Modeling the Supply Chain in the Semi-Integrated Steel Industry: A Case Study in Colombia

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Zusammenfassung This paper presents an approach for modeling the supply chain in the semi-integrated steel industry. A case study is taken from a Colombian company. The production of this company is based on waste management: recycled iron and steel scrap. The supply chain is modeled using linear programming. The model looks for the minimization of total logistics (production and distribution) costs considering intermediate and final products. Input data and constraints concerning raw material suppliers, manufacturing plants, distribution centers and local sales and imports are considered. The model is intended to be used as a support tool for decision-making at a strategic and tactical decision levels. The strength of this contribution is that it gives some insights about the situation and the structure of the semi-steel industry (i.e., based on recycled steel waste) in Colombia by modeling the different costs for production and transportation.

1 Introduction

The society increasingly demands companies to take responsibility about the effects that their products and processes cause on the environment [11, 13, 15]. Therefore, in recent years the interest in environmental conservation and the (re-) use of resources have led to new approaches to production and logistics, among them, Reverse Logistics. Fleischmann et al. [5] presents a review about quantitative models

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for Reverse Logistics, including applications in distribution, inventories and study cases. Seeking to reduce the negative impact on the environment, several companies have been implementing successful reverse logistics processes of seeking the recovery of materials and products, and the link with traditional production models [5]. Some examples of such companies are IBM, HP or BMW [15].

For instance, Hafeez et al. [9] describe the analysis and modeling of a two-echelon steel industry supply chain that services the construction industry using an integrated system dynamics framework and performes simulation experiments. Using process mapping techniques, Potter et al. [14] study the evolution of a case study steel supply chain within the UK over the past decade. The changes that have occurred are identified and categorized and their impact on inventory, lead times and asset utilization are assessed. They propose that supply chains evolve from a traditional (uncoordinated, disparate, sub-optimal) to an integrated supply chain structure. The paper concludes that although the steel supply chain has evolved between 1990 and 2001 towards an integrated structure, there are currently constraints imposed by organizational boundaries. Zäpfel and Wasner [17] analyze the problem efficient warehouse management of in a real logistic centre of a steel supply chain (SC). Geyer et al. [7] present a detailed account of the SC for iron and steel in the UK, using material flow analysis. They show that the UK no longer has the capacity to recycle the scrap it collects and is increasingly relying on foreign economies to do so. We also observe that trade in iron and steel products and ferrous metal containing final goods has increased dramatically over the years, but remained relatively balanced. Today, one-half of UK's iron and steel production is exported, whereas one-half of the iron and steel entering the UK use phase comes from imported final goods. The efficiency with which the UK iron and steel industry transforms iron ore and scrap into iron and steel products has increased substantially. Chandra [3] studies a case of production scheduling for a steel SC by modeling SC workflows and capturing and organizing knowledge necessary for managing them. To model workflows, this author proposed a combination of two frameworks: (1) SC operation reference model for higher-level process and (2) process modeling tools, such as integrated definition (IDEF) and unified modeling language (UML), for the lower, application-level process model representation.

For workflow knowledge capturing and representation, this paper introduced two standards: situation calculus and SC markup language (SCML). The former is utilized for capturing process logic with mathematical expressions, and the latter for coding this logic with a computational language. The work of Spengler et al. [16] presents the development of sophisticated operations research models for two selected planning problems: recycling of industrial byproducts and dismantling and recycling of products at the end of their lifetime. To the best of our knowledge, no more papers have been published in literature analyzing the use of reverse logistics operations research-based techniques for the steel industry. The steel industry is a traditional heavy industry. Being a commodity product the price is elastic. This makes the various players in the SC "price takers"where the price is set a level that the market will bear [14]. Furthermore, the basic nature of the products means that differentiation is difficult to achieve. With the price of steel declining margins are tight making profitability on the basic products low. Therefore, companies in the SC are increasingly looking to provide extra value to their customers by improving customer service or providing additional services. Cost reduction is also mandatory for enterprises if they want to continue being in the marketplace. This paper aims to provide a formal methodology for decision-making in a semi-integrated steel SC. The modeling and design of distribution networks has been extensively studied in literature (see, for example, the works of [1, 4, 6, 8]). As our work, the work of Bielefeld [2] also focused on the steel industry presenting however a computer-based strategic planning system for the manufacturing process. We develop a tactical decision support model for the design of the supply and distribution network. The production process and hence the SC is based on recycling waste iron and steel ("recycled"vehicles at the end of their life-cycle) from the automotive industry. Taking a case study of one of the biggest companies in Colombia, this paper proposes a linear programming model that minimizes the overall logistic cost of the SC by defining the flow of products through the supply network. One of the aspects that allow us to study this industry's SC is that the production process in the semi-integrated steel industry is based on recycled scrap. The optimization of the SC is not only motivated by the traditional economic metrics, but also by the fact that improving the performance of this industry will lead to an improvement on the treatment of recycled steel. This paper is organized as follows. Section 2 presents a description of the steel industry in Colombia, including the production process and the organization of the SC under study. Section 3 is devoted to the detailed description of the mathematical model of the SC. The implementation of the model and the analysis of obtained results are presented in Section 4. The paper ends with Section 5 and Section 6 presenting some concluding remarks.

2 Production Process and the Supply Chain

Colombian steel manufacturers have experienced an important growth over the last years mainly due to the increase in building constructions in Bogotá, D.C., the capital of the country, and in investment in public infrastructure along the country [10]. During the first semester of 2008, this growth was about 0.9% of the total tons of steel manufactured in comparison with the same period in 2007. There are two main processes to obtain steel: integrated manufacturing (steel obtained from mines) and semi-integrated manufacturing (steel obtained from scrap). Choosing one of these two manufacturing processes depends on the structure of the marketplace, as well as on the availability of raw material. Steel manufacturing requires high investments in machinery and demands large production rates in order to reduce fixed costs. About 60% of world production is performed in integrated processes, about 33% of world production is done in electric furnaces (semi-integrated production) and the other 7% uses obsolete technology. In Colombia, 65% of the steel industry employs semi-integrated processes, using national and foreign iron and steel scrap. The scrap sources are mostly the urban and freight vehicles, while customers are construction, automotive and cement industries. Figure 1 illustrates a generic semi-integrated steel manufacturing process and the dismantling and recycling of scrapped products at the end of their life time. A schematic representation of the SC considered in this paper is presented in Figure 2. The SC is composed of three main echelons: scrap sources, steel manufacturer and steel stockholder/distributor. The end users source their materials from a steel stockholder/distributor who performs a break bulk role within the SC. The steel stockholders order in large quantities form the main producers and then sell the material in small quantities according to the customer requirements [12]. The steel stockholders are mainly located in the principal cities of the country. The steel suppliers can be classified as general producers who convert steel scrap into billets, which are then rolled into a variety of steel products. For the purpose of our research, some manufacturers were aggregated into conglomerates. These conglomerates are sets of facilities for each echelon in the chain of the semi-integrated steel sector that are group strategically to supply between them the necessary materials and equipment for their operations. Each conglomerate corresponds to a big main city of the country. Other manufacturers are not grouped into conglomerates and consist on independent plants. We also take into account the external entities that participate in the chain, especially in the third echelon. Foreign steel producers are also located in Brazil, Venezuela and Panama. The primary echelon in our SC is the scrap suppliers. National scrap sources are grouped into a conglomerate, representing nearly 90% of the scrap market. Foreign scrap sources include Venezuela, Brazil, Panama and Ecuador.

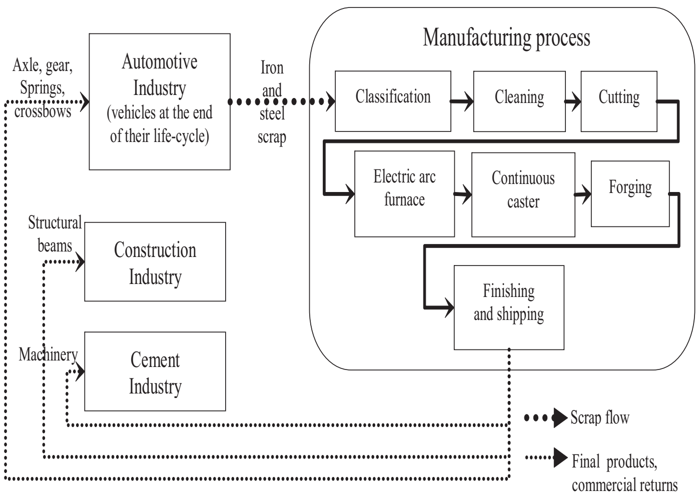

Abb. 1 Schematic Representation of the Flows in Semi-Integrated Steel Industry Supply Chain.

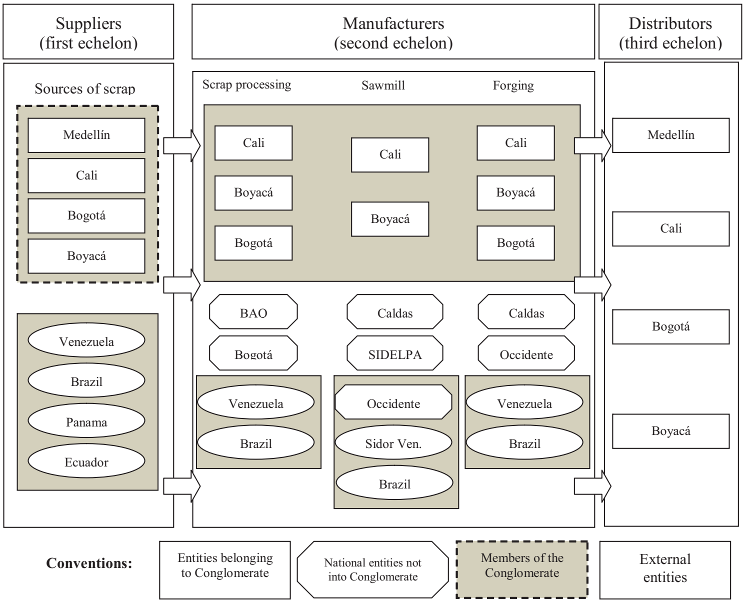

Abb. 2 Configuration of the semi-integrated steel supply chain.

3 Mathematical Model

The proposed mathematical model base on linear programming considers the problem of the physical distribution of intermediate and finished products. The model seeks the minimization of the total logistics costs. These costs include both product manufacturing and transportation, supporting mid-term decision-making processes. The model is based on the following hypothesis:

- We only consider national distribution. Hence, neither product exportation nor such associated costs are taken into account. The focus will be on minimizing production and distribution costs in Colombia.
- The processes of scarp processing, sawmill, and forging are considered to be completely independent from each other.
- Transportation is always performed by tier parties, not by companies themselves. There is unlimited transportation capacity for the mathematical model.
- There is unlimited storage capacity for raw material and finished products at each production unit.
- Forging plants deliver finished products only to distribution centers. No product flows exist neither between manufacturing plants nor from manufacturing plants and clients.

To describe the model, the following notation is needed.

Indexes

t: Each month of the production horizon,
i: Source of scrap,
j: Scrap processing unit,
k: Sawmill,
l: Forging plant,
p: Product,
c: Distribution center

Sets

Products

PA_p: Types of wire,
PA_b: Types of bars,

Sources of scrap

FCS_i: National,
FCE_i: From outside Colombia,

Scrap processing plants

PPC_j: Plants belong to the conglomerate,
PPW_j: From outside Colombia,
PPN_j: National plants not belonging to the conglomerate

Sawmill plant

PPA_k: Belonging to the conglomerate,
PAW_k: From outside Colombia,
PAN_k: National plants not belonging to the conglomerate

Forging plants

PPL_l: Belonging to the conglomerate,
PPW_l: From outside Colombia,
PLN_l: National plants not belonging to the conglomerate

Parameters

- $FNJ_{i,j}$: Transportation cost between scrap source i and scrap processing plant j (\$/Ton),
- $FNA_{j,k}$: Transportation cost between the processed scrap supplier j and sawmill k (\$/Ton),
- $FNL_{k,l}$: Transportation cost between sawmill k and forging plant l (\$/Ton),
- $FNL_{l,c}$: Transportation cost between forging plant l and distributor c (\$/Ton),
- CPC_i: Production capacity of scrap source i (Ton)
- CPP_j: Scrap processing capacity of scrap processing plant j belong to the conglomerate (Ton),

- CPA_k: Production capacity of intermediate product in sawmill k belonging to the conglomerate (Ton),
- CPT_l: Production capacity of finished products of forging plant l belonging to the conglomerate (Ton),
- CPD_j: Maximum storage capacity of raw scrap in scrap processing plant j (Ton),
- CPW_j: Maximum storage capacity of processed scrap in scrap processing j (Ton),
- CQA_k: Maximum storage capacity of processed scrap in sawmill k (Ton),
- CQW_k: Maximum storage capacity of intermediate products at sawmill k (Ton),
- CQL_l: Maximum storage capacity of intermediate products in forging plant l (Ton),
- $CAL_{l,p}$: Maximum storage capacity of wire l in forging plant p (Ton),
- $CBB_{l,p}$: Maximum storage capacity of bars of type l in forging plant p (Ton),
- $CEB_{c,p}$: Maximum storage capacity of bars of type c in distribution center p (Ton),
- $CAP_{c,p}$: Maximum storage capacity of wire c in distribution center p (Ton),
- $DEMAND_{p,c,t}$: Demand of product p in distribution zone c at period t,
- CIP: Yield of intermediate product to produce 1 ton of finished product,
- CMP: Yield of raw scrap to be converted in processed scrap,
- $CWPS$: Yield of raw scrap to be converted in processed scrap,
- CVA_j: Cost of processing 1 ton of raw scrap in scrap processing plant j ($/Ton),
- CVB_k: Cost of processing 1 ton of processed scrap in sawmill k ($/Ton),
- CVC_l: Cost of processing 1 ton of finished product in forging plant l ($/Ton),
- PAS_j: Price of national raw scrap j ($/Ton),
- PCX_i: Price of foreign raw scrap i ($/Ton),
- PPF_j: Price of buying national processing scrap outside the conglomerate j ($/Ton),
- PPX_j: Price of buying foreign processing scrap j ($/Ton),
- PQF_k: Price of buying national intermediate product outside the conglomerate,
- PQX_k: Price of buying foreign intermediate product,
- $PRICE_{l,p}$: Price of buying finished product p to both national and foreign forging plant outside the conglomerate and foreign,
- $IPT_{p,c}$: Storage cost of product p in distribution center c,
- $IPP_{p,l}$: Storage cost of product p in forging plant l,
- IQN_l: Storage cost of intermediate product in forging plant l,
- ICA_k: Storage cost of scrap in sawmill k,
- IQA_k: Storage cost of intermediate product in sawmill k,
- ICZ_j: Storage cost of raw scrap in scrap processer j,
- ICX_j: Storage cost of processed scrap in scrap processor j.

Decision Variables

- $CXC_{j,t}$: Quantity of raw scrap to be processed in scrap processor belonging to the conglomerate (Ton),
- $CCF_{k,t}$: Quantity of processed scrap to be processed in sawmill k (Ton),
- $CQP_{l,p,t}$: Quantity of intermediate product to be processed in forging plant l belonging to the conglomerate per product p (Ton),

- $CCC_{i,j,t}$: Quantity of raw scrap to request to a national source (Ton),
- $CCE_{i,j,t}$: Quantity of scrap to buy a foreign scrap source (Ton),
- $CCJ_{j,k,t}$: Quantity of processed scrap to distribute from scrap processor j belonging to the conglomerate to sawmill k belonging to the conglomerate (Ton),
- $CCK_{j,k,t}$: Quantity of processed scrap to buy to a national scrap processor not belonging to the conglomerate for sawmill k in the conglomerate (Ton),
- $CCL_{j,k,t}$: Quantity of processed scrap to buy to foreign scrap processor for sawmill k belonging to the conglomerate (Ton),
- $CCA_{k,l,t}$: Quantity of intermediate product to distribute from sawmill k of conglomerate to forging l belonging to conglomerate (Ton),
- $CCQ_{k,l,t}$: Quantity of intermediate products to buy from a foreign sawmill to a forging plant belonging to the conglomerate (Ton),
- $CCZ_{k,l,t}$: Quantity of intermediate products to buy from a national sawmill not belonging to the conglomerate for a forging plant l of the conglomerate (Ton),
- $CCX_{p,l,c,t}$: Quantity of finished product p to buy to a foreign forging plant for distribution center c (Ton),
- $CCY_{p,l,c,t}$: Quantity of finished product p to buy to a national forging plant outside the conglomerate for distribution center c (Ton),
- $CLC_{p,l,c,t}$: Quantity of finished product p for distribution from forging plant l to distribution center c (Ton),
- $IAC_{p,c,t}$: Inventory level of product p in distribution center c,
- $IAB_{l,p,t}$: Inventory level of product p in forging plant l,
- $IUP_{l,t}$: Inventory level of intermediate product p in forging plant,
- $IQL_{k,t}$: Inventory level of intermediate product in sawmill k,
- $ICF_{k,t}$: Inventory level of scrap processed in sawmill k,
- $ICO_{j,t}$: Inventory level of scrap processed in scrap processor j,
- $ICP_{j,t}$: Inventory level of raw scrap in Scrap processor j.

4 Objective Function

As explained before, the objective function seeks to minimize the total cost of operations, including raw material purchasing, manufacturing costs, inventory holding costs, transportation and distribution. Equation 1 presents the objective function.

$$\begin{aligned} \min Z = & \text{Raw material aquisition} + \text{Transportation cost} \\ & + \text{Inventory holding cost} + \text{Production cost} \end{aligned} \tag{1}$$

Each part of the total cost is given below.

Raw material acquisition (RMAC):

$$RMAC = \sum_{i\in FCS}\sum_{j\in PPC}\sum_{t=1}^{12} CCC_{i,j,t}PAS_i + \sum_{i\in FCE}\sum_{j\in PPC}\sum_{t=1}^{12} CCE_{i,j,t}PCX_i + \sum_{j\in PPN}\sum_{k\in PPA}\sum_{t=1}^{12} CCK_{j,k,t}PPF_j + \sum_{j\in PPW}\sum_{k\in PPA}\sum_{t=1}^{12} CCL_{j,k,t}PPX_j + \sum_{k\in PAN}\sum_{l\in PPL}\sum_{t=1}^{12} CCZ_{k,l,t}PQF_k + \sum_{k\in PAW}\sum_{l\in PPL}\sum_{t=1}^{12} CCQ_{k,l,t}PQX_k + \sum_{p}\sum_{l\in PLN}\sum_{c}\sum_{t=1}^{12} CCY_{p,l,c,t}PRICE_{l,p} + \sum_{p}\sum_{l\in PLW}\sum_{t=1}^{12} CCX_{p,l,c,t}PRICE_{l,p} \quad (2)$$

Transportation costs (TC):

$$TC = \sum_{i\in FCS}\sum_{j\in PPC}\sum_{t=1}^{12} FNJ_{i,j}CCC_{i,j,t} + \sum_{i\in FCE}\sum_{j\in PPC}\sum_{t=1}^{12} FNJ_{i,j}CCE_{i,j,t} + \sum_{j\in PPC}\sum_{k\in PPA}\sum_{t=1}^{12} FNA_{j,k}CCJ_{j,k,t} + \sum_{j\in PPN}\sum_{k\in PPA}\sum_{t=1}^{12} FNA_{j,k}CCK_{j,k,t} + \sum_{j\in PPW}\sum_{k\in PPA}\sum_{t=1}^{12} FNA_{j,k}CCL_{j,k,t} + \sum_{l\in PPL}\sum_{k\in PPA}\sum_{t=1}^{12} FNL_{k,l}CCA_{k,l,t} + \sum_{l\in PPL}\sum_{k\in PAN}\sum_{t=1}^{12} FNL_{k,l}CCZ_{k,l,t} + \sum_{l\in PPL}\sum_{k\in PPA}\sum_{t=1}^{12} FNL_{k,l}CCQ_{k,l,t} + \sum_{l\in PPL}\sum_{c}\sum_{p}\sum_{t=1}^{12} FNC_{l,c}CLC_{p,l,c,t} + \sum_{l\in PLN}\sum_{c}\sum_{p}\sum_{t=1}^{12} FNC_{l,c}CCY_{p,l,c,t} + \sum_{l\in PLW}\sum_{c}\sum_{p}\sum_{t=1}^{12} FNC_{l,c}CCX_{p,l,c,t} \quad (3)$$

Inventory holding costs (IHC):

$$IHC = \sum_{c}\sum_{p}\sum_{t=1}^{12} IAC_{p,c,t}IPT_{p,c} + \sum_{l\in PPL}\sum_{p}\sum_{t=1}^{12} IAB_{l,p,t}IPP_{p,l} + \sum_{l\in PPL}\sum_{t=1}^{12} IUP_{l,t}IQN_t + \sum_{k\in PPA}\sum_{t=1}^{12} IQL_{k,t}IQA_k + \sum_{k\in PAA}\sum_{t=1}^{12} ICF_{k,t}ICA_k + \sum_{j\in PPC}\sum_{t=1}^{12} ICO_{j,t}ICX_j + \sum_{l\in PPL}\sum_{t=1}^{12} CQP_{l,t}CVC_l + \sum_{j\in PPC}\sum_{t=1}^{12} CXC_{j,t}CVA_j + \sum_{k\in PPA}\sum_{t=1}^{12} CCF_{k,t}CVB_k + \sum_{j\in PPC}\sum_{t=1}^{12} ICP_{j,t}ICZ_j \quad (4)$$

Production costs (PC):

$$PC = \sum_{l \in PPL} \sum_{t=1}^{12} CQP_{l,t} CVC_l + \sum_{j \in PPC} \sum_{t=1}^{12} CXC_{j,t} CVA_j + \sum_{k \in PPA} \sum_{t=1}^{12} CCF_{k,t} CVB_k \quad (5)$$

Constraints:
Constraints (6) and (7) are associated to the inventory of scrap material in processing plants. Constraints (8) and (9) concern the inventory of processed scrap and intermediate products in sawmill. The inventory of intermediate and finished products in forging plants is given by constraints (10) and (11). Constraint (12) represents the inventory of finished products distribution centers.

$$ICP_{j,t} = ICP_{j,t-1} + \sum_{i \in FCS} CCC_{i,j,t} + \sum_{i \in FCE} CCE_{i,j,t} - CXC_{j,t} \qquad \forall t, \forall j \in PPC \quad (6)$$

$$ICO_{j,t} = ICO_{j,t-1} + CXC_{j,t} CWP - \sum_{k \in PPA} CCJ_{j,kt} \qquad \forall t, \forall j \in PPC \quad (7)$$

$$ICF_{k,t} = ICF_{k,t-1} + \sum_{j \in PPC} CCJ_{j,k,t} + \sum_{j \in PPN} CCK_{j,k,t} \quad (8)$$

$$+ \sum_{j \in PPW} CCL_{j,k,t} - CCF_{k,t} \qquad \forall t, \forall k \in PPA \quad (9)$$

$$IQL_{k,t} = IQL_{k,t-1} + CCF_{k,t} CMP - \sum_{l \in PPL} CCA_{k,l,t} \qquad \forall t, \forall k \in PPA$$

$$IUP_{l,t} = IUP_{l,t-1} + \sum_{k \in PPA} CCA_{k,l,t} + \sum_{k \in PAN} CCZ_{k,l,t} + \sum_{k \in PAW} CCQ_{k,l,t} - \sum_{p} CQP_{l,p,t} \qquad \forall t, \forall l \in PPL \quad (10)$$

$$IAB_{l,p,t} = IAB_{l,p,t-1} + CQP_{l,p,t} CIP - \sum_{c} CLC_{p,l,c,t} \qquad \forall t, \forall l \in PPL \quad (11)$$

$$IAC_{p,c,t} = IAC_{p,c,t-1} + \sum_{l \in PPL} CLC_{p,l,c,t} + \sum_{l \in PLW} CCX_{p,l,c,t} + \sum_{l \in PLN} -DEMAND_{p,c,t} \qquad \forall p, c, t \quad (12)$$

Capacity of scrap processors is expressed by Constraints (13). Constraints (14), (15), (16), (17), (18) and (19) represent the production and storage capacity in sawmills. Constraints (20), (21), (22) and (23) represent production and storage capacity in forging plants. Storage capacity in distribution centers is given by Constraints (24) and (25).

$$\sum_{j\in PPC} CCC_{i,j,t} \leqslant CPC_i \qquad \forall t,i \tag{13}$$

$$CXC_{j,t} \leqslant CPC_j \qquad \forall t,\forall j\in PPC \tag{14}$$

$$ICO_{j,t} \leqslant CPW_j \qquad \forall t,\forall j\in PPC \tag{15}$$

$$ICP_{j,t} \leqslant CPD_j \qquad \forall t,\forall j\in PPC \tag{16}$$

$$CCF_{k,t} \leqslant CPA_k \qquad \forall t,\forall k\in PPA \tag{17}$$

$$ICF_{k,t} \leqslant CQA_k \qquad \forall t,\forall k\in PPA \tag{18}$$

$$IQL_{k,t} \leqslant CQW_k \qquad \forall t,\forall k\in PPA \tag{19}$$

$$\sum_p CQP_{p,l,t}CIP \leqslant CPT_l \qquad \forall t,\forall l\in PPL \tag{20}$$

$$IUP_{l,t} \leqslant COL_l \qquad \forall t,\forall l\in PPL \tag{21}$$

$$IAB_{l,p,t} \leqslant CBB_l \qquad \forall l\in PPL,\forall p\in PB \tag{22}$$

$$IAB_{l,p,t} \leqslant CAL_l \qquad \forall t,\forall l\in PPL,\forall p\in PA \tag{23}$$

$$IAC_{c,p,t} \leqslant CAP_{c,p} \qquad \forall t,\forall c,\forall p\in PAP \tag{24}$$

$$IAC_{c,p,t} \leqslant CEP_{c,p} \qquad \forall t,\forall c,\forall p\in PBP \tag{25}$$

Constraints (26), (27) and (28) express the selling capacity of foreign suppliers while their maximum delivery capacity is expressed in constraints (29), (30), (31) and (32). Right sides in such equations correspond to capacity parameters given by national of foreign total capacity. Finally, demand coverage is given by constraint (33).

$$CCK_{PPN,PPA,t} \leqslant CAPNAL \qquad \forall PPN,\forall PPA,\forall t \tag{26}$$

$$CCZ_{PAN,PPL,t} \leqslant CAPNAL \qquad \forall PAN,\forall PPL,\forall t \tag{27}$$

$$CCY_{p,PLN,C,t} \leqslant CAPNAL \qquad \forall p,\forall PLN,\forall c,\forall t \tag{28}$$

$$CCE_{FCE,PPCL,t} \leqslant CAPINT \qquad \forall FCE,\forall PPC,\forall t \tag{29}$$

$$CCL_{PPW,PPA,t} \leqslant CAPINT \qquad \forall PPW,\forall PPA,\forall t \tag{30}$$

$$CCQ_{PAW,PPL,t} \leqslant CAPINT \qquad \forall PAW,\forall PPL,\forall t \tag{31}$$

$$CCX_{p,PLW,c,t} \leqslant CAPINT \qquad \forall p,\forall PLW,\forall c,\forall t \tag{32}$$

$$DEMAND_{t,p,c} \leqslant \sum_{l\in PPL} CLC_{p,l,c,t} + \sum_{l\in PLW} CCX_{p,l,c,t} + \sum_{l\in PPL} CCY_{p,l,c,t} \qquad \forall t,\forall c \tag{33}$$

All decision variables are non-negative (34)

5 Model Implementation

The mathematical model was implemented using the General Algebraic Modeling System (GAMS) through CPLEX® solver and run on a PC Pentium 4 with 2.0 GB of RAM. For the case study presented previously, the model consisted on a total of 11945 constraints and 13289 decision variables. After running the model, resulting values of decision variables are obtained for each production period. As shown in Figure 3, product flow between members of each echelon is giving the quantity of products transported is obtained. Raw material is bought from scrap sources belonging to the Conglomerate, mainly the site located in Boyaca. This site supplies 52.6% of the total raw scrap. The site located in Bogotá supplies 23.3%, while the site in Cali supplies 24.1% of the total raw scrap. Scrap processing is performed by the three entities belonging to the Conglomerate. The site located in Cali processes 23.9% of the scrap, the site of Boyaca processes 52.8% and the site of Bogotá processes 23.3%. Overall, a total of 250.500 tons of scrap is processed during the production period. An interesting result is that the production volume remains constant over each month of the whole production period. Foreign entities, those not belonging to the Conglomerate, do not process scrap. Because of transportation costs, each scrap processor belonging to the Conglomerate supplies in processed scrap the sawmill units located in the same region. Besides, in some production months, there is some product flow of processed scrap between national entities not belonging to the Conglomerate and sawmill units. This is principally due to the high demand of the corresponding month. From the total processed scrap, 74.7% is obtained from plants belonging to Conglomerate, while 25.3% is obtained from national processor not belonging to the Conglomerate. Concerning the manufacturing of intermediate products, sawmill plants located in Cali and Boyaca work at their maximum production capacity. They become the bottleneck of the whole SC. Sawmill in Boyaca processes 42% of scrap while sawmill in Cali processes the other 58%. Forging plants works during all production periods. The plant in Boyaca is observed to be the one with the highest quantity to produce. Both plants in Cali and in Boyaca are constrained to work uniformly in every month at their maximum production capacity. The forging plant in Bogotá has the highest variability of manufactured quantity during the whole production period. This result is not surprising since there is no sawmill in Bogotá. Hence, all its incoming material must be supplied by other units in the Conglomerate or by foreign entities. Also, this sawmill allows the system to react when demand increases; its capacity is used at 75%.

The higher manufacturing flows are generated between distribution centers located in the same region of the forging plant. This is due to high transportation costs between units located in different regions. In the results it is to notice that in all production periods, a transportation flow is always present between the forging plant in Boyaca and the distribution center in Bogotá. This is mainly due to the low production capacity of the forging plant in Bogotá, compared with the actual demand. Concerning foreign units, only those located in Venezuela are found in the solutions simply because of low transportation costs. A sensitivity analysis on some parameters of the model was also performed. Results show that production capacity

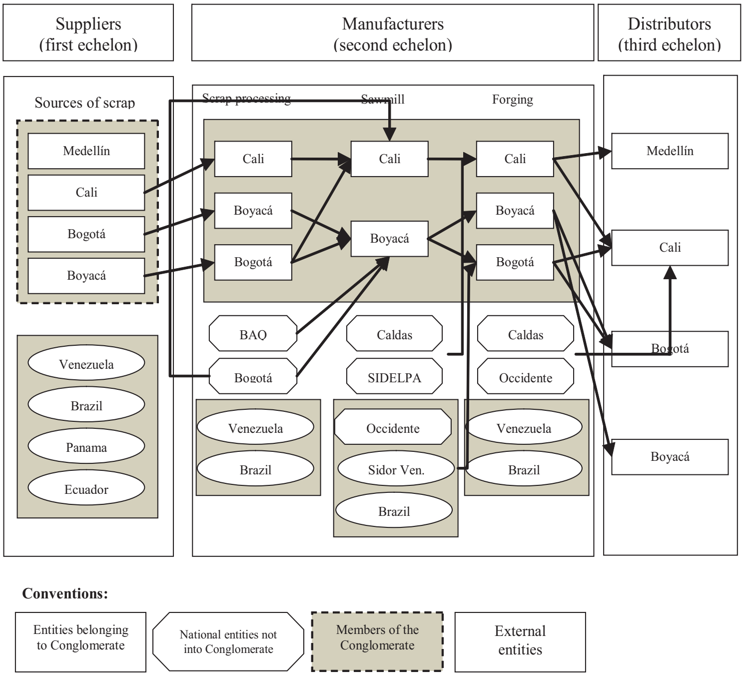

Abb. 3 Example of results for a given month of production flows after model implementation.

in processing plants, forging plants and sawmill units must be increased as shown in Table 1. This will allow an important decrease in global costs over the whole production horizon. Performing a sensitivity analysis of the terms on the right side, it is concluded that the production capacity at the processing plants, rolling mills and steel must be increased. For the particular case of the processing plant located in Boyacá is noted that a production capacity between 7.875 and 11.000 tons will produce an increase in the objective function, from 11.000 to 12.000 tons will produce a decrease and a quantity of 12.000 tons will not make any change in the objective function, so in conclusion it's best to increase the plant capacity to until 12.000 tons in case of being extended with a cost study to justify this change.

Tabelle 1 Increase in production capacity.

Unit	Increase in capacity (Ton)
Processing unit – Boyacá	4.13
Sawmill – Boyacá	80
Forging plant – Cali	70

6 Concluding Remarks

The concern for both the environment and the rational use of resources has led the enterprises to improve their processes, including recycling and waste management operations. These processes are linked to the traditional logistics and therefore have been included in the modeling and optimization of SCs. Enterprises are today extensively implementing optimization procedures, including mathematical modeling and heuristics, for the analysis and design of their SCs. Such optimizations allow them to improve their performance in the competitive marketplace. This paper focused on the analysis of the semi-integrated SC industry. Little has been done in the literature for the Latin-American case, at least to the best of our knowledge. This paper analyzed the problem for a semi-integrated steel manufacturing company located in Colombia and having suppliers and clients within the country and also in the north of South America. A mathematical model, based on linear programming, was proposed in order to design the supply/distribution network so as to minimize the global cost. The model considered that each stage of the manufacturing process is performed in different sites, while it is commonly found in Colombian steel manufacturer that all three process are being performed in the same site. Our model considered constraints associated at this particular scenario. For further research it could be interesting if the impacts in prices of international trade agreements (e.g., Andean Community) are considered in order to give more flexibility to the different supply and distribution networks.

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