PY^t_i} \geq \sum_p y^t_{jp} \qquad \forall t, j \tag{3}$$

$$\sum_i I_h.Qs^t_{ih}.x^t_{ij} \geq I_h.Qp^t_{jh}.\sum_i x^t_{ij} \qquad \forall t, j, h \tag{4}$$

$$\sum_j x^t_{ij} \leq \overline{CS}^t_i \qquad \forall t, i \tag{5}$$

$$\sum_p y^t_{jp} \geq \underline{U}_j.\overline{CP}^t_j \qquad \forall t, j \tag{6}$$

$$\sum_p y^t_{jp} \leq \overline{CP}^t_j \qquad \forall t, j \tag{7}$$

$$y^t_{jp} \leq \overline{CC}^t_{jp} \qquad \forall t, j, p \tag{8}$$

$$y^t_{jp} = \exp^t_{jp} + \sum_k z^t_{jkp} \qquad \forall t, j, p \tag{9}$$

$$\sum_k\sum_p imp^t_{kp} \leq \overline{I}^t \sum_j\sum_p y^t_{jp} \qquad \forall t \tag{10}$$

$$\sum_j\sum_p \exp^t_{jp} \geq \underline{E}^t \sum_j\sum_p y^t_{jp} \qquad \forall t \tag{11}$$

$$x^t_{ij}, y^t_{jp}, z^t_{jkp}, imp^t_{kp}, \exp^t_{jp} \geq 0 \qquad \forall t, i, j, k, p \tag{12}$$

In the above formulation, objective function (1) minimizes the total costs including transportation and purchasing costs of iron ore from mines to producers, production costs, attained net income by export (with negative sign), import costs and transportation costs from producers to customers, respectively.

Constraints (2) ensure that the demand of each customer is fulfilled. In order to provide the required molten steel proportional to customers' demands, constrains (3) assure that each producer receives enough volume of iron ore from all mines. Inequalities (4) ensure that each producer attains its required iron ore in conformity with its admissible range of CCs in each time period. Thus, these constrains enforce the blending problem into the proposed model [6,7].

Constraints (5) impose the supply capacity on each iron ore mine. Constraints (6) ensure that output of each producer is more than a given minimum level. Constraints (7) state the maximum smelting stage capacity in each producer. Constraints (8) state the maximum casting line capacity of each product in each producer. Equations (9) impose the product flows conservation of producers while the demands of customers are gratified.

Constraints (10) ((11)) state that the total volume of

imported (exported) products must not be more than (less than) a given maximum (minimum) level at each time period. Note that, these levels are legislated by government. Finally, constraints (12) enforce the non-negativity restrictions on the corresponding decision variables.

3.3. Model development

There are some actual issues in the real world SSCs which have not been considered in the formulation of the problem. For example, it is not possible to purchase iron ore in small batches, e.g. Chadormalo mine in Iran would contract to supply at least 300 thousand tons of iron ore per year. In order to enhance this matter to formulation, the following lemma can be used, efficiently.

Lemma: In order to confine the continuous variable x such that it takes either the value of zero or a value greater than or equal to K, new binary variable u and the following constraints set are introduced:

$$x < M.u \tag{13}$$

$$x \geq K.u \tag{14}$$

In which K is the minimum admissible batch size and M is a big number which should be at least greater than the sum of all supply capacities of iron ore mines.

Proof:

a) If u=0, we will have $x < 0$ according to constraint (13) and $x \geq 0$ according to constraint (14), which means x= 0, and

b) If u=1, we will have $x < M$ according to constraint (13) and $x \geq K$ according to constraint (14). Since M is greater than the biggest possible value for x, constraint $x < M$ is not an active constraint and the model can be solved regardless of this constraint. So, we will have $x \geq K$.□

In order to exert this issue into the formulation, the three following constraints are appended to model M_1.

$$x_{ij}^t < M.u_{ij}^t \qquad \forall t, i, j \tag{15}$$

$$x_{ij}^t \geq K_i^t.u_{ij}^t \qquad \forall t, i, j \tag{16}$$

$$u_{ij}^t \in \{0,1\} \qquad \forall t, i, j \tag{17}$$

By applying the above mentioned realistic issue in the problem, the new MILP model (namely M_2) is obtained.

(M_2) *Minimize*

Objective function (1)

Subject to

Constraints (2) till (12),

Constraints (15) till (17).

A large portion of complexity of the above model is related to minimum admissible batch size constraints (i.e., constraints (15), (16) and (17)). So, when the number of iron ore mines or crude steel producers increases in the problem, the complexity of the model will increase. It is important to mention that the proposed model is not very difficult to solve with standard solvers (e.g., LINGO, Cplex, Xpress, etc.) in small and medium test problems. Because, based on our recent investigation, the problem is not more general than any known NP-hard or NP-complete problems like location-allocation problem (LAP), traveling salesman problem (TSP) and etc. So, the proposed model does not belong to these classes. However, the complexity of the model increases by enhancing the number of binary variables (i.e., u_{ij}^t).

4. A case: Iran SSC

To assure the correct performance of constraints and objective function, the model is applied to a realistic scenario in Iran SSC where the customers' demands are deterministic. In the discussed SSC, domestic iron ore mines are Chadormalo, Golgohar, and Choghart; and exotic mines are Samarco, Kudermukh, Carajase, CVRD, Ferteco, and MBR. As mentioned in section 2, each of these mines supplies iron ore with specific CCs. By using CCs of each mine for some time periods, a regression model can be applied to forecast CCs at some time periods in the future.

Steel producers' layer consists of Khouzestan Steel Co. (KSC), Mobarakeh Steel Co. (MSC), Esfahan Steel Co. (ESC) and an outside producer (OUT) to import products. Customers' layer comprises 1) MSC, 2) ESC, 3) Kavian Steel Co., 4) National Industrial Steel Group Co., 5) Ahwaz Pipe and Rolling Mills Co., 6) Khuzestan Oxin Steel Co., 7) Azerbayjan Steel Co., 8) Khorasan Steel Co., 9) Amir Kabir Khazar Steel Co., 10) Iran Alloy Steel Co. and 11) an outside customer to export products.

It is assumed that there are three inside and one outside crude steel producers in the chain such that their capacities are expanded proportional to customers' demands. Materials flowing from the first layer to the second layer consist of iron ore with different CCs and from the second layer to the third layer which consist of three kinds of steel products namely; Billet, Bloom and Slab. The value of production yield from iron ore to steel products depends on total amount of Fe metal in iron ore and has to be less than 1.65. It means that the steel production process converts 1.65 tons iron ore to 1 ton steel products.

The demand of the customers was estimated using moving average based on the available data from their demands in the last two time periods. Since steel is a functional and strategic commodity, consumer demand can be estimated with a high reliability [8].

Import policy should be exerted such that the ratio of imported products to the total domestic demands at each time period becomes less than or equal to 5 percent. Instead, export policy should be exerted such that the ratio of exported products to the total domestic crude steel production becomes more than or equal to 10 percent at each time period.

Each steel producer has some melting furnaces (e.g., blast furnaces, electric arc furnaces or etc.) which feed some parallel casting lines. MSC is only able to produce slab, and ESC produces both billet and bloom. But, KSC and OUT can produce all three kinds of steel products. As noted earlier, due to flexibility in production, the capacity of melting furnaces is less than the total capacity of casting lines. For example, KSC has a capacity of 260 thousand tons per month in melting furnaces and its capacity in billet, bloom, and slab casting is 120, 120 and 100 thousand tons per month, respectively. Since this is the dominant scenario among steel producers, smelting stage has been considered as the bottleneck of steel production process.

The main tactical objectives for modeling and analyzing this countrywide case are to plan for importing/exporting products, allocation of customers to the producers, iron ore suppliers selection for long term contracts and transportation planning.

To solve the proposed model by LINGO11.0, the required data were gathered in advance and were recorded in an Excel sheet subsequently. The data were transferred from Excel sheet to LINGO environment by using *OLE* function. The Branch and Bound (B-and-B) solver was applied to solve the model and the *Dept First* strategy was chosen for node selection. After solving the model by LINGO11.0 some noteworthy results are obtained. Fig. 2 demonstrates production plan for three kinds of products at 5 time periods in the future. As can be seen in this figure, total production volume of billet by KSC and ESC at the first time period is 215 thousand tons. Since, total inside demands for billet is 190 thousand tons; 25 thousand tons (equivalent to 11.6 percent of domestic production) of this product should be exported by KSC to satisfy the constraint of minimum export volume. Instead, total inside demands for bloom is 205 thousand tons at the first time period, whereas total domestic steel production volume is 195 thousand tons. Thus, it is necessary to import 10 thousand tons (equivalent to 4.9 percent of total inside demands) to satisfy demands of this product and the constraint of maximum import volume. According to output of the model, National Industrial Steel Group Co. should be supplied which a portion of its required bloom at the first time period by importing this product.

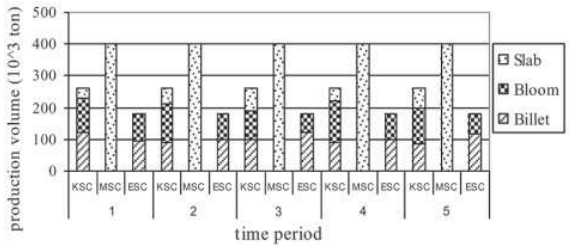

Fig.2. Planned production volume for three kinds of products.

Fig. 3 shows the assignment of consumers to the billet's producers at the first time period. Based on this figure, total demands of inside consumers for billet are supplied by the domestic production. As an example, the required billet for ESC is supplied by itself, whereas National Industrial Steel Group Co. provides its required billet by purchasing 30 thousand tons from KSC. In general, the aforementioned results are obtained based on import/export policies, producers' capacities and transportation costs between producers and customers.

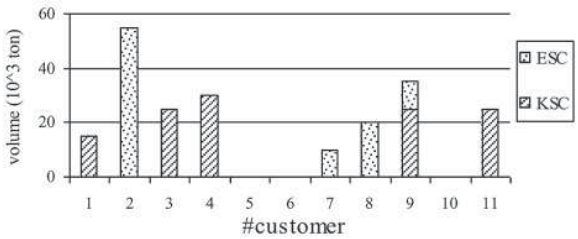

Fig.3. Proposed plan for allocating customers to billet's producers in Iran SSC.

5. Conclusion and future research

In this paper, we have proposed a general innovative model for multi-period, multi-commodity production and transportation planning problem in SSC management. Our approach can be used both to design new networks and to improve existing networks. The main contributions of our work are to consider intra-layer product flows, blending problem and modeling a real case in steel industry. Moreover, determination of production levels and efficient allocation of customers to the producers are also taken into our consideration. In a practical application, Iran National Steel Co. can apply the proposed model to prepare production planning for steel producers and exert its import/export policies to reduce total costs in Iran SSC at a multi-period planning horizon.

We have assumed that the admissible ranges of CCs in all producers have been defined prior to model design empirically. So, in order to design a more realistic model, a case can be considered in which these ranges are unavailable. The essential work in this case is investigation of the influence of CCs on process costs with statistical tools like regression models or design of experiments in advance; and subsequently, optimizing the total costs consist of steel production process costs and supply iron ore costs (e.g., purchase and transportation costs) by designing and solving a multi objective model.

In this paper, it was also assumed that there are some steel producers whose capacities are expanded proportional to the deterministic demands. But, locating new steel producers has not been considered in the problem. So, exerting an inventory and a facility

location with stochastic demands in the problem is an interesting new area for research.

References

[1] E.H. Sabri and B.M. Beamon: Omega, 28(2000), 581.
[2] S. Chopra and P. Meindl: Supply chain management: strategy, planning, and operation, (3rd edition), New Jersey: Prentice Hall, (2007), 42.
[3] M.T. Melo, S. Nickel and F. Saldanha da Gama: Eur. J. Oper. Res., 196(2009), 401.
[4] A. Atighechian, M. Bijari and H. Tarkesh: Comput. Oper. Res., 36(2009), 2450.
[5] S. Zanoni and L. Zavanella: Int. J. Prod.Econ., 93(2005), 197.
[6] B. Bilgen and I. Ozkarahan: Int. J. Prod.Econ., 107(2007), 555.
[7] L. Chiun-Ming and Hanif D. Sherali, C.M.Liu and H.D. Sherali, Omega, 28(2000), 433.
[8] M.L. Fisher: What is the right supply chain for your product, Harvard Business Review, March-April, (1997).