Aggregate Planning: Opportunities and Challenges between Developed and Developing Countries

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Abstract

Aggregate planning (AP) is a crucial step of the production planning procedure. It is the process by which a company determines optimal levels of capacity, production, subcontracting, and inventory for its long term planning. This paper presents a comparative analysis related to the impact of social and economic factors on building reliable aggregate plans for companies operating in an international framework. The comparison is carried out between facilities of an international cement company, located in two different countries, a developing country and a developed one, namely Morocco and Belgium. The comparison is based on their aggregate planning and computational results based on profitability are analyzed.

Keywords
Production rate, Workforce, Capacity level, Overtime, Inventory level, Productivity

1. Introduction

Developing and developed countries have different social and economic environments. In the context of industrial organizations, it is hard to determine whether these environments are advantageous or disadvantageous in terms of cost and profit. This article aims to compare two cement facilities in a developed and developing country to derive the differences between them. The comparison of the two facilities will allow us to derive the impact of the two environments on the profitability of the cement company. Aggregate planning will be used to compare the two cement facilities located in Morocco and Belgium.

An organization seeks to use its resources effectively in order to satisfy demand at the lowest cost. In this context, demand and supply can vary depending on the requirements of the aggregate planning model. In general, this type of planning can be used over a period of 18 months at most using different strategies. These strategies may differ depending on the requirements of the product or business. For example, an organization may want to match production with demand for each period, or have a specific number of employees. The aggregate planning model uses a set of forecasted parameters on hand to find optimizing values for production, subcontracting, inventory, workforce, and overtime while keeping costs at the lowest level. There are many techniques for determining an aggregate plan such as the linear decision rule, heuristic and simulation method, mathematical techniques, and linear programming (Pan and Kleiner, 1995). In our case, we will be using the linear programming method which forecasts demand, hiring, firing and other costs. Although linear programming seems to be one of the best methods for solving an aggregate plan, it is based on estimates for costs (hiring, firing, inventory, etc.) that can change over time and according to context.

This paper initially examines the aggregate planning process and describes the essential tasks involved. A literature review of the current aggregate planning methods is then examined and the main methods of modeling are highlighted.

This paper also seeks to outline the impact of externalization on international manufacturing companies, through the computation of logistical cost incurred locally and externally and the profit generated. Using the aggregate plans of two factories from the same company located in two different countries, a developed and a developing country, the paper will emphasize the impact on the profitability of the company in terms of customer price and the workforce cost, considered as a competitive advantage for international companies.

The aim of aggregate planning is to determine the optimal supply chain parameters to minimize costs and maximize profits. This article will attempt to compare two cement facilities in Morocco and Belgium. As mentioned, the two facilities are located in two different environments, developing and developed; therefore, they have different supply chain variables related to labor, pricing, production, and inventory. These variables may be advantageous or disadvantageous. Through the comparison of the two facility's aggregate models, we will be able to elucidate the impact of social and economic factors on AP for both facility's and show how to ensure high profitability levels despite their differences.

2. Review of Related Literature

The first production planning research was conducted by Hax and Meal (1975) and aimed to find feasible solutions to planning. In his article "On the Feasibility of Aggregate Production Plans", Sven Axsäter (1985) held that planning is divided into two parts: "detailed and aggregate planning". Unlike detailed planning, aggregate planning is performed at a higher level. It also covers a longer time horizon although it provides less detail. Importantly, aggregate planning should not create restrictions for detailed planning while at the same time should consider long-term constraints. Figure 1 shows the hierarchical relationship between the two levels of planning and the plant.

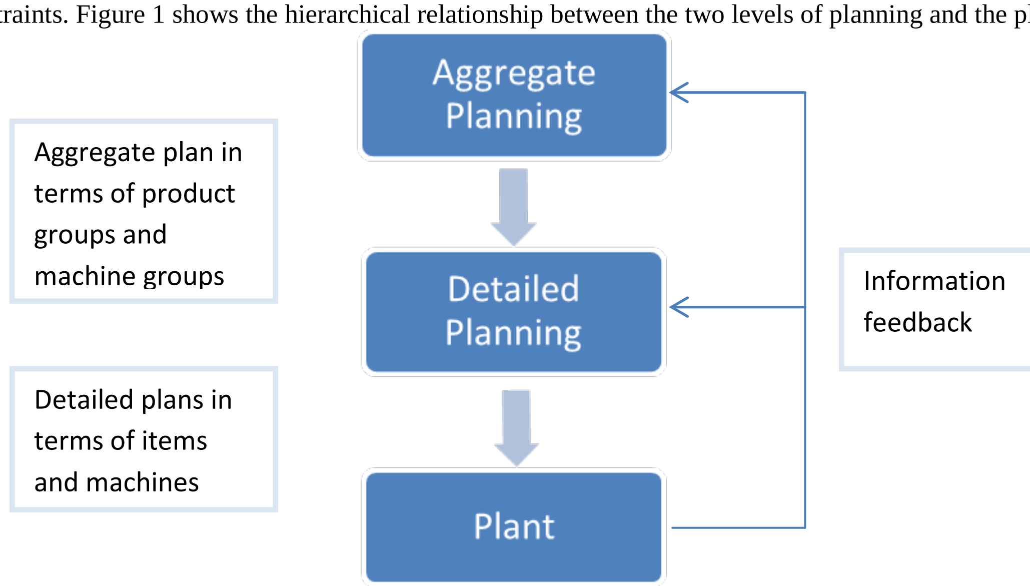

Figure 1: Hierarchical planning process

Axsäter (1985) also discusses means for formulating constraints and functions for finding a feasible detailed plan. The goal of the paper is to find a plan that would be relevant to the different stages of production planning. At the first level of planning, which is the detailed level, N items and M machines were considered. Constraints on the different variables are summarized in the context of both a nonnegative inventory and a production that does not exceed capacity. The demand is satisfied by the initial inventory and the cumulated production. For the aggregate level, the time horizon is longer than the detailed level the production is assumed to be a linear function for n product groups. Once the aggregate plan is formulated, and the detailed plan is created through the disaggregation of the latter. The condition of the feasibility of aggregate planning can only be evaluated if the plan can be decomposed into a feasible detailed plan.

In an effort to examine the ways of modeling the aggregate planning, a review of some existing research on modeling methods is presented. Examples of such models are conceptual models, analytical models (such as linear programming and mixed integer linear programming), and artificial intelligence models (such as Multi-agent systems and genetic algorithms) or simulation models.

Gunasekaran et al. (2002) focus on the application of Aggregate Production Planning (APP) models to industries in developing countries (DCs). The main objective of APP is to identify the optimum level of work force and production speed requirements to mitigate the effect of fluctuations in demand.

Buxey (1995) explores the divergence between theory and practice and provides algorithms which yield significant cost savings, via an empirical study.

Barman et al. (1993) analyze the sensitivity of the linear programming (LP) model to forecast errors in aggregate planning (AP), in addition the paper compares the performance of LP with that of the production switching heuristic (PSH) model. The author explains that while the LP tends to outperform the PSH in situations with high forecast errors, the performances of the models are comparable for low to moderate forecast errors. The use of an additional production and workforce level in the PSH is not justified unless forecast errors are high.

Holt (1981) presents a method for making work force level and inventory planning decisions, i.e., dynamic aggregate planning decisions. Many researchers, in order to estimate the work force size and production rate by minimizing the total production cost, have followed different types of approaches.

Mula et al. (2006) adds the consideration of uncertainty, he explains how to use artificial intelligence models in aggregate planning and simulation models as well under uncertainty. The same work demonstrates other variants of AP called the hierarchical production planning and material requirement planning by using analytical models, conceptual models and artificial intelligence models in addition to simulation models.

In this paper the aggregate-planning models are formulated as an analytical model using linear programming.

3. Model

In order to compare the two facilities, we will compare their aggregate production models. As indicated earlier, the goal is to minimize costs; therefore, we will determine optimal levels of workforce, production, inventory, and pricing for the Moroccan and Belgian facilities. We will use a time frame of 12 months, which means that we will be specifying the output parameters for each period of time. The mathematical model is developed and entered to Excel Solver and the aggregate model is produced. In order to perform the aggregate plan we will need the following information: the demand forecast in each month (unit), the production cost of materials (Euros/t), regular labor costs (Euros/hour), overtime labor cost (Euros/hour), cost of changing workforce capacity: hiring or layoff (Euros/worker), cost of changing workforce capacity: hiring or layoff (Euros/worker), inventory holding cost (Euros/unit/period). In addition, we will need further information about constrains that control the latter parameters: capacity of the facility, maximum working hours, limit on workforce required, limit on inventory, and limit on overtime working hours.

Next, we will define decision variables that will construct our mathematical model for 12 periods, in other words, from $t = 0$ to $t = 12$:

Decision Variables

Wt = Workforce size for month.
Ht = Number of employees hired at the beginning of month t.
Lt = Number of employees laid off at the beginning of month t.
Pt = Production in month t.
It = Inventory at the end of month t.
Ot= Overtime worked hours in month t.

Parameters

C1, C2, C3, C4, C5, C6 = cost per month of workforce, production, inventory, overtime, hiring, and firing respectively.
Ut = Number of units produced by each employee in a month.
h = Labor hours required per ton.
m= Maximum overtime allowed per employee per month.

After defining our variables and parameters, we need to define the objective function which aims to minimize the cumulative overall costs incurred for production, workforce and inventory.

Objective function

$$Min\sum_{t=1}^{12} C1 W_t + \sum_{t=1}^{12} C2\, P_t + \sum_{t=1}^{12} C3\, I_t + \sum_{t=1}^{12} C4\, O_t$$
$$+\sum_{t=1}^{12} C5\, H_t + \sum_{t=1}^{12} C6\, L_t$$

Constraints

Workforce size for each month is based on hiring and layoffs:

$$W_t = W_{t-1} + H_t - L_t$$

Production for each month cannot exceed capacity:

$$P_t \leq U_t * W_t + O_t / h$$

Inventory balance for each month:

$$I_t = I_{t-1} - D_t + P_t$$

Overtime should not exceed the maximum hours per employee:

$$O_t \leq \mathrm{m} * W_t$$

The model constructed above will be applied to both cement facilities located in Morocco and Belgium. We assume in the models that the two facilities do not subcontract any of their production to external companies and that no backlogs are carried from month to month.

4. Numerical application

In the case of the Moroccan facility, we ignored the hiring and firing costs. In general, employees that are freshly hired are only paid a low salary during their period of training. For this reason, we assume the workforce to be constant in all periods. All the facilities of each country are considered as one big facility. In other words, production runs simultaneously in all facilities of each country. Morocco and Belgium have 4 facilities each, which produce 1 ton of cement in 1 hour; this is represented in our model as a production rate of: 1 ton per 15 minutes (60min/4tons). Also, the currency for Morocco is Dirhams (MAD); while Belgium is Euros. In order to compare the two facilities, we chose to use Euros as a common currency using an exchange rate of: 1 Euro = 11.5 MAD.

Table 1. Data for the Moroccan facility

Input Data (Demand)		***Input Data (Costs etc.)***		
Month	**Demand**	**Item**	**Cost(MAD)**	**Cost (in Euros)**
January	250,000	Materials cost/t	350	31.22
February	250,000	Inventory holding cost/unit/month	15.0	1.304
March	170,000	Labor hours required/t	0.25 hrs/t	
April	310,000	Regular time cost/hour	10.0	0.8955
May	120,000	Over time cost/hour	15.0	1.3432
June	260,000	Initial workforce size	623	
July	230,000	Maximum overtime per worker per month	10	
August	180,000	Starting inventory (t)	50000	
September	630,000	Monthly capacity (t)	375,000	
October	275,000	Price/t (Dirhams, Euros)	700	61
November	260,000	Monthly worked hours/employee	176	
December	350,000	n° of tons produced/ employee/ month	704	
		Labor cost/employee/month (Euros)	157.608	

Table 2: Data for the Belgian facility

Input Data (Demand)		***Input Data (Costs etc.)***	
Month	**Demand**	**Item**	**Cost (in Euros)**
January	500,000	Materials cost/t	50
February	650,000	Inventory holding cost/unit/month	5
March	690,000	Labor hours required/t	0.25
April	490,000	Regular time cost/hour	7.5
May	700,000	Over time cost/hour	10
June	650,000	Hiring Cost/employee	200
July	760,000	Firing Cost/employee	400
August	600,000	Initial workforce size	1,250
September	630,000	Maximum overtime per worker per month	30
October	770,000	Starting inventory (t)	30 000
November	690,000	Monthly capacity (t)	750,000
December	700,000	Price/t (Euros)	100
		Monthly worked hours/employee	176

Morocco Cement facility model

Objective function

$$Min\sum_{t=1}^{12}157.6W_t+\sum_{t=1}^{12}31{,}22\,P_t+\sum_{t=1}^{12}1.304\,I_t+\sum_{t=1}^{12}1.34\,O_t$$

Constraints

$$W_t = \mathbf{623}$$

$$P_t \le \mathbf{704}\,W_t + O_t\,\mathbf{/0{,}25}$$

$$I_t = I_{t-1} - D_t + P_t$$

$$O_t \le \mathbf{10{*}}W_t$$

Table 3: Moroccan model

Moroccan Facility								
Aggregate Plan Decision Variables (demand, inventory, production in tons)								
Variables						***Constraints***		
	Wt	Ot	It	Pt				
Period	***# Workforce***	***Overtime***	***Inventory***	***Production***	***Demand***	***Inventory***	***Overtime***	***Production***
0	**623**		**50,000**			0	-6230	188592
1	**623**	0.0	50000.0	250000	250,000	0	-6230	188592
2	**623**	0.0	50000.0	250000	250,000	0	-6230	188592
3	**623**	0.0	130000.0	250000	170,000	0	-6230	188592
4	**623**	0.0	70000.0	250000	310,000	0	-6230	188592
5	**623**	0.0	200000.0	250000	120,000	0	-6230	188592
6	**623**	0.0	190000.0	250000	260,000	0	-6230	188592
7	**623**	0.0	210000.0	250000	230,000	0	-6230	188592
8	**623**	0.0	280000.0	250000	180,000	-100000	-6230	188592
9	**623**	0.0	0.0	250000	630,000	-25000	-6230	188592
10	**623**	0.0	0.0	250000	275,000	-10000	-6230	188592
11	**623**	0.0	0.0	250000	260,000	-100000	-6230	188592
12	**623**	0.0	0.0	250000	350,000	0	0	0
Total cost =	96376997.4	Euros						
Total Revenues	200385000.00	Euros						
Total profit=	104008002.59	Euros						

Belgian Cement facility model

Objective function

$$Min\sum_{t=1}^{12}1320W_t+\sum_{t=1}^{12}50P_t+\sum_{t=1}^{12}5I_t+\sum_{t=1}^{12}30O_t+\sum_{t=1}^{12}200H_t+\sum_{t=1}^{12}400L_t$$

Constraints

$$W_t = W_{t-1} + H_t - L_t$$

$$P_t \leq \mathbf{704.00}W_t + O_t\,\mathbf{/\ 0,25}$$

$$I_t = I_{t-1} - D_t + P_t$$

$$O_t \leq \mathbf{30*}W_t$$

Table 4: Belgian model

Belgian Facility											
Aggregate Plan Decision Variables (demand, inventory, production in tons)											
Variables								***Constraints***			
	W_t	O_t	I_t	P_t	H_t	L_t					
Period	***# Workforce***	***Overtime***	***Inventory***	***Production***	***Hiring***	***Firing***	***Demand***	***Inventory***	***Overtime***	***Prod***	***Workforce***
0	**1,250**	**-**	**9000.00**					-131000	-31960.23	0.00	0.00
1	**1,065**	-	-	750,000	-	185	890,000	0	-31960.23	0.00	0.00
2	**1,065**	-	100,000	750,000	-	-	650,000	0	-31960.23	0.00	0.00
3	**1,065**	-	50,000	750,000	-	-	800,000	0	-31960.23	0.00	0.00
4	**1,065**	-	20,000	750,000	-	-	780,000	-180000	-31960.23	0.00	0.00
5	**1,065**	-	-	750,000	-	0	950,000	-100000	-31960.23	0.00	0.00
6	**1,065**	-	-	750,000	-	-	850,000	-5000	-31960.23	0.00	0.00
7	**1,065**	-	-	750,000	-	-	755,000	0	-31960.23	0.00	0.00
8	**1,065**	-	150,000	750,000	-	-	600,000	0	-20454.55	0.00	0.00
9	**682**	-	-	480,000	-	384	630,000	0	-31534.09	0.00	0.00
10	**1,051**	-	-	740,000	369	-	740,000	0	-29616.48	0.00	0.00
11	**987**	-	5,000	695,000	-	64	690,000	0	-29616.48	0.00	0.00
12	**987**	-	-	695,000	-	-	700,000				
Total cost =	432,543,430.40	Euros									
Total Revenues=	903,500,000.00	Euros									
Total profit=	470,956,569.6	Euros									

5. Analysis of Data

- *Difference in labor cost*

As can be seen from the data shown in the figures, there is a difference in costs between Belgium and Morocco. The labor cost in Morocco is 0.8955 Euros per hour (See Table 1). Conversely, the labor cost in Belgium is 8 times higher at 7.5 Euros per hour (See Table 2).This gives Morocco a competitive advantage in terms of labor cost. However, it is important to mention that the Belgian employees are more technically qualified than the Moroccan employees.

- *Difference in capacity, employees and production*

The Belgian company owns 4 cement facilities with 1250 employees. Dividing the number of employees equally between the facilities, we obtain 312 employees per facility. In the case of Morocco, we have 4 facilities with a total number of 623 employees; therefore 156 employees are theoretically allocated to each facility. In addition, the Belgian facility has a production capacity of 750 000 tons per month; while Morocco has a capacity of 375 000 tons.

We conclude that the Belgian facilities have nearly twice the capacity of the Moroccan facilities and employ twice as many employees as the Moroccan facilities.

- *Difference in material cost and client price*

The main raw material required to produce cement is limestone. Other needed materials are gypsum, bauxite, iron, fly-ash, electricity, coal, etc. In order to obtain limestone, the Moroccan facility extracts it from quarries near to the factory. The material cost for 1 ton of cement is estimated to be 31.22 Euros for Morocco and 50 Euros for Belgium. The difference in material cost is due to the difference in resource availability in terms of limestone in the two countries. Morocco on one hand, owns abundant resources of limestone; while Belgium has less available resources. Besides the material cost, the final client price per ton differs from Morocco to Belgium. Indeed, the Moroccan factory charges 61 Euros per ton; while the Belgian facilities charge 100 Euros per ton. This gives Morocco high competitiveness in terms of price but not in terms of quality.

- *Comparing the profitability of the two facilities*

In general investment opportunities involve an investment in return for future income. As any investment project, aggregate planning projects in cement industry entail a variety of costs, such as material procurement cost, operation and inventory costs, which are consumed to generate incomes and revenues. To calculate the profitability of such investment projects, a cost-benefit analysis (CBA) can be performed. CBA is a commonly used financial and economic evaluation tool for projects. It has been used in several investment projects for both public and private sectors Brent (2006). Mishan (1988), Booardman (2005) and Pearce (2006) cover the application of CBA in private sectors. Whereas Gao and Li (2009) studied the development of cost-benefit methods in the public project decision-making area. This approach is particularly useful in the case of different alternatives' comparison, when a selection decision has to be made from a set of plausible alternatives that are considered as mutually exclusive (compete with each other where only one alternative can be selected), or as independent (don't compete and can all be selected as long as they are economically justified). CBA assumes that these proposed projects involve a combination of incomes (benefits) and costs over a planning horizon of a given timeframe. CBA identifies whether the facilities are economically viable and justified in terms of the best tradeoff between benefit generated and costs incurred, provided the information aforementioned.

As we can conclude from the input demand data, the Belgian facility receives more than twice the demand of Morocco (See Tables 3 and 4). And although the costs and prices are different for both facilities, the profit is almost the same considering the two factories have the same demand. This can be explained by a positive correlation between prices and costs. While the costs are high in the Belgian facility, the price of cement per ton is also high compared to the Moroccan facility. For Morocco, price and costs are both low compared to the Belgian facility. To prove this statement, we will compute the ratio cost/benefit for both facilities:

$$\text{Ratio (Morocco)} = \frac{96{,}376{,}997.41}{104{,}008{,}002.59} = 0.9266$$

$$\text{Ratio (Belgium)} = \frac{432{,}543{,}430.40}{470{,}956{,}569.6} = 0.91843$$

We can conclude from and relatively equivalent in terms of productivity.

6. Conclusion

The aggregate models produced for both the Belgian and the Moroccan facilities of the international cement companies provide us with the optimal inventory, overtime, production, and workforce to maximize profit. The first facility is situated in a developing country (Morocco) and has low labor costs, low material costs, and low price. While the second facility is situated in a developed country which has high labor cost, high material cost, and high price compared to the Moroccan facility. Although the two facilities differ in their input data, after running the model, the resulting costs and profits produced for the two facilities are almost equivalent while ignoring scale.

The models we ran were based on a forecasted demand for both facilities. These demand values are uncertain and can vary with respect to different factors of the cement market. We tried to apply an effective forecasting of demand for Morocco and Belgium in order to develop comparable models. The Moroccan facility benefits from a low labor cost but lacks employee's technical performance compared to the Belgian facility. This is a disadvantage for Morocco since the product produced will not be as well finished as that of the Belgian facility. One solution to this problem is for the Moroccan facilities to consider implementing employee training prior to hiring; this may improve effective performance.

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