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Strategic decision-making at a steel manufacturer assisted by linear programming

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Abstract

We show how a linear programming model can assist strategic decision-making, understanding it either within the neoclassical theory of the firm, the industrial organization theory, the resource-based view, or other approaches of strategic management. The model relays on Activity Based Costing (ABC) for calculating unit product cost, and on dynamic Activity Based Management (ABM) for assessing the feasibility of prospective production plans. It was implemented 4 years ago in a Chilean integrated steel manufacturer, and it is currently being used to optimize its business plan.

Keywords: Cost; Feasibility; ABC; Planning; Steel

1. Introduction

In order to survive, manufacturers must strategically plan their product mix, sales prices, volumes, inventory levels, production capacity, and so on. This requires the assessment of two critical issues: the feasibility of production plans and the unit costs of products. If a company lacks a feasible estimation model, it may commit itself to an unreasonably high workload, which will cause the company to default on its obligations and lose the goodwill of its customers (Spearman and Zhang, 1999). Conversely, the company could adopt a more conservative policy, constraining itself to lower production volumes and artificially reducing its profits. By the same token, the company must have a good forecast of total costs as a function of the production plan in order to maximize its revenue. Otherwise, lucrative products may be exchanged for unprofitable ones, affecting the company's competitiveness.

The purpose of this paper is to show how a mathematical programming model can assist in strategic decision-making by forecasting the results of possible actions and providing quantitative feedback to managers. The model is based on *Activity Based Management* (ABM), an approach that conceptualizes production systems as a network of work centers that add value to a flow-in-process, constrained by the available resources. We applied this methodology at the Chilean integrated steel manufacturer *Compañía Siderúrgica Huachipato* (Huachipato). The steel industry has received a great deal of attention in the field of strategy and operations research, because of the heavy pressure from worldwide competition (Denton et al., 2003).

In the steel industry, a number of studies have reported how to minimize cost, maximize profit or maximize capacity utilization, with a linear programming model (Sinha et al., 1995; Chen and Wang, 1997). However, little effort has been devoted to explicit the connection between the mathematical program and strategic decision-making. Most likely, this is due to a weak understanding of the relationship between operational and financial indices (Melnyk et al., 2004).

Our contribution to linking mathematical programming and strategy research is two-fold. First, in Sections 2 and 3 we propose a dynamic activity-based model for calculating unit cost and for assessing the feasibility of production plans for a general production operation. This accounts for one of the five potential areas for future research in the steel industry proposed by Dutta and Fourer (2001): "Simultaneous optimization of

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product-mix, inventory, and transportation problems over multiple periods." In Section 4, we apply this model in a Chilean integrated steel manufacturer. A second contribution, presented in Section 5, is to explain how the model can assist managers in making better strategic decisions. Finally, in Section 6 we present our conclusions.

2. Activity Based Costing

Activity Based Costing (ABC) assigns resources to activities and activities to cost objects based on their use. This allows obtaining specific product revenue in the steel industry (Degraeve and Roodhooft, 1998). We apply ABC to a system that manufactures a set P^{F} of final products from a collection P^{M} of raw materials through the set A of activities that generate a set P^{I} of intermediate products, consuming a set R of resources. Define $\vec{x}^t = \left\{x_p^t\right\}$ as the flow at time t of product $p \in P = (P^{\mathrm{F}} \cup P^{\mathrm{I}} \cup P^{\mathrm{M}})$, and C^t as the total cost at time t, which is regarded to be a function of $\vec{x}^t$, so $C^t = c(\vec{x}^t)$. Assuming that historical records exist until the present time T, both production $\overrightarrow{X^t} = \left\{X_p^t\right\}$ and total cost C^t are known at $t=1,\ldots,T$. We consider the linear cost function $c(\vec{x}^t) = f + \Sigma_p c_p \cdot x_p^t$, where f is the fixed cost and c_p is the unit variable cost of each product $p \in P$ (Maher and Marais, 1998).

Define ${}^{\mathrm{D}}c_p$ and ${}^{\mathrm{I}}c_p$ as the *direct* and *indirect* component of the unit variable cost of product p, so $c_p = {}^{\mathrm{D}}c_p + {}^{\mathrm{I}}c_p$. The direct cost ${}^{\mathrm{D}}c_p$ due to raw materials is estimated by defining the parameter ${}^{q}Y_p$ as the amount of product q required by each unit of product p. Assuming that the price ${}^{m}\pi$ of raw material m is known, the direct cost of a product p due to raw materials is ${}^{\mathrm{D}}c_p = \sum_{m \in P^{\mathrm{M}}} {}^{m}\pi \cdot {}^{m}Y_p$. Traditional accounting methods usually estimate ${}^{\mathrm{I}}c_p$ by prorating indirect cost according to the product weight, price or other criteria that, because of their simplicity, usually generate biased conclusions. ABC follows a different approach. It forces the firm to uncouple the indirect cost ${}^{\mathrm{I}}C^t$ at time t into parameters ${}^{r}C^t$ that measure the cost of resource r at time t, and then into parameters ${}^{r}_{a}C^t$ that report the cost of resource r used by activity a at time t. This cost is then assigned to products by the variable ${}^{r}_{a}c_p$ that measures how much resource r is used by activity a when it processes product p. Defining ${}^{r}_{a}f$ as a fixed cost component, both ${}^{r}_{a}c_p$ and ${}^{r}_{a}f$ are obtained by statistical inference.

3. Feasibility according to activity based management

A number of publications have modeled feasibility by mapping business processes into activities subject to resource availability constraints that restrict throughput (Gupta, 2001; Singer et al., 2005). We apply ABM to a plant whose physical flows visit a set of stations $S = M \cup W \cup \{*\}$, where M is the set of manufacturing work centers, W is the set of warehouses and "*" represents the exterior of the system. Define variable ${}_{a,b}x_p^t$ as the flow of product $p \in P$ that is transferred during time period t from station a to station b with a, $b \in S$ and $a \neq b$, and define variable ${}_{w}y_p^t$ as the inventory of product p in station $w \in W$ at the end of time period t. Any production plan $\{{}_{a,b}x_p^t\}$ must comply with the following families of linear constraints.

- Maximum demand (D_p is the upper bound of sales): $\Sigma_{s \in S}\, {}_{s,*}x_p^t \leq D_p \qquad \forall p \in P^F$.
- Maximum throughput (${}^{r}V^t$ is the maximum availability of resource r at time t, ${}_{a,b}^{\,r}U_p^t$ indicates how much resource r product p consumes from station a to b at time t):$\Sigma_{p \in P} \left(\Sigma_{a,b \in S}\, {}_{a,b}^{\,r}U_p^t \cdot {}_{a,b}x_p^t\right) \leq {}^{r}V^t \qquad \forall r \in R$.
- Recipe constraint: $\Sigma_{s \in S}\, {}_{s,m}x_q^t \geq {}^{q}Y_p \cdot \Sigma_{s \in S}\, {}_{m,s}x_p^t \qquad \forall m \in M$, $\forall p,\, q \in P$.
- Inventory equation: for every $p \in P$ and $w \in W$ such that product p visits warehouse w, $-\,{}_{w}y_p^t + {}_{w}y_p^{t-1} + \Sigma_{s \in S}\, {}_{s,w}x_p^t - \Sigma_{s \in S}\, {}_{w,s}x_p^t = 0 \qquad \forall w \in W, \forall p \in P$.
- Maximum inventory (${}_{w}M$ is warehouse capacity): $\Sigma_{p \in P}\, {}_{w}y_p^t \leq {}_{w}M \qquad \forall w \in W$.
- Non-negativity: ${}_{a,b}x_p^t \geq 0$; ${}_{w}y_p^t \geq 0$ $\forall_p \in P\ \forall\, a,\, b \in S$ and $a \neq b\ \forall\ w \in W$.

4. Description of the steel plant and the system

The Huachipato plant produces more than 1 million metric tons of crude steel a year. It makes more than 40 different types of products, whose final prices can reach $900 per ton. Its ABM characterization is depicted by Fig. 1. The dashed lines show the centers of responsibility, which manage independent accounts of indirect cost. The process consists of four main stages: iron-making, steel-making, primary rolling, and finishing rolling (Dutta and Fourer, 2001). Our model classifies the different types of raw materials, intermediate products, and final products into categories, defining sets P^{M}, P^{I} and P^{F} to have 9, 63, and 40 categories, respectively.

The activity-based framework of Section 3 allows modeling the capacity balance, the material balance, the product-dependent yield, and electrical energy balance. As the steel industry is capital intensive, we assume that the only restrictive resource is equipment availability. The availability ${}^{r}V^t$ is obtained from an operational factor that depends on both preventative and corrective maintenance. The utilization parameter ${}^{r}_{p}U_{a,b}^{\,t}$ depends on the machinery's throughput. Recipe parameters ${}^{q}Y_p$ are taken from chemical formulae and historical production yields. The optimization model was implemented in a Microsoft Excel spreadsheet using a Frontline System solver. It has 356 variables and 876 constraints including non-negativity.

5. Strategic decision-making at the steel plant

An extensive body of literature has attempted to comprehend the relationships between the manufacturing strategy and the competitive advantage of the firm (Schlie and Goldhar, 1995), as well as between operational and financial performance indices (Melnyk et al., 2004). However, the link between manufacturing optimization methods and strategic decision-making has been less explicit. Below we intend to bridge this gap in the context of an activity-based optimization system.