Term Project Assignment: Analysis of Aluminum Production

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Abstract

The production process of aluminum is reviewed in this paper. Through research into production processes and various factors that go into creating aluminum, the methodology used to reduce costs and maximize profits is linear programming. The results showed that each raw material should be purchased depending on the cost during a specific period rather than purchasing throughout the year or all at once. Furthermore, the storage is dependent on the consumption when a certain amount of production is required. In this case, one metric ton of aluminum requires a specific amount of each material.

Introduction

The production process for metals can be costly and complex. When looking specifically at a metal like aluminum, its resistance to corrosion, light weight, high strength, and recyclability has made it an important part of human lifestyle. However, recent shortages, in alumina supply, increasing energy costs, and industry consolidation have forced aluminum producers to develop new methods for efficiency while remaining competitive (Thermo Scientific n.d.). This research is conducted to understand how efficiency is built when it comes to producing aluminum by a real company when it is dealing with various raw materials, costs, and storage.

A mathematical model can be developed for a production process to help managers optimize decision making and maximize profits. When building this model, however, there are several questions that need to be answered. One of the key research questions for the production process is not only which raw materials should be used, but also how much quantity should be bought during throughout a time that is broken up into periods. Another essential part of the research is to question how much initial storage and maximum storage exists. This leads to the question of how much production there should be when considering the cost of making, demand, supply, and sell price (Farkas et al. 1993).

A factory must improve its production process to maximize its profits based on the market value of materials (Farkas et al. 1993). With that in mind, the general nature of the problem includes multiple factors that are broken down further into multiple variables. In this case, each raw material must be taken into consideration, including each material's cost and quantity, as well as the supply, demand, and time periods. This sort of problem can be viewed as a blending problem, which is generally solved using linear programming (Williams 2013). The ideas and concepts from the research can be extrapolated to other production processes, whether it is steel, copper, or even glass. There are extensive number of processes that need to optimize blending problems, and as raw material continues to become expensive for producing goods, organizations will look to further enhance their processes, so a problem like the one in this research becomes a focal point for those organizations.

Literature Review

Research about aluminum production process has been researched extensively in various literature. Other research papers addressed similar decision problems regarding aluminum or metal production, whether it is reducing costs, optimizing scheduling, or optimal allocation to prevent production output from not exceeding capacity (e.g. Context 1.0). Researchers raised key questions that needed to be addressed followed by breaking down the production process to find possibilities of improvements. Several researchers also relied on quantitative data, qualitative interviews, or both to build a method to optimize the production process (e.g. Context 1.4).

The advantage seen in the state-of-the-art research was that the methodology helped build models that gives the ability to manipulate data to determine not just impactful information but also missing information (e.g. Context 2.3). Another advantage seen through literature review was that the researchers were able to set limits or boundaries. A drawback seen in the state-of-the-art research is that the models can become extremely complex and difficult to replicate at times. As mentioned before, majority of the researchers relied heavily on data to determine the method and the development of the model. When dealing with a decision problem regarding a production process, it appears that extensive amount of data is necessary to build a strong model (e.g. Context 1.5).

Based on the literature review, it was essential to follow the fundamental parts of state-of-the-art research. This meant understanding the process, including the key raw materials needed and the key parts of a production process, which takes into account supply, demand, and inventory. Another similar part of the research was determining the best model to build. However, unlike the state-of-the-art research, it was hard to come by extensive data. Additionally, to avoid convoluted models, the research was focused on building a model that simplifies research analyzed through literature review. This helps to recreate or build upon the model if necessary.

Methods

The method to conduct research consisted of searching for reliable literature focused on aluminum production processes. From there, additional research was conducted on the raw materials required for aluminum production, as well as the costs of the raw materials. Once the process was analyzed, it became clear that much of the costs accrue through the purchase and storage of the material. If these aspects of a process were to be optimized, costs can be reduced and subsequently, profits could be increased. The “Food manufacture 1” mentioned in “Model Building in Mathematical Programming” was the basis of building the model (Williams 2013). With that problem in mind, the parameters for the aluminum production process were designed to consider storage, cost, capacity, minimum and maximum amounts of production, and selling price [Formulation 1.2]. The objective function was designed to maximize the total profits by considering cost, consumption, and storage, and the constraints were also designed with the objective in mind, including the change in storage, levels of production, reaching target storage, and consumption [Formulation 2.0]. When the model is put together, there are key factors to also consider. For example, research indicated that alumina and petroleum coke can be stored together while the other materials can be stored together [Formulation 1.2]. Furthermore, pitch coke can also be used for the process instead of petroleum coke. Ultimately, the model design can help to determine profits, as well as the amounts of materials purchased, consumed, and stored.

Results

Results showed that different materials should be bought at different periods, depending on the cost [Table 1.0]. The cost numbers used in this model indicated that all the materials should be bought during periods three and four. However, the model can always be adjusted to show that purchase periods can change depending on the costs. Since the aluminum production process is done over periods, the purchase, consumption, and storage of the raw materials changes over the periods. The analysis helps to show that purchase for a particular material should be done in one period, which is generally the period with the lowest cost for that particular material. Additionally, the purchase is dependent on consumption, and storage over each period depends on the consumption [Table 1.1 and Table 1.2].

Conclusion

This research helped to build a production process model that can help not just an aluminum company, but any production processing company determine where costs are highest, the ideal time to purchase material, and best storage capacity. While this particular model had a set capacity, this capacity can also be manipulated to determine if demand can be met while lower or increasing storage and purchase power. The model simplified existing models that were highly complex. To further improve the model, it should be implemented to several scenarios, and additional variables can be added from there. This focus of this research and model was to find where production can be optimized, which in this case was through selected purchasing of raw materials, storage, and consumption. Moving forward, the model can be implemented on a large amount of data to expand the model and also enhance it to develop better accuracy. The approach was based on a blending problem that required linear programming (Williams 2013). The “blending” process for aluminum took the same approach, but moving forward, it could be adjusted to account for every raw material during every period.

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Appendix

Formulation 1.0: Sets

Set of periods
$\mathrm{t} \in \ \mathrm{periods} = \{\mathrm{P1}, \mathrm{P2}, \mathrm{P3}, \mathrm{P4}\}$

Set of raw materials 1
$\mathrm{r1} \in \ \mathrm{raw1} = \{\mathrm{Raw1\_PetCoke}, \mathrm{Raw1\_Alumina}\}$

Set of raw materials 2
$\mathrm{r2} \in \ \mathrm{raw2} = \{\mathrm{Raw2\_Flouride}, \mathrm{Raw2\_Cryolite}, \mathrm{Raw2\_PitCoke}\}$

Formulation 1.2: Parameters

Sale price of aluminum
$\mathrm{price} \in \ \mathrm{R} +$

Initial storage in tons
$\mathrm{init\_store} \in \ \mathrm{R} +$

Target storage in tons
$\mathrm{target\_store} \in \ \mathrm{R} +$

Holding storage in tons
$\mathrm{holding\_store} \in \ \mathrm{R} +$

Holding storage in tons
$\mathrm{holding\_store} \in \ \mathrm{R} +$

Raw1 capacity in tons
$\mathrm{raw1} \in \ \mathrm{R} +$

Raw2 capacity in tons
$\mathrm{raw2} \in \ \mathrm{R} +$

Lowest production in tons
$\mathrm{min\_prod} \in \ \mathrm{R} +$

Highest production in tons
$\mathrm{max\_prod} \in \ \mathrm{R} +$

Production in tons
$\mathrm{prod} \in \ \mathrm{R} +$

Cost in tons
$\mathrm{min\_prod} \in \ \mathrm{R} +$

Formulation 1.3: Variables

Tons of production during period
production $\in$ R +

Tons of material bought during period
buy $\in$ R +

Tons of material consumed during period
consume $\in$ R +

Tons of material stored during period
store $\in$ R +

Formulation 2.0: Objective function

$$maximize_z = \sum_{\mathrm{t \in periods}} price * produce_t - \sum_{\mathrm{t \in period}} \sum_{\mathrm{t \in materials}} (cost_{t,m} * holding_{cost} * cost_{t,m})$$

Formulation 3.0: Initial balance constraint (tons of materials purchased in P1 + previously stored = tons consumed and stored in period)

$$init\_store + buy_{P1,m} = consume_{P1,m} + store_{P1,m} \quad \forall \mathrm{m} \in \text{ materials}$$

Formulation 3.1: Balance constraint (tons of materials purchase in period P + previously stored = tons consumed and stored in period)

$$store_{t-1,m} + buy_{t,m} = consume_{t,m} + store_{t,m} \quad \forall (\mathrm{t, m}) \in \text{ periods} \setminus \{\mathrm{P1}\} * \text{materials}$$

Formulation 3.3: Inventory target (tons of material stored should hit target)

$$store_{P4,m} = target\_store \quad \forall \mathrm{m} \in \text{ materials}$$

Formulation 3.4: Refinement target (tons of material consumed in period P cannot pass capacity)

$$store_{P4,m} = target\_store \quad \forall \mathrm{m} \in \text{ materials}$$

Formulation 3.5: Refinement target (tons of material consumed in period P cannot pass capacity)

$$store_{P4,m} = target\_store \quad \forall \mathrm{m} \in \text{ materials}$$

Formulation 3.6: Production (production of aluminum produced in period P within min and max)

$$\min_{\mathrm{prod}} * produce_P \leq \sum\nolimits_{\mathrm{t \in periods}} hardness_m * consume_{t,m} \leq \max \_prod \quad \forall \mathrm{m} \in \text{ periods}$$

Formulation 3.7: Mass conservation (tons of materials consumed in period P)

$$\sum\nolimits_{\mathrm{m \in materials}} consume_{t,m} = produce_t \quad \forall \mathrm{t} \in \text{ periods}$$

Table 1.0: Purchase table

	Raw1_PetCoke	Raw1_Alumina	Raw2_Flouride	Raw2_Cryolite	Raw2_PitCoke
P1	0.0	0.0	0.0	0.0	0.0
P2	0.0	0.0	0.0	0.0	0.0
P3	100.0	0.0	0.0	0.0	0.0
P4	0.0	700.0	250.0	750.0	0.0

Table 1.1: Consumption table

	Raw1_PetCoke	Raw1_Alumina	Raw2_Flouride	Raw2_Cryolite	Raw2_PitCoke
P1	42.9	157.1	250.0	0.0	0.0
P2	0.0	200.0	0.0	250.0	0.0
P3	57.1	142.9	0.0	250.0	0.0
P4	0.0	200.0	0.0	250.0	0.0

Table 1.2: Storage table

	Raw1_PetCoke	Raw1_Alumina	Raw2_Flouride	Raw2_Cryolite	Raw2_PitCoke
P1	457.1	342.9	250.0	500.0	500.0
P2	457.1	142.9	250.0	250.0	500.0
P3	500.0	0.0	250.0	0.0	500.0
P4	500.0	500.0	500.0	500.0	500.0

Context 1.0:

Nathalie Lihvv looked to develop an IT-application to optimize the production process of a metal producer and improve the return of investment (Lihv 2017).

Context 1.2:

While each study focused on various aspects of a production process, the researchers were able to achieve their ultimate goal of optimization successfully. For example, research by M.A. Hariga for the Journal of King Saud University helped build a model to minimize total cost of aluminum production for a company (Hariga 1994). Research conducted for IOP Conference Series also built a model successfully for optimization, but in this case, it was to optimally allocate steel fulfill demand. Like much of the other conducted research during the literature review, this was done by collecting data, analyzing a production process, and building a mode (Hapsari and Rosvidi 2018)l.

Context 1.3:

When looking at Hariga's research, the company obtained results that would help make decisions with respect to out-of-hand parameter changes such as demands and raw material prices, as well as modifications it its production policy (Hariga 1994).
Context 1.4:

Research at the Polytechnic of Porto drew up a model based on the data collected. Similarly, a study for the Internal Journal of Production Economics outlined operational characteristics as purchasing, production, and sales. By taking a deeper look into each characteristic, the researchers were able to then select an optimization method (Almeida 2019).

Context 1.5:

When looking at Hariga's research, the process was broken down to formulate 135 variables and 160 constraints, and this can generally create a convoluted model that makes it hard to keep track of various aspects of the model. If this does occur, it can become difficult to manipulate data, which also brings up another drawback seen in the research (Hariga 1994).