Aggregate Production Planning: A Case Study of Installation Elevator Company

Chanipa Nivasanon and Isaree Srikun
Faculty of Industrial Technology, Phranakhon Rajabhat University, Thailand
chanipa@pnru.ac.th, isaree@pnru.ac.th

Pasura Aungkulanon
Faculty of Engineering, King Mongkut's University of Technology North Bangkok, Thailand
pasurachacha@hotmail.com

Abstract

Competition affects increases in production and economic growth. Good production planning has direct effects on production system modifications. The company in the case study was an Installation Elevator Company currently encountering problems in the area of aggregate production planning and sales prediction, causing the company to be unable to deliver products on schedule with effects on customer satisfaction. This study had the objective to study and compare prediction methods of companies in the Installation Elevator Company and to study aggregate production planning in order to analyze and determine the lowest aggregate production cost by using data from 12 months in retrospect to determine the most appropriate prediction method. This study used 6 prediction methods consisting of the moving average method, single exponential smoothing, double exponential smoothing, winter's method, linear trend model and quadratic trend model. Accuracy of predictions was measured using the lowest mean absolute percent error (MAPE). According to the findings, the prediction method with the most appropriate model was the quadratic trend model because the method had the lowest mean absolute percent error of 17.85. Scores from predictions were then used to make aggregate production plans processed through Lingo Program Version 13 under changing circumstances of demand in 5 cases. The findings revealed the lowest production cost for normal demand was 3,233,000 baht and 2,607,000 baht when demand declined by 20 percent.

Keywords
Forecasting Methods, Aggregate Production Planning, Optimization

1. Introduction

The manufacturing and service industries are having problems in business operations due to economic changes, causing businesses to have problems ranging from employment problems to investment problems. Therefore, businesses or organizations need to improve and increase capacity to be able to compete in various fields such as price, quality and use technology to improve operations in order to meet customer needs and satisfaction as much as possible to provide quality goods and services and be able to compete with competitors.

The company in the case study was a company which accepts contracts to assemble and install elevators. The company is an industrial business involved in highly competitive construction work with current operating problems such as management of material, equipment, and inventory costs, predicting customer needs, readiness of buildings and structures and electricity problems, etc. The problems caused the company to be unable to manufacture goods on schedule while incurring high production costs, resulting in loss of opportunity, income and confidence from customers. The main cause of the problems was from ineffective production planning amidst uncertain customer demand. Thus, improvements needed to be made to work capacity to reduce operating costs and use limited resources such as workers, machines, materials, equipment, methods, and investments to maximum benefit.

Therefore, appropriate aggregate production planning is highly important in decisions related to production to be able to achieve goals. In general, the main objective of aggregate production planning was to create maximum profit or income with the lowest production costs. Work limitations consisted of demand at each time, inventory levels, worker levels and working hours. Furthermore, aggregate production planning enables use of limited resources to create maximum benefit.

2. Literature Review

Aggregate production planning is production planning to meet expected demand in the next 6-18 months (Phruksaphanrat, 2009) with the objective of specifying production levels and capacity to be used for the next year by making consideration from data on sales, inventory levels, current production capacity, costs and related policies including limitations in the factory with coverage of current and new products in the company. Aggregate production planning provides data for use in determining main production schedules. Aggregate production planning is related to the organization's overall activity and all operations in the specified time. Demand forecast is used for planning use of resources to create maximum benefit in the factory such as maximizing labor, raw material and machine efficiency (Aungkulanon et al. 2012).

In previous studies, aggregate production planning was applied to solve problems. For example, an aggregate production model for a Portuguese firm that produces construction materials by using a multiple criteria mixed integer linear programing (MCMILP) to enhance production efficiency under the limitations of maximum profit, reduce purchase order delays and minimize changes to the workforce in order to solve production problems (Silva et al. 2004).

Hossain et al. (2016) shows a multi-period, multi-product aggregate production planning model to reduce cost of waste in the production process and increase employee motivation by comparing the lowest cost after considering the two new cost factors in aggregate costs of waste and workers' motivation using the meta-heuristic (Genetic Algorithm) method and the Big-M linear programming method.

Mantilla et al. (2017) shows aggregate production planning using a case study in a medium-sized industry of the rubber production line in Ecuador and found industrial factories in Ecuador to have diverse production, causing inability to produce a sufficient amount of products and failure to produce products according to purchase orders created delays when delivering products. Aggregate production planning was applied to solve the problem with limitations consisting of specification of demand volume at each time by predicting demand in advance, specification of production capacity, overtime work, production hiring at each time, labor costs, employment and storage costs. Aggregate production planning was then analyzed by following the two guidelines of the Exact Production Plan (Zero Inventory and the Constant Workforce Plan (Vary Inventory). The Exact Production Plan (Zero Inventory) was found to have a total cost of $ 123,089.07 and had only labor cost from having no zero inventory with high employee variance. The Constant Workforce Plan (Vary Inventory) had a total cost of $ 125,897.74 consisting of labor costs and inventory maintenance costs.

Campo et al. (2018) shows an aggregate production planning model to determine appropriate strategies for a textile company and found production waste and labor problems. Because of the aforementioned problem, a linear program model was created to find the lowest overall costs for the following costs: 1. Labor costs related to employees' monthly expenses per production process per month, employee training costs and administrative costs of employee hiring and dismissal; 2. Inventory management cost proportionate to monthly inventory levels in each production process. Development of a mathematical program model for aggregate production planning helped with obtaining the best answer for operations in production plans while enabling specification of modification strategies such as increases to production capacity and inventory storage levels to reduce total costs.

Attia et al. (2016) shows an aggregate production planning model to reduce production costs with different operation limits consisting of demand, inventory, work time, overtime work for employees and temporary employees, etc., by creating a model using the ILOG-CPLEX software. The findings from this study were then compared to the company's old method. The model was found to be successful in reducing production costs by 5.43 percent in the first year, 2.66 percent in the second year and 1.86 percent in the third year.
In solving aggregate production planning problems, several researchers applied meta-heuristic methods. Meta-heuristic methods were obtained from development and modification to have flexibility in determining solutions for any complex decision-making problem with many deciding variables in a quick and effective manner. Although solutions may not be the most suitable and good solutions cannot be guaranteed from every data processing,

solutions were accepted and found in an appropriate time. Therefore, meta-heuristic methods were widely accepted in every field of research. Meta-heuristic methods such as genetic algorithm (GA) (Laoraksakiat and Asawarungsaengkul 2021), particle swarm optimization (PSO) and harmony search algorithm (HSA) (Hossain and Islam 2018) were used to solve aggregate production planning problems. Aggregate production planning can be seen to be highly important for business operations while increasing capacity to compete. Therefore, this research explored aggregate production planning with the lowest production cost while being able to meet customer demand on schedule.

3. Methods

3.1 Demand Forecasting

In predicting elevator installation demand in this study, the researcher used a simple prediction method by applying the Minitab computer program and using elevator installation job data from the company in the case study. The prediction methods used consists of the moving average, single exponential smoothing, double exponential smoothing, winter's method, linear trend model and quadratic trend model. Accuracy of predictions were tested with mean absolute percent error (MAPE), a score for comparing prediction efficiency.

Prediction accuracy in this study was measured by using mean absolute percent error (MAPE) in Equation 1, which compared effectiveness of predictions from data used in analysis.

$$\mathrm{M} = \frac{1}{n}\sum_{i=1}^{n}\frac{|A_t - F_t|}{A_t} \tag{1}$$

Provided that

M	=	mean absolute percentage error
n	=	number of times the summation iteration happens
A_t	=	actual value
F_t	=	forecast value

Mean absolute percent error is a measurement of prediction deviations compared to real values. Lower MAPE indicated high prediction accuracy. (Aungkulanon and Luangpaiboon 2018).

3.2 Aggregate Production Planning

The goal of aggregate production planning consists of need for the lowest production costs, a problem model with the lowest production costs (Arumugham et al. 2016) with the following scope of aggregate production planning:

$$\text{Min}\,Z = \sum_{t=1}^{6} RcW_t + \sum_{t=1}^{6} OcO_t + \sum_{t=1}^{6} HcH_t + \sum_{t=1}^{6} LcL_t + \sum_{t=1}^{6} ScS_t + \sum_{t=1}^{6} McP_t + \sum_{t=1}^{6} CcC_t + \sum_{t=1}^{6} IcI_t \tag{2}$$

Constraints

$$Min\ W \le W \le MaxW \tag{3}$$
$$Ot_t \le Otmax \tag{4}$$
$$P_t = (W_h * W_i + Ot_i) * P_r \tag{5}$$
$$W_t = W_{t-1} + H_t - L_t \tag{6}$$
$$I_{i-1} + P_t + C_t = D_t + S_{t-1} + I_t - S_t \tag{7}$$
$$W_t, O_t, H_t, L_t, I_t, S_t, P_t\ and\ C_i\ \ge 0 \tag{8}$$

Decision Variables

t	=	Forecasting time
N	=	Number of Product
Wt	=	workforce size
Ot	=	number of overtime hours
Ht	=	number of employees hired
Lt	=	number of employees laid off
St	=	number of units stocked out/backlogged
Pt	=	number of units produced
Ct	=	number of units subcontracted
It	=	inventory at the end

Equation 2 was the objective equation consisting of raw material costs, labor and overtime costs, costs in hiring labor in and out, costs from inventory storage and product shortage. Equations 3-8 consisted of production limitations, labor limitations, overtime work limitations and variable type limitations in full numbers (Arumugham et al. 2017).

4. Data Collection

4.1 Demand on Elevator Installation Work

The research group collected data on elevator installation work volume from 12 months in retrospect for use in calculations to make aggregate production planning for the company in the case study as shown in Figure 1.

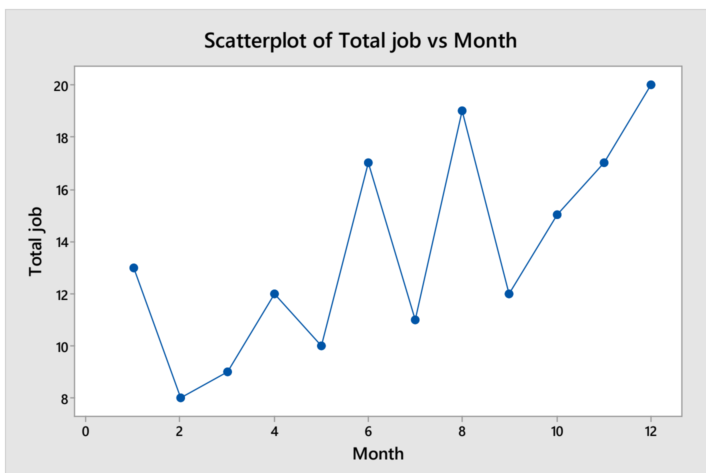


Figure 1. The graphical plot of demand on elevator installation work volume from 12 months.

In Figure 1, data can be seen to have up and down dispersion characteristics as a result of the current economy with uncertain customer demand volume.

4.2. Aggregate Production Planning Problems

Aggregate production planning is planning to determine the amount of products and times when products should be manufactured in relation to customer demand while remaining consistent with the company's production capacity according to information shown in Table 1.

Table 1. Data for Aggregate Production Planning of elevator installation.

Data	Quantity
Materials cost	15000 Baht/Work
Production volume in normal time	5% of all work/day/person
The amount of production during overtime	3% of all work/day/person
The largest number of combined overtime hours	≤ 30 hour/month
Inventory Cost (Ic)	1000 Baht/unit
Stocked out Cost (Sc)	500 Baht/unit
Hired Cost (Hc)	500 Baht/person
Laid off Cost (Lc)	1500 Baht/person
Recruitment Cost (Rc)	12000 Baht/month
Overtime Cost (Oc)	100 Baht/hour
Subcontracted Cost (Ct)	50000 Baht/unit
Inventory quantity	0 unit
Final inventory amount	0 unit
The amount of product shortage in the last month	0 unit
Workforce size	9 persons
Working time	24 day/month

According to Table 1, necessary data for aggregate production planning consisted of data on capacity, aggregate units, and expenses such as raw material costs, labor costs, overtime wages, contract hiring, costs from hiring more employees and costs from dismissing employees, etc.

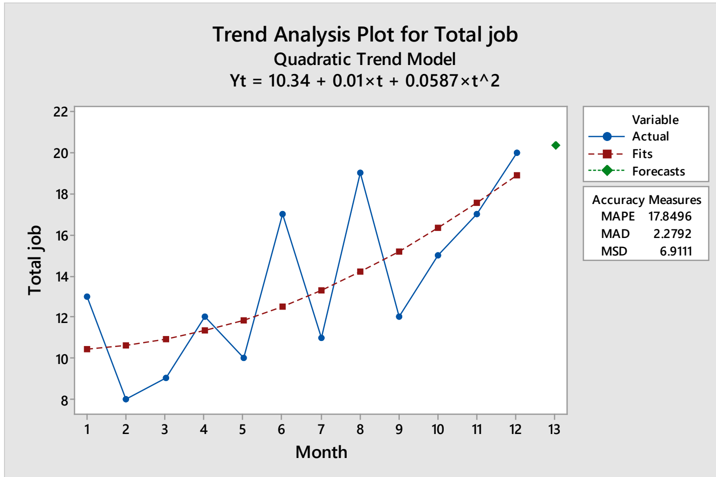
5. Results and Discussion

According to predictions of demand volume for elevator assembly and installation for 12 months in retrospect by a moving average of 3 months and 5 months, single exponential smoothing, double exponential smoothing, winter's method, linear trend model and quadratic trend model by using the Minitab program, all 6 methods had results shown in Table 2.

Table 2. Forecasting Errors.

Forecasting Models	MAPE
Moving Average N=3	20.49
Moving Average N=5	20.06
Single Exponential Smoothing $\alpha = 0.37$	22.13
Double Exponential Smoothing $\alpha = 0.22$ and $\gamma = 0.31$	18.85
winter's method $\alpha = 0.2$, $\beta = 0.2$ and $\gamma = 0.2$	22.41
Linear Trend Model	18.62
Quadratic Trend Model	17.85

According to Table 2 on predicted demand, demand from prediction by quadratic trend model had the lowest mean absolute percent error (MAPE) as shown in Figures 2.



Figures 2. The graphical plot of demand with quadratic trend model.

Therefore, the research group used predictions from the quadratic equation model in aggregate production planning for the company in the case study. This study applied mathematical programs to calculate appropriate production planning by creating hypothetical situations to determine solution models before comparing costs in each case. This study designed comparisons in the following 5 cases:

Case 1 – Demand from Prediction by the Quadratic Trend Model.
Case 2 - Demand from Predictions at 10% Lower
Case 3 - Demand from Predictions at 10% Higher
Case 4 - Demand from Predictions at 20% Lower
Case 5 - Demand from Predictions at 20% Higher

Analysis of lowest production cost was performed by applying the LINGO program, Version 13, to solve problems in each case as shown in Table 3.

Table 3. Simulations for aggregate production planning.

Demand	Case 1	Case 2	Case 3	Case 4	Case 5
Month 1	20	18	22	16	24
Month 2	22	20	24	18	26
Month 3	24	22	26	19	29
Month 4	26	23	29	21	31
Month 5	27	24	30	22	32
Month 6	29	26	32	23	35
Total Cost	3,233,000	2,907,000	3,568,000	2,607,000	3,875,000

Tables 4 - 7 show the number of workers per month, total overtime per month, number of workers hired, and number of workers laid off each month in Cases 1-5.

Tables 4. Number of workers per month.

Case	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
Case 1	10	10	11	13	13	14
Case 2	9	10	10	11	11	13
Case 3	10	12	13	14	14	16
Case 4	6	10	10	10	10	11
Case 5	11	13	13	14	14	20

Tables 5. Total overtime per month.

Case	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
Case 1	300	300	326.67	380	380	406.67
Case 2	240	300	300	326.67	326.67	380
Case 3	300	353.33	346.67	406.67	406.67	460
Case 4	160	300	300	300	300	326.67
Case 5	326.67	380	380	406.67	406.67	600

Tables 6. Number of hiring worker.

Case	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
Case 1	1	0	1	2	0	1
Case 2	0	1	0	1	0	6
Case 3	1	2	1	1	0	2
Case 4	0	4	0	0	0	1
Case 5	2	2	0	1	0	6

Tables 7. Number of layoff worker.

Case	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
Case 1	0	0	0	0	0	0
Case 2	0	0	0	0	0	0
Case 3	0	0	0	0	0	0
Case 4	3	0	0	0	0	0
Case 5	0	0	0	0	1	0

6. Conclusion

This study applied predictions and aggregate production planning to analyze problems in operations through mathematic equations with the objective to calculate minimum production cost in various situations. The lowest production cost was in Case 1 with demand values from predictions and production cost at 3,233,000 baht. In Case 2, when demand declined by 10 percent, production cost was equal to 2,907,000 baht. In Case 3, when demand increased by 10 percent, production cost was 3,568,000 baht. In Case 4, when demand declined by 20 percent, production cost was 2,607,000 baht. In Case 5, when demand increased by 20 percent, production cost was 3,875,000 baht. The company was able to increase efficiency and customer satisfaction. Data collection from the company in the case study may have slight deviations. This was because production models had similar characteristics while production factors may not be the same. Therefore, design of experiments may be applied to develop suitable production systems and other methods may be used to find solutions for problems such as meta-heuristic methods, etc.

The effects of aggregate production planning were consistent with a study conducted by Shun et al. (2016) a study conducted by David G. et al. (2016) including a study conducted by Bart et al. (2107), which was able to reduce production costs while enhancing efficiency and building customer satisfaction. Costs calculated in each case study showed status of insufficient workers for work. In cases where the number of workers increased to 5 workers, costs were lower than when having only 3 workers in production. Therefore, consideration of worker allocation was another factor in reducing production costs. However, data collected from factories may have deviations because each production model had different production details depending on each customer's needs. Therefore, this study recommended application of many-objective optimization a study conducted by Luangpaiboon (2 0 1 7). and the Fuzzy Set Theory study conducted by Phruksaphanrat et al (2011). including design of experiments too develop appropriate production systems and reduce production time. Furthermore, consideration should be given to uncertain demand, more diverse inventory, and application of other programs for solving problems to obtain values quickly with the least deviation (Aengchuan and Phruksaphanrat 2013).

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Biographies

Chanipa Nivasanon received a bachelor's degree in industrial engineering from Burapha University, Thailand. Her completed her master's degree in industrial engineering from Kasetsart University Thailand. Currently, she works as a lecturer at the Faculty of Industrial Technology, Phranakorn Rajabhat University. His research interests are operational research, design of experiment, forecasting and production planning control.

Isaree Srikun is an Assistant Professor in Electrical Engineering, she received a bachelor's degree in electrical engineering from Sirindhorn International Institute of Technology, Thammasat University, Thailand and completed her master's degree in electrical power systems from University of Bath, United Kingdom. She currently works as a lecturer at the Faculty of Industrial Technology, Phranakhon Rajabhat University and she has published journals and conference papers related to electrical technology area. Her research interests include artificial intelligence, optimization, electrical control and automated machines

Pasura Aungkulanon, received a bachelor's degree in industrial engineering from Kasetsart University, Thailand. Then, he continued higher education. He completed his master's degree and Ph.D. in industrial engineering from Thammasat University Thailand. Currently, he works as a lecturer at the Faculty of Engineering, King Mongkut's University of Technology North Bangkok. His main research interests are in the fields of operational research, and meta-heuristic algorithms, with applications in production planning, logistics and supply chain.