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Research Paper

Production efficiency improvement: case study in roasted and ground coffee industry

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Abstract: The roasted and ground coffee industry has grown very rapidly during the past decade and has become a highly competitive business in Thailand. Despite numerous coffee importers and international franchises, the number of domestic coffee plants has increased to sixty-nine in 2007 (Department of Industrial Works, 2008.) To survive in this business, the domestic manufacturers need to reduce costs and improve their production efficiency. In this paper, the production system of a small roasted and ground coffee plant was investigated using computer simulation technique. Computer simulation model served as a decision support tool for comparing the current production system to two alternatives for capacity planning. One alternative involved determining optimal workforce levels for various future demand scenarios and the other required high investment in replacing bottleneck manual operations with automatic machines with superior capacity that could significantly improve the quality of the produced coffee beans. Simulation results demonstrated the capability of this tool in capacity planning and that the cost of processing machine investment could be justified by the payback period.

Keywords: food, beverage industry, process improvement, computer simulation, production efficiency.

Introduction

The roasted and ground coffee industry in Thailand has grown rapidly during the past decade. It has become a highly competitive business among numerous coffee importers, international franchises and domestic coffee producers. To survive in this business, domestic manufacturers need to improve their production efficiency and properly perform capacity planning to meet the increasing demands. This paper presents a case study of production efficiency improvement in a roasted and ground coffee plant.

The plant selected for the case study has experienced continuously increased demand for the past few years. The producer has been unable to meet these demands due to the limitations of production capacity. Two available solutions for capacity expansion include increasing the workforce, particularly where bottlenecks occur in the processing operation or investing in an automatic machine to fulfill the same purpose. Therefore, the objectives of this study are twofold: 1) to determine optimal levels of workforce for different scenarios of (increasing) demands, and 2) to estimate the payback periods for machine investment justification. The analytical tool used for determining optimal workforce is computer simulation technique, while the payback periods under various scenarios are computed using economic analysis.

Computer simulation modelling is a technique that imitates a real system as a logical/mathematical model constructed by computer software. The main advantage of using simulation is that changes to the real system can be examined by experimenting with the simulation model so that the real system is not interrupted. This provides benefits to the users through savings in cost, time and other resources. Computer simulation has been widely used in many research studies across different fields.

Savsar and Al-Jawini (1995) used computer simulation to compare two types of production systems: push system and pull system. Savsar (1997) analyzed and compared *kanban* sizes in an electronic assembly line with simulation modelling. The objective was to determine the appropriate *kanban* size that has a high responsiveness to customer demands while minimizing inventory costs. Baesler and Sepulveda (2004) identified and analyzed operation bottlenecks to determine alternatives for production improvements in a lumber industry with the use of computer simulation. A 25% improvement in production throughput was reported. Marvel *et al*. (2005) employed computer simulation modelling to evaluate the efficiency in operation planning of a tire manufacturer. In the food industry, Vaidyanathan *et al*. (1998) applied computer simulation techniques to daily production scheduling in the roasted and ground coffee industry.

Some research studies that used economic analyses in combination with computer simulation to evaluate investment justification were Taylor (1999) and Owens and Levary (2002). Taylor (1999) used computer simulation to study the financial effects of three different inventory policies in a case study factory. A mixed-strategy inventory policy that minimizes the total operating cost was suggested. Owen and Levary (2002) use simulation to compare an existing extruded foods production line to a newly designed production line and found that the new design can significantly reduce the cost of production.

Finally, background information on the production process in the case study plant was collected and analyzed. The plant has two main products: product T which is roasted and ground coffee in cans and product Z which comes in two types: roasted coffee beans and roasted and ground coffee. The production steps are as shown in Figure 1.

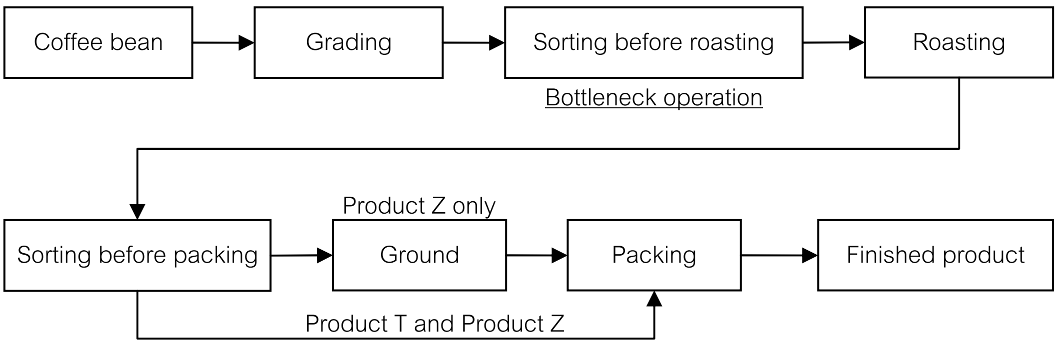

Figure 1. Roasted and ground coffee production line.

There are two types of raw coffee beans used in this operation, Robusta and Arabica. The raw coffee beans are graded by a grading machine. They are then sorted to get rid of physical contamination by sorting workers before roasting. The coffee beans are mixed and roasted in roasting machines at appropriate temperature. Following this, roasted beans for product T are all packed in cans, whereas roasted beans for product Z are packed or ground and left for degassing for one night before packing in bags.

Materials and Methods

This study consisted of three major steps: 1) data collection and input data analysis, 2) simulation modelling and 3) computational experiment and economic investment analysis. In the first step, data were collected by observing the operation and gathering one year of historical data at the case study coffee plant. These data included weekly production schedules, amounts of raw coffee beans that were processed, number of machines and workforce and processing times in each production step. To capture the process randomness for the simulation model, the data were fitted to find appropriate probability distributions for incoming weekly demands and the processing times using the Input Analyzer tool in ARENA 11.0. The input data analysis revealed that the weekly demands for product T were relatively constant and approximately six times as many as those for product Z. Despite considerably less demand, product Z demand (in kilograms) had a much higher variability in terms of amount.

In step 2, input probability distributions and the knowledge of the production processes were used to construct a simulation model (in ARENA 11.0) that represents the current production system. Once developed, the model was run and initial findings were that the operational bottleneck was at the 'sorting before roasting' operation for both products. This result was verified by experts at the plant, thus validating that the developed model was a sound representative of the current system. This insufficient number of sorting workers was due to continuously increasing demands. At the time of the analysis, the plant had ten sorting workers for product T and six for product Z. It was noted that, although product T has six times higher weekly demand, the assigned number of sorting workers was not proportionately higher. This was due to the constant variability in demand. In other words, the plant has to hire sorting workers more than necessary for product Z to handle very high variability in demand.

Finally, in the last step, two alternatives for capacity expansion were investigated and compared.

1) Increasing the workforce at the sorting operation: The optimal number of sorting workers was determined by OptQuest tool in ARENA 11.0. The objective function is to minimize the total labour cost, subject to the constraints that demand must be satisfied with the number of overtime hours not exceeding two hours per day for product T and four hours per day for product Z (due to higher variability in demand). These restrictions were suggested by the supervisor at the plant. The study planning horizon was chosen at 5 years. Each simulation run was therefore made at 5 years replication length with a warm-up period of 1,100 hours to ensure that the system reached its steady state. The number of replications per experimental setting was set at 40.

2) Automatic sorting machine investment: This alternative replaces the sorting workers for both products with an automatic sorting machine that requires two operators. The cost for this alternative consists of a fixed capital investment cost for the machine and operating costs for running the machine (i.e. electricity and wages for the operators.) The net present values (NPV) of both alternatives and payback period for the machine investment were computed in an Excel spreadsheet.

Computational experiment (alternative 1) and economic investment analysis (alternative 2) were conducted in various scenarios. Two sensitivity analyses were also performed on yearly demands for product Z and on interest rates (varied from 6% to 10% with 1% increment). All scenarios tested are listed as follows.

Scenario 1 The current level of demand;

Scenario 2 The most likely scenario with a linear increasing trend in demand at 20% per year (based on the information provided by the plant);

Scenario 3 Linear trends in demand – continuous increase (and decrease) in demand by 5%, 10%, 15% and 20% per year for the next five years; in combination with varying interest rates;

Scenario 4 Constant changes in demand – increase (and decrease) in demand by 5%, 10%, 15% and 20% and remaining at that level for the next five years; in combination with varying interest rates.

Note that sensitivity analysis on the demand for product T was omitted due to the information provided by the plant that the demand for product T will be constant because of the contract term with the customer.

Results and Discussion

Scenario 1: The current demand level of the case study coffee plant

For alternative 1 (increasing the sorting workforce), using OptQuest tool, it was found that the optimal workforce should be 12 sorting workers for product T and 9 for product Z, so that the capacity is sufficient for current demand. This optimal workforce would reduce the average amount of OT to be within the restrictions imposed by the plant supervisor (i.e. 2 hours for product T and 4 hours for product Z). The optimal workforce also reduced the percentile occurrence of OT. These results can be seen in Figure 2.

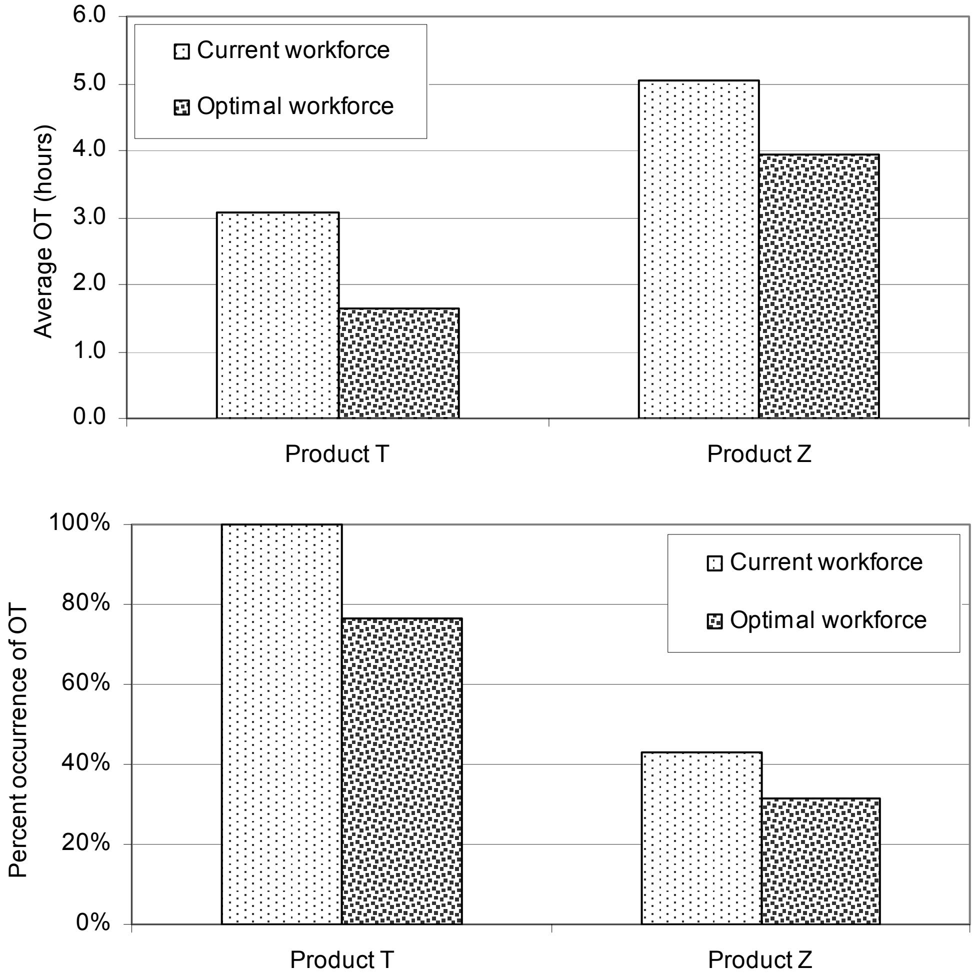

Figure 2. Average number of OT hours and percentile of occurrence between the current workforce and the optimal workforce.

For alternative 2, replacing sorting workers with an automatic sorting machine can completely eliminate the number of OT hours. As can be seen in Figure 3, with the sorting machine the average number of working hours per day at the sorting operation was reduced to 3.4 hours.

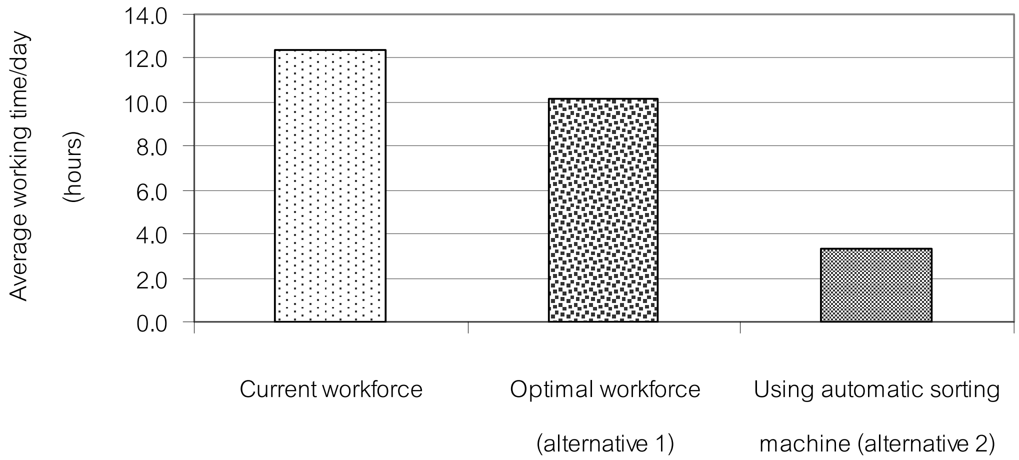

Figure 3. Average number of working hours per day.

Scenario 2: The most likely demand level

The most likely scenario was found to be that demand for product T remains constant while demand for product Z increases by 20% per year. The analysis planning horizon is 5 years with an interest rate of 8% for capital investment. The wage rate is at 191 baht/worker/day with OT rate at 1.5 times the regular rate. The wage rate will increase by 2.4% per year, according to the average increase in the lowest wage rate as required by labour regulations. Other benefits include an annual bonus of 2-months salary, social security at 5% of monthly salary and one worker's uniform at 500 baht per year. The capital investment for the automatic sorting machine is 3,100,000 baht with an annual maintenance cost at 10% of the machine's cost. The machine has a capacity of 1.5 tons per hour and requires 2 kW of electricity. The electricity price is at 1.73 baht per unit with 2.4% increase in its price rate per year.

For alternative 1, OptQuest gave the optimal workforce level for each year of increasing demand (see Table 1). Detailed cash flow for alternatives 1 and 2 can be found in Tables 2 and 3, respectively. The payback period for the capital investment on the automatic sorting machine is 23 months. Detailed calculation of payback periods is provided in Table 4.

Table 1. The optimal workforce for 20% increase in annual demands for product Z.

	Year				
	1	2	3	4	5
Product T	12	12	12	12	12
Product Z	12	15	18	22	27
Total	24	27	30	34	39

Table 2. Cash flow for the most likely scenario with increasing workforce alternative.

Cost (baht)	Year					
	0	1	2	3	4	5
Regular wage						
Product T		732,266	749,429	766,591	783,754	800,916
Product Z		732,266	936,786	1,149,887	1,436,882	1,802,062
OT wage						
Product T		174,768	169,113	187,680	194,625	119,716
Product Z		145,254	187,032	261,863	333,977	420,355
Benefits						
Product T						
- Social security		36,613	37,471	38,330	39,188	40,046
- Worker uniform		6,000	6,000	6,000	6,000	6,000
- Bonus		122,044	124,905	127,765	130,626	133,486
Product Z						
- Social security		36,613	46,839	57,494	71,844	90,103
- Worker uniform		6,000	7,500	9,000	11,000	13,500
- Bonus		122,044	156,131	191,648	239,480	300,344
Total cash flow		2,113,870	2,421,207	2,796,259	3,247,376	3,726,528
NPV at year 0	11,175,972					

Table 3. Cash flow for the most likely scenario with automatic sorting machine alternative.

Cost (baht)	Year					
	0	1	2	3	4	5
Capital investment						
Sorting machine	3,100,000					
Wage						
Machine operators		122,044	124,905	127,765	130,626	133,486
Benefits						
- Social security		6,102	6,245	6,388	6,531	6,674
- Worker uniform		1,000	1,000	1,000	1,000	1,000
- Bonus		20,341	20,817	21,294	21,771	22,248
Utility		1,896	1,960	2,030	2,107	2,193
Machine maintenance		310,000	310,000	310,000	310,000	310,000
Total cash flow	3,100,000	461,383	464,928	468,478	472,035	475,601
NPV at year 0	4,600,321					

Table 4. Payback period calculation.

Month	Cash flow (baht)		Monthly saving	NPV at time 0
	Alternative 1	Alternative 2		
1	176,156	38,449	137,707	136,795
2	176,156	38,449	137,707	272,685
⋮				
12	176,156	38,449	137,707	1,583,052
13	201,767	38,744	163,023	1,732,584
14	201,767	38,744	163,023	1,881,127
⋮				
22	201,767	38,744	163,023	3,034,592
23	201,767	38,744	163,023	**3,174,512**
24	201,767	38,744	163,023	3,313,505
⋮				
60	310,544	39,633	270,911	9,571,735

Scenario 3: Linear trends in demands

In this scenario, similar analysis to scenario 2 was repeated with continuous increase and decrease in demand by 5%, 10%, 15% and 20% per year for the next five years; in combination with varying interest rates of 6%, 7%, 8%, 9% and 10%. The payback period results are provided in Figure 4. For the effect of decrease/increase trends in demand, it can be seen that increasing trends in demand reduce the payback period significantly, while decreasing trends in demand prolong it.

For the effect of interest rate, it was found that decreasing interest rates would result in reduction in the payback period. This effect also depends on the level of increase/decrease in demand. That is, the effect is most significant when the annual demand has a continuous decreasing pattern at 20% per year (i.e. the effect is most evident on the left tails of the graphs). When trends in demand change from decreasing to increasing, the effect gradually diminishes to almost no effect at 20% increase per year (i.e. the right tails of the graph has no effect of interest rate).

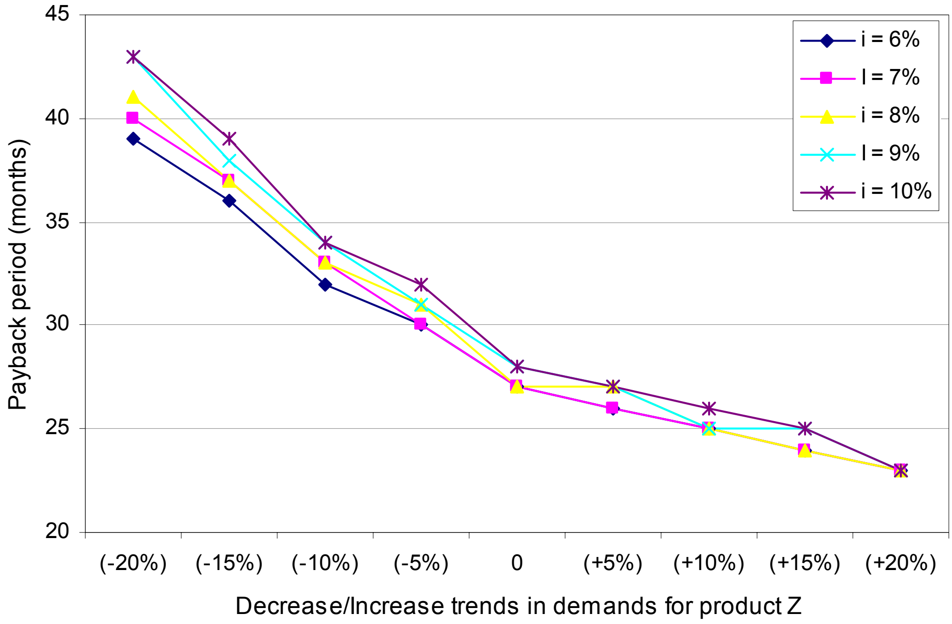

Figure 4. Payback periods at various demand trends and interest rates.

Scenario 4: Constant changes in demand levels with no trends

In scenario 4, similar analysis was repeated with changes in demand (increase and decrease) by 5%, 10%, 15% and 20% from the current level, remaining at those levels for the next five years; in combination with varying interest rates of 6% to 10%. The payback period results are illustrated by the graph in Figure 5. Similar effect of changes in demand to that of scenario 3 can be observed in this scenario; but in a less dramatic fashion (i.e. slopes are less steep). Similar statements can be drawn for the effect of interest rates – that is, a decrease in interest rate results in reduction in the payback period. However, because the changes in demand remain constant in this scenario, the interest rate effect is almost the same, regardless of the decrease/increase changes in demand.

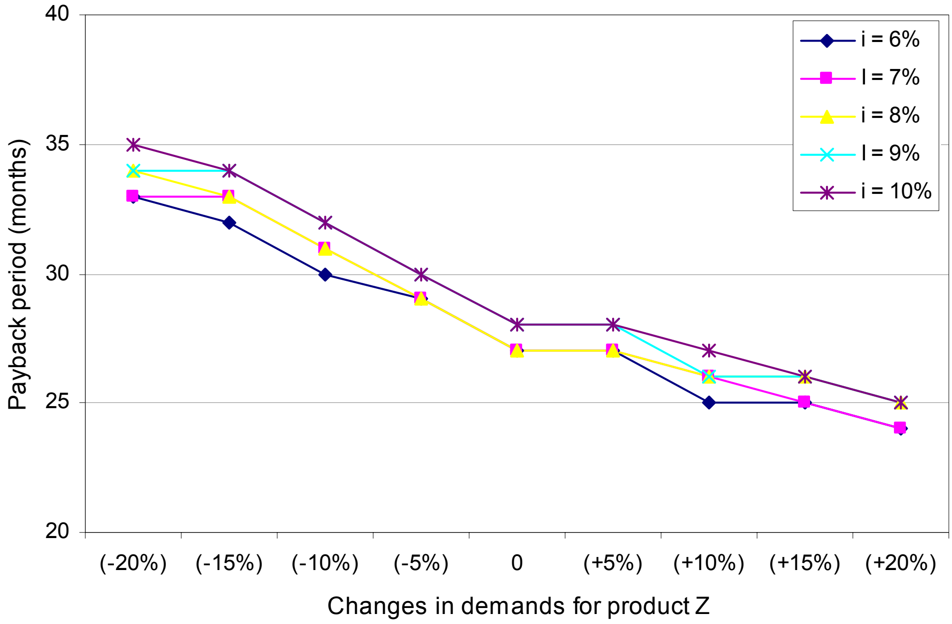

Figure 5. Payback periods at various demand changes and interest rates.

Overall discussion

The comparisons between increasing workforce at the sorting operation (alternative 1) and using an automatic sorting machine (alternative 2) based on the estimated payback periods in various scenarios showed that investing in the sorting machine to replace sorting workers at the operation bottleneck is a very attractive choice, especially when demand is on the rise. In most scenarios, it only takes a few years to pay itself off and is a better alternative for cost saving compared to alternative 1. Use of a sorting machine also has a number of other advantages. It can remove the bottleneck at the sorting operation and completely eliminate the number of waiting jobs (i.e. batches of coffee beans to be sorted before roasting), thus making waiting time at this operation zero. This results in a much better flow in the production system. Also, the capacity of the machine is so high (1.5 tons per hour) that the remaining capacity is capable of handling increases in annual demand in the future. In addition, it can handle the high variability in demand for product Z. In other words, there is no need to hire more sorting workers than necessary just to handle excessive weekly demands that rarely occur (a few times per year.) Another very important benefit is that the sorting machine can perform the sorting operation to get rid of physical contamination (e.g., rocks, soil, chips of woods, glass, etc.) and produce a much higher quality of sorted coffee beans than the human workers, which leads to higher quality of the final product to customers.

Conclusion

This study demonstrates the use of computer simulation modelling in determining the best alternative for capacity planning and expansion for a case study in the roasted and ground coffee industry. Simulation results in various demand scenarios show that investment in the automatic sorting machine is well justified with its short payback period and is a more attractive choice than hiring more workers.

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