Flexibility in Plastic-Bottle Production System

ESD.71 Application Portfolio

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ABSTRACT

This paper is intended to study the possible financial benefits for a plastic bottle production system in Thailand if the flexibility is incorporated into their production system design. The system description is firstly introduced along with its background before the study reveals some sources of the salient uncertainties identified in its surroundings, especially in this particular case study. The fixed-capacity system design and proposed flexible system designs are compare and contrast to show what kind of system design would be suitable to deal with the surrounding uncertainties. The popular evaluation techniques, consisting of decision tree, binomial lattice are also used to assess the designs. After the assessment, the flexible system design is favorable due to the ability to provide higher value to the manufacture since the flexible design allows the manufacture to take all the opportunities while avoiding a commitment in large investment without a clear picture about their demand.

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Background

Many traditional production systems in developing countries have usually been designed based on the requirements that are believed to provide the optimum value in a stable environment. **However, the optimal production system design sometimes lacks an ability to deliver the promising value when the system environment changes due to uncertainties**. For that reason, to enjoy the advantages of upside opportunities while avoiding downside eventualities, one way is to incorporate flexibility into the design of the production system.

This paper examines the current design of the production system of a plastic-bottle manufacturer in Thailand while analyzing the possible benefits if the system of the manufacturer could be redesigned by taking flexibility into consideration. As it is believed that a flexible design of the production system would be able to better deal with the surrounding uncertainties, implementable production strategies for the plastic manufacturer are invented to evaluate whether the flexibility can possibly help the manufacturer production system and to assess how much benefit the manufacturer could gain from the system redesign.

It was a fact that Thailand had been facing economic regressions due to internal political problems, which then led to inconsistent market behaviors. This long-lasting unstable system environment becomes a key driver for this manufacturer to pay more attention to the flexibility in the production system design.

Thanks to the crisis, the manufacturer provided me an opportunity acquire some proprietary information for analytical purpose, in order to construct recommended strategies for the manufacturer to improve the production system design by incorporating the flexibility to allow the manufacturer to continue staying in the unpredictable business environment competitively.

Chapter 1: System Description

In this case study, the main system component being considered is the **plastic-bottle production system** in which seven plastic bottle-molding machines[1] with a production capacity of 1,600 bottles/hour are operating in parallel to produce plastic bottles for various customers. The machines are the key system element of this system as the total production capacity relies on those high-end machines' performance. Although the machine operations are fully automatic, they still need human to periodically monitor in order to control manually when needed. This practice can ensure that the machines are fully utilized to reach the largest production volume while maintaining the product qualities at their best. For that reason, the experienced labor force is another important system element identified in this production system.

Figure 1: Actual Image of a Plastic Bottle-Molding Machine

Furthermore, another relevant system component is the manufacturer's customers who are the soft drink manufacturers like Coca Cola, the vegetable oil manufacturers, the bottled-tea manufacturers, etc. They have maintained a good relationship with the manufacturer for years and are still ordering several millions of bottles regularly, leading to several millions baht in manufacturer's revenue.

Based on the information obtained from the manufacturer's MD, the manufactory always produces the bottles as many as possible to utilize the assets at their best. This consistent production policy ensures that the customer orders will be ready before the product delivery date. As a consequence, the internal warehouse is built to serve stocking purpose. The inventory has become another relevant system element due to the production policy since then.

To efficiently operate the plastic bottle-molding machines, a steady stream of electricity and water are indispensable in the manufacturing operations. They are so critical that the safety of the machine conditions and the labor forces can be annihilated. As a result, these infrastructures are considered in the scope of this production system. The following illustration is constructed to provide a better understanding of the production system scope.

[1] http://www.nisseiasb.co.jp/en/products/pf84b_e.html

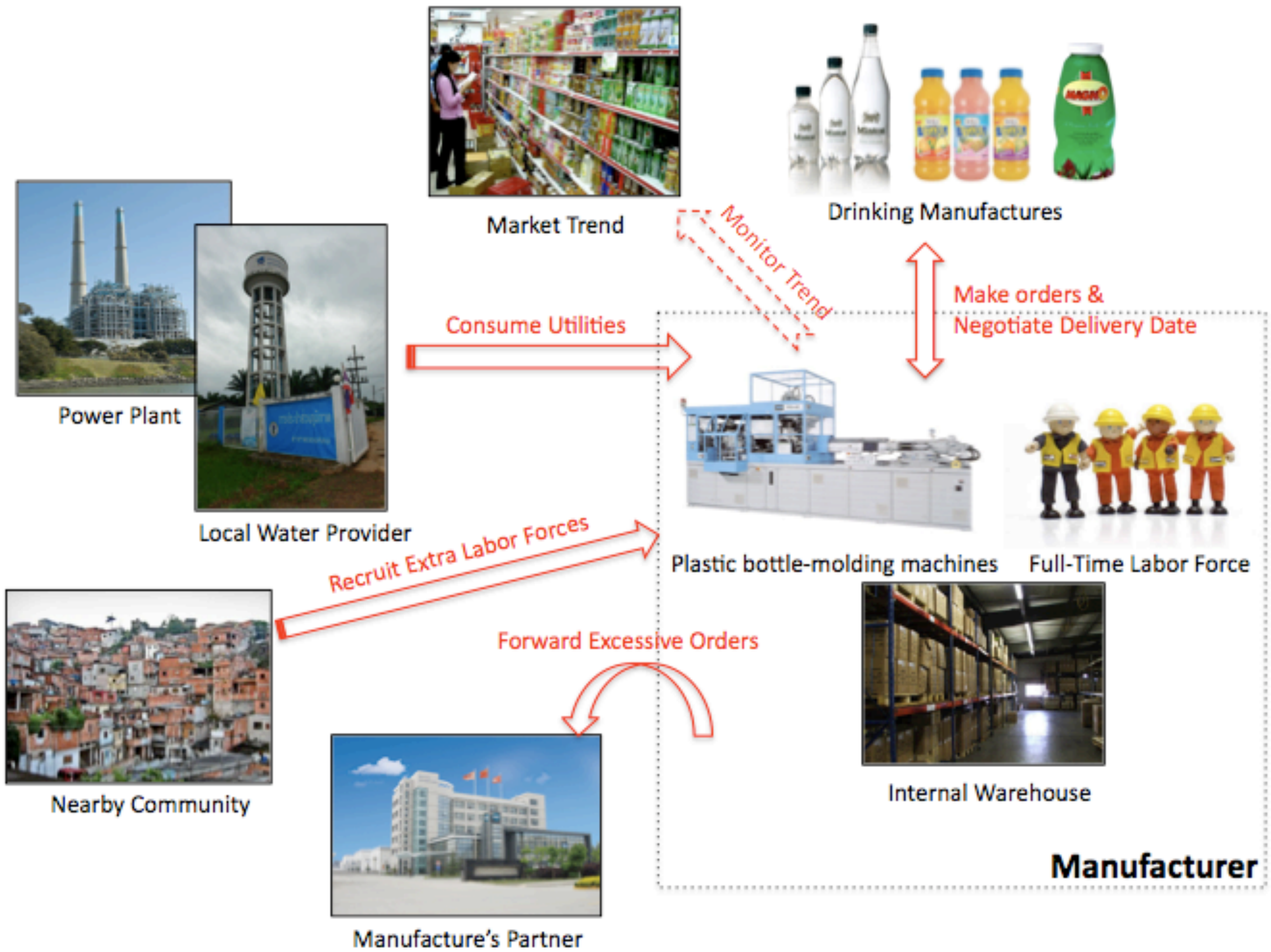

Figure 2: Production System Components

As shown in the illustration, the system scope includes:

- 7 plastic bottle-molding machines
- 150 full-time workers
- Manufacturer's warehouse[2]
- Market trend[3]
- Records of customer purchase orders (i.e., drinking manufacturers)
- Utilities – electricity and water
- Strategic partner
- Nearby community[4]

Recently, the managing director foresees the unsteady demand from the slight drop in customer orders, which lead to the management concern about the design of the production system. Hence, this study is conducted to help the manufacturer reveal all of the possible uncertainties that could affect the production system, which will be present in the subsequent chapter. To confirm the impact of each uncertainty identified, a series of interviewing sessions has also been conducted along the way.

Chapter 2: Source of Uncertainty

Like any other well-defined systems, the production system being considered was initially designed based on the opportunity to make money, which appeared to be the strongest driver for current investors to invest in the manufacture and this kind of businesses. Unfortunately, the current design of the production system depends on the accurate sale forecast and strict cost controls to survive in its competitive landscape since the investment was spent on this long-term business.

As the forecast is the extension of the past, the current system design is always affected when the sale forecast is totally wrong. This seems to be the design defect in the production system. To solve the right problem, the current system and its surroundings were investigated in this case study to identify the sources of uncertainties, which seem to be the root cause of the problem. In addition, a series of interviewing sessions with manufacturer's MD was conducted to gain insights about other sources of uncertainties as well as to confirm the findings in the production system. Since there are many sources of uncertainties, the only salient uncertainty sources that significantly impact the ENPV of the plastic-bottle manufacture are investigated in-depth while other related uncertainties are gathered and listed for readers' information. Note that N/A means data is not available.

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[2] This real information about this system component is not included in the decision tree model and lattice model. Instead, the assumption is applied in the analysis for simplification

[3] Same as above

[4] Same as above

Uncertainty	Likelihood	Impact	Range	Variability	Justification
Client Demand (For the manufacture)	High	Very High	5M-8M units per Month	±13%	This salient variable will be justified in the subsequent section.
National Market Trend of Plastic Bottle Demand	High	High	N/A	N/A	The trend of market demand in plastic bottles keeps changing over time due to several exogenous factors such as the national economic growth, political concerns, foreign direct investment, etc., Since the manufacture customers are selling their product to the local market, the local market trend impacts the sales of manufacture customers, resulting in the uncertainty of the manufacture client demand at the end. So, the production system is affected indirectly from this variable.
Production Technology Changes	High	Medium	N/A	N/A	The new production technologies are always introduced to the manufacture to help them produce their products faster. However, every technologies need to be evaluate and careful choose due to the limited manufacturer's investment. As a result, the potential effect of this uncertainty might not be strong in this particular case.
Government Regulation on Plastic Usage	Very Low	Very High	N/A	N/A	A "green" trend is going toward non-recycled plastic products, which impose the great risks in this business domain. If the government decide to develop any environmental policy discouraging use of the plastic-contained products, the production system might be stagnate and the operation might suddenly close to save the manufacture profit.
Machine Breakdown	Low	Very High	0 – 500,000 baht per machine	+5%	The machine breakdowns severely impact the production system, as the machines are the key system elements. Consequently, the production system cannot deliver what it commits if the breakdown occurs

Uncertainty	Likelihood	Impact	Range	Variability	Justification
Labor Wage	Low	Low	3,300-4,840 baht per Month	±5%	Labor wage is an uncertainty that could possibly affect the ENPV of the production system. However, the cost of labor wage is relatively small when compared to other costs.
Utility Cost	Low	High	2.2M-3M baht per Month	±2%	Water and electricity are the main inputs for the production system. The utility costs account for a large amount of manufacturer's expenses. For that reason, the uncertainty could affect the production system greatly. Luckily, the cost is quite constant over past few years. So, there is less chance for it to change much
Inventory Cost	Medium	Medium	12,500-25,000 baht per Month	±8%	The cost of warehouse varies from month to month because the manufacturer might need to hold stocks for some time periods while they might not want extra storage space in some months as they also have their own inventory.

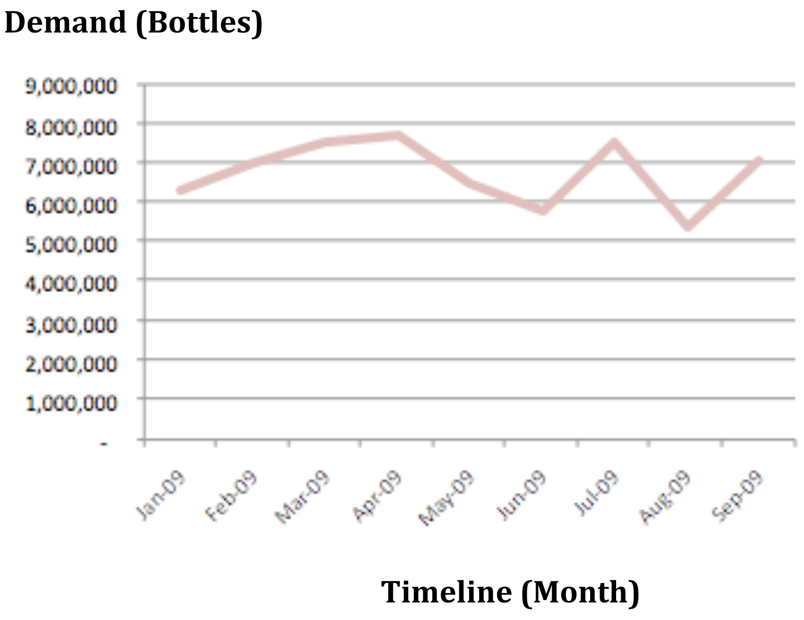
Table 1: Sources of Uncertainty for the Current Plastic Production System

Salient Sources of Uncertainty

Since the salient uncertainties found in any system usually pose great risks on the expected system outcomes, it is important for the system designers to identify those uncertainties and understand how they impact the system. These insights will help the system designers to design a better system that is preferred for its variable surroundings.

Client Demand: Like most production systems, the most salient uncertainty is the client demand because the more the client demand is, the higher profit the manufacture could make (assuming the other variables are fixed). Inversely, if the clients' demand drops, the manufacture could be in trouble due to the on-going costs (i.e., full-time labor wages, inventory rents, etc.,). In fact, there are many exogenous factors that affect the client demand. For example, the national economic problem can significantly decrease the client demand since the client cannot sell their drinking products, which use plastic bottle as a container. Also, the green trend can kill the needs of the plastic bottles in the market. Luckily, it takes time for the trend to become a mandatory national law. With the strong influence of this uncertainty on the expected financial outcome, client demand will be used in the further model to suggest a better design of the production system.

Based on the historical purchase orders, the average production volume for the clients each month is about 6.7 millions bottles whereas the standard deviation of these records is about 800,000 bottles, which is quite high volatile. The latter statistical measurement indicates that the client demand strongly fluctuates over time, resulting in the difficulty in planning of the current production system design where the production capacity is fixed at particular volume. Specifically speaking, the manufacturer cannot take any upside opportunities while being responsible for the fixed monthly costs when the downside eventualities occur.



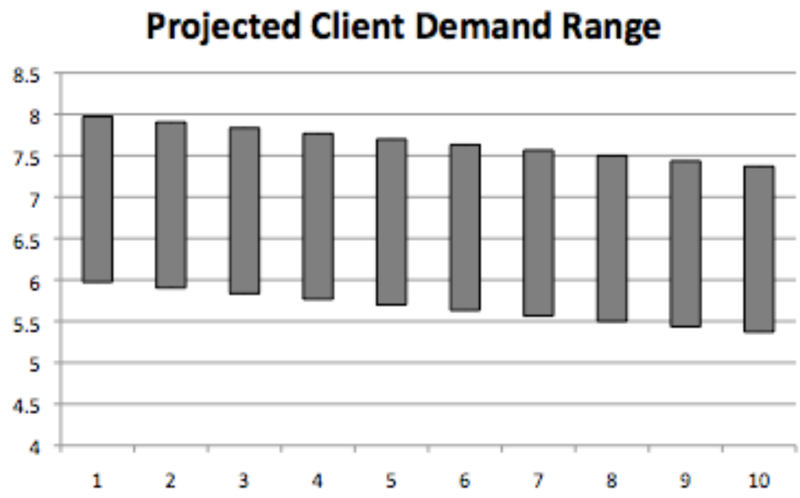
Jan	6,317,747
Feb	7,011,764
Mar	7,554,308
Apr	7,709,384
May	6,496,144
Jun	5,784,354
Jul	7,542,820
Aug	5,385,466
Sep	7,043,463

Figure 3: Historical Client Demand in 2009

Also, the demand trend in this manufacturer is perceived to decrease at 1% per period, which corresponds to the US plastic bottle demand in 2007 when the average demand growth has started decelerating to about 2% (0.2% per period approximately) due to the double whammy of high resin prices and sluggish growth in consumer spending, growth was even slower in the first half of 2008[5].

Assuming that the trend remains the same over the next 10 periods (0.6% decrease[6]) while the variability is evenly distributed, the range of the expected clients' demand could be displayed in the graph below.

Demand (Millions Unit)



Period (Month)

Figure 4: Projected Client Demand for next 10 periods

[5] http://www.thefreelibrary.com/Plastic+bottles+face+slower+growth.-a0179160392
[6] The average decrease rate between the actual historical orders of the manufacture (1% per period) and the US demand trend of plastic bottles (0.2% per period)

Machine Breakdown

Having interviewed the managing director of a studied plastic manufacture, another salient uncertainty in the production planning system is the failure of the plastic bottle-molding machines. As the production volume heavily depends on the machine availability time, the breakdown becomes a bottleneck of the system. A part of the production system must be stopped and put into a waiting mode until the failed machine is repaired. According to the manufacturer's MD interview, the worst case posed the loss in the opportunity cost about 600,000 baht.

The losses of the opportunity costs are estimated from the number of days that the failed machine is out of operation. Based on the company historical records, there are three types of machine breakdowns.

- **Minor Machine Breakdown:** This breakdown is usually fixed within 1-3 hours by the internal technicians, resulting in 10,000 baht in loss.
- **Major Machine Breakdown:** This breakdown is usually fixed within 8 hours by a combination of the internal technicians and on-phone consultation with the supporting team from the vendors (1 working day). This type of breakdown costs 40,000 baht in loss.
- **Severe Machine Breakdown:** This breakdown is usually fixed within 3 weeks by the supporting vendor on the site (15 working days), causing 600,000 baht in loss.

Although this uncertainty is crucial, it is not incorporated in the further model due to the fact that the manufacturer cannot provide sufficient data to justify the range and variability of the expected loss. Anyhow, it is worth mentioning that machines breakdown is another important uncertainty to be aware in this production system. Unfortunately, this case study will not further investigate this uncertainty.

Chapter 3: Alternative Designs Chosen for Analysis

Two chosen production system designs, which are so-called a fixed-capacity design and flexible-capacity design, are modeled to be analyzed and then evaluated. To make this system design analysis more useful in reality, the fixed-capacity design mimicked the current production system of the manufacturer in this case study while the flexible system design is a proposed system design that allows flexible options to be executed when needed. Anyway, it is worth introducing how the actual production system works to gain better understanding about the system currently operating.

In the actual production system being considered, there is one main system input, which is the final customer orders (or client demand). Obviously, the ENPV of the manufacturer depends on the volume of plastic bottles made for those customers. In order to maximize the manufacturer's profit, the MD usually takes the customer orders that can meet two main conditions:

1. The purchase order is considered a high-profit order
2. The manufacturer must have enough capacity to satisfy the amount specified in the purchase order within the given timeframe

Based on the manufacturer's database records, there are two types of customer orders:

- **A Single-Time Order:** This kind of order is done only once. The orders specify a precise numbers of the products
- **A Contract:** This kind of order requires a monthly production, which is usually defined in the contract. For this reason, the contract-type order required a longer period of production and has more impact to the ENPV of the production system.

Once the orders are received, a set of machines is assigned for mass production based on the machine availability and the machine ability to produce the given products. A customer order is usually finalized when the customer can accept the offered deadline of product delivery, which is primarily based on the availability of the machines at that time. Unfortunately, there are some constraints on the machines limiting their availability at a given time:

1. Some products can be produced by a specific type of machines only. For that reason, the specialization of machines becomes one of the constraints of the production system.
2. Sometimes orders with higher value are prioritized so the manufacturers can make more money than the currently processing order. As a result, a given machine A, which has a high capacity and normally produce product A, can be switched to produce product B if the new order of product B can make a higher profit. Other machines that have an ability to produce product A will be assigned to maintain the work of machine A.

Other four internal system inputs, presenting in the actual production system, are the current manufacture capacity, utility costs, labor costs and machine breakdown possiblity. The costs of utility and labor can either increase or decrease based on the current machine capacity. These five system inputs are needed to calculate the ENPV of this production system. The conceptual view of the actual production system is illustrated below.

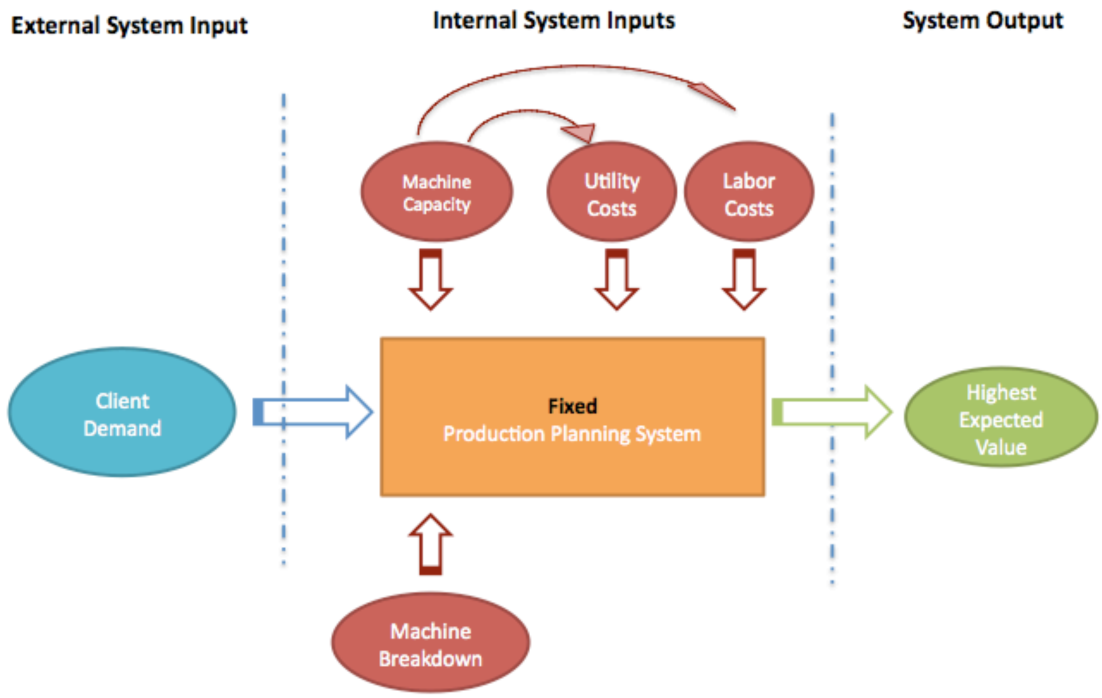


Figure 5: Actual System Design

Nevertheless, to simplify this complex production system, a variety of customer orders are consolidated to single homogeneous type of order. So, there is no differences (i.e., orders have same profit margin, orders require same product type, etc.,) in customer orders, result in the absence of order prioritization. This assumption is applied to the product, so the product can be produced by any of the 7 machines. Subsequently, no machine switching occurs in the further models. Last but not least, the machine breakdown is not incorporated in the further models due to the fact that the manufacturer cannot provide sufficient data for estimation.

Design 1: Fixed-Capacity System Design

This production system design has fixed capacity to produce the plactic bottles. Regardless the demand evolution, the manufacture can produce products as many as the monthly orders indicate but cannot produce beyond the capacity limit. Also, this system design will not produce the product more than what is prescribed in the total amount in purchase orders (PO) suggested by the monthly demand estimation. The system architecture can be displayed below for better understanding.

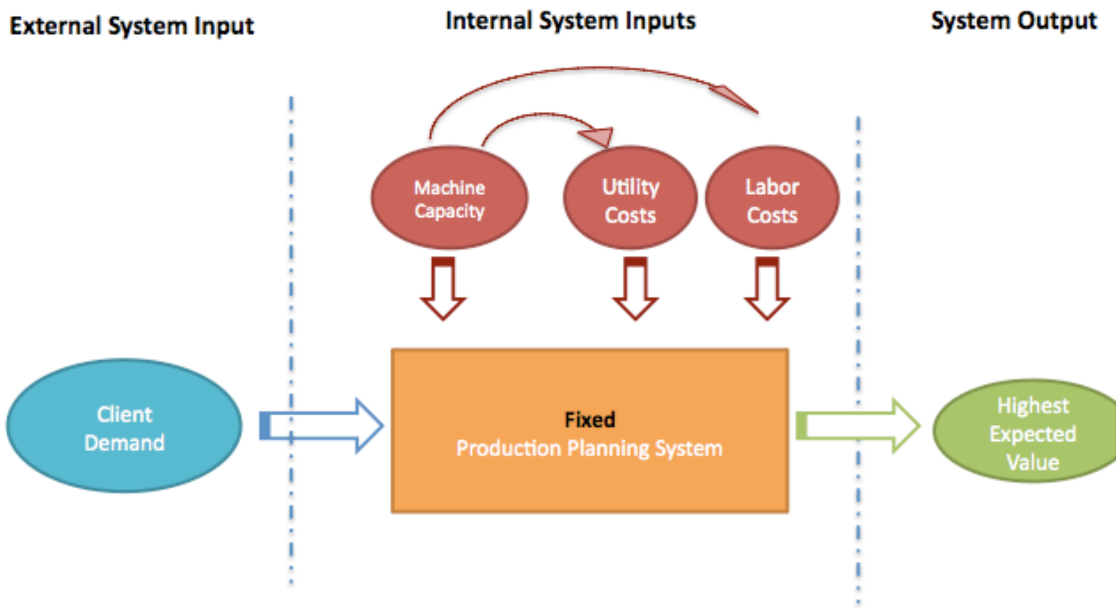


Figure 6: Fixed-Capacity System Design

As a consequence, **the monthly total production volume can be only equal or less than the total production capacity because the MD needs to reject the customer orders that might not be satisfied by the current capacity of the manufacturer's available machines.** In the system specification of this design, the maximum production volume is at 5,929,000 bottles per month or 38,500 bottles per day when assuming that 1 month has 22 working days.

System Specification	Bottle/Month (Assuming 22 working days)
Maximum Capacity	5,929,000

Table 2: Specification Fixed-Capacity System Design

In addition to that, the normal production costs 726,000[7] baht per month for the labor wages while the utility costs are about 2,200,000 baht monthly or 100,000

[7] This cost is based on a multiplication of the average salary rate at 220 baht per day and 150 full-time employees at this time

baht a day, resulting in a normal monthly expense at 2,926,000 baht in total. The table below summarizes all the major manufacturing expenses.

Expenditure Source	$/Month (assuming 22 working days)
Full-Time Labor Cost	726,000
Utility Costs	2,200,000
Total Monthly Expenditure	2,926,000

Table 3: Monthly Expenditure of Fixed-Capacity System Design

The apparent advantage of this design is to gain the benefit of the economy of scale if the demand has small fluctuations and remain at the production limit at 5,929,000 bottles a month.

The financial model of the fixed-capacity design

The **financial model of the fixed-capacity design** focuses only the actual customer orders, which is the main source of income. Since the selling price is set at the competitive price at 1.65 baht a bottle. For that reason, the revenue structure can be calculated as follow.

Revenue Structure
Monthly Total Revenue = Monthly customer orders * Predefined Selling Price *If the Monthly customer orders >= Limit,* *Then, monthly customer order = limit*
Cost Structure
Monthly Total Costs = Cost of Utility + Cost of Labor

Table 4: Financial Structure of Fixed-Capacity System Design

This fixed-capacity system design can be alternatively depicted in the following figure.

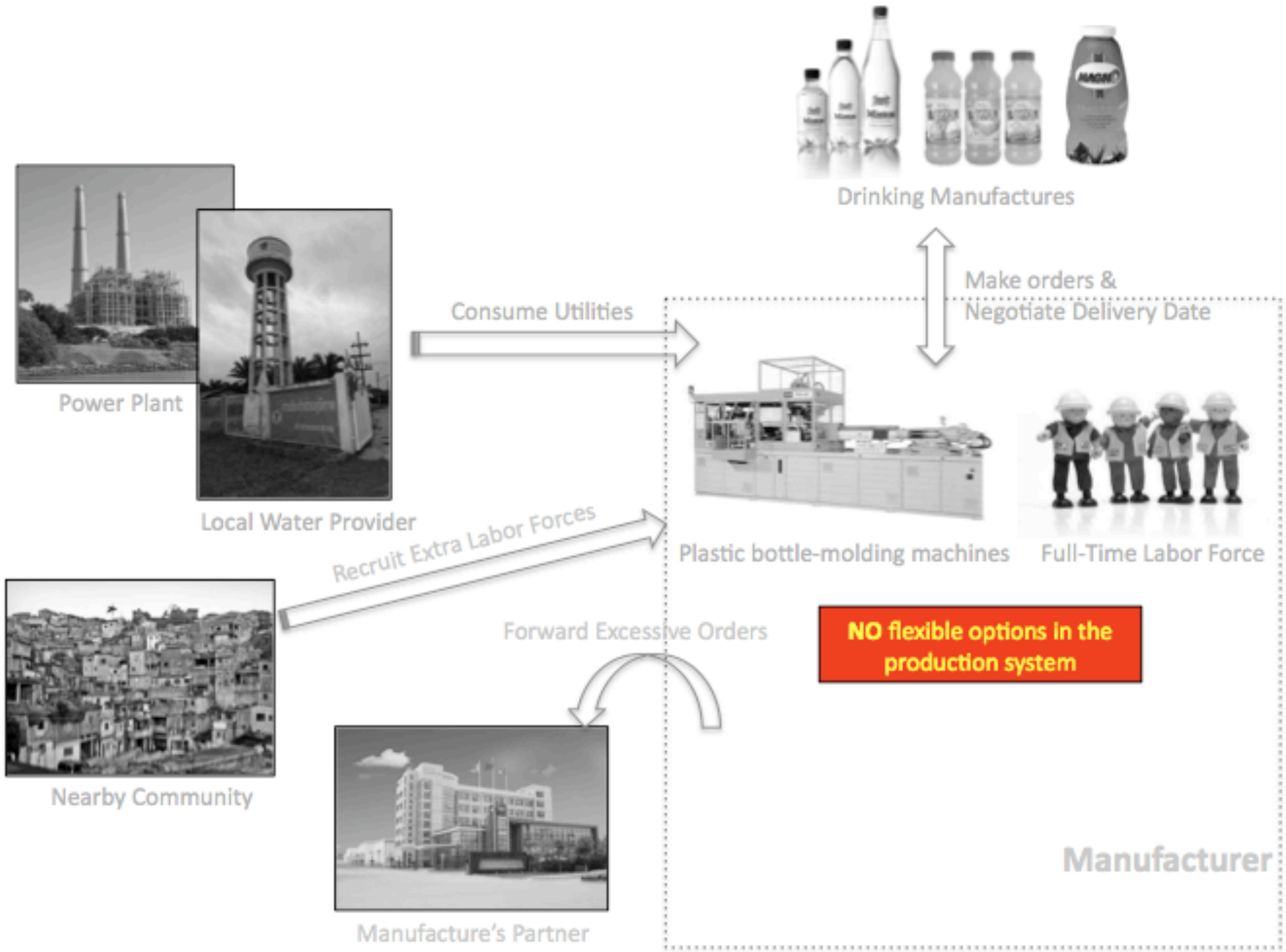


Figure 7: Fixed-Capacity System Design in the Entire Production System

Design 2: Flexible-Capacity System Design

Although the flexible production system design has partially been implemented in the current system settings, it is still possible for the manufacturer to extend their system capacity when needed to enjoy the full benefit of the flexible production system, which is believed to successfully capture the higher demand, resulting in the higher profit in many upside scenarios while saving investments in expanding the production capacity by delaying the decision until the uncertainty is resolved. Consequently, the manufacturer can avoid paying a large amount of monthly on-going costs (i.e., utility, labor, etc.,) when the demand is low. The system architecture can be illustrated below for better understanding.

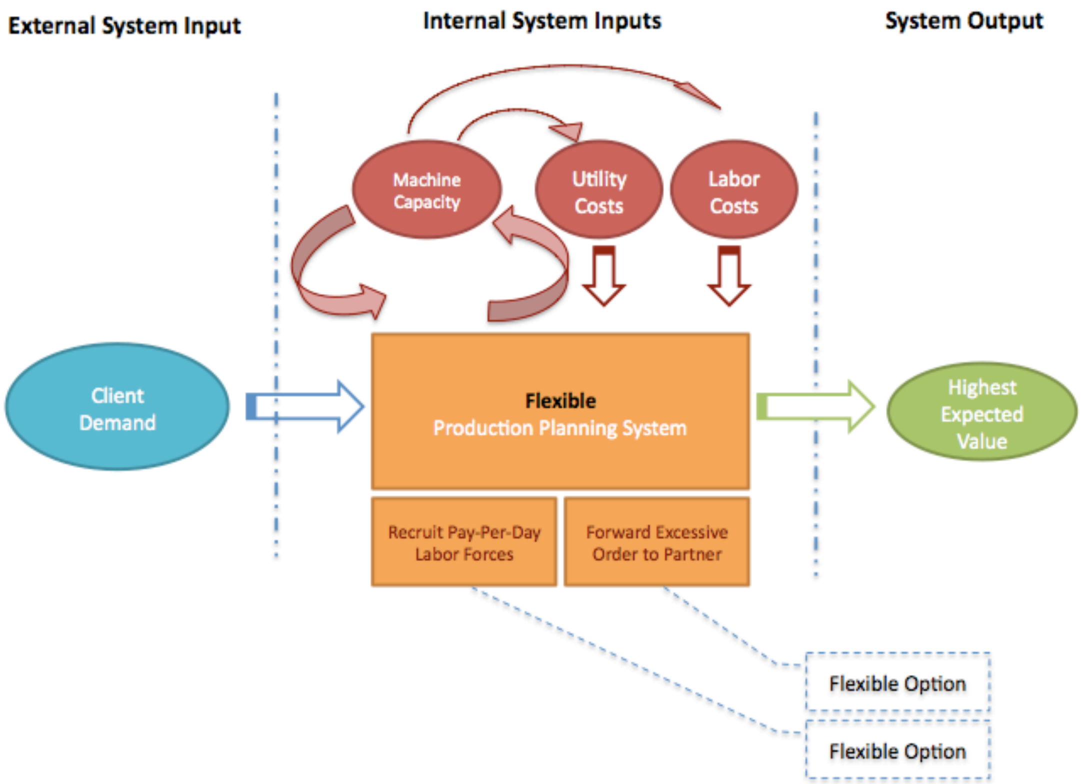


Figure 8: Flexible-Capacity System Design

The flexible production system can be expanded from the actual system design by implementing the following policies:

- **Recruit labor force for flexible working shifts:** When there are high customer orders, which require more working hours than the normal working hours, the extra temporary labor forces can be recruited to handle the increased production volume as needed.

- **Forward excessive orders to manufacturing partner:** The policy will ask for help from the manufacturing partner to produce over-capacity orders so that the manufacturer can commit to produce plastic bottles for extra customer orders although the current capacity is not large enough to cover all the orders at the given time.

In conclusion, the flexible production system design empower the MD to take over-capacity customer orders to fill up the rest of the available machine capacity while forwarding the excessive orders to the partners to produce the products instead of rejecting the customer orders due to the over-capacity orders. This could be the case when the customer orders are high in some periods (seasonality of the products). Furthermore, when the product quantity of the customer orders is smaller, which can be handled with the current machine capacity, but there is not enough time to process and fulfill the orders within the normal operation, the extra labor force can be recruited to provide flexibility to operate the machines more than the normal working hours, resulting in the ability to produce higher volume when needed.

As a subsequent, **the monthly total production volume will be equal to the total monthly demand because the MD can accept all the customer orders.** This flexible design is based on the following assumptions.

- No other competitors claiming the market share. So, all the client demand will be processed by the manufacture
- There is an agreement with the partner to produce products for the manufacture with prioritization
- There are abundant labor resources that can be recruited at the beginning of each month

Unfortunately, nothing comes for free as there is always a trade-off. The cost per unit of these two strategies is more expensive than normal in-house production. Specifically speaking, the manufacturing partner asked, on average, for an additional 30% on the production cost, which is about 30,000 baht per a 100,000-bottle order. The average cost of producing a plastic bottle is about 1 bath. For this reason, the partner's outsourcing price per bottle costs 1.30 baht according to the MD interview. This yields an additional cost at 0.3 baht a bottle for the manufacture.

Similarly, if the manufacturer decides to recruit more workers to work during weekends, the additional cost the manufacturer must pay for the extra labors is equal to the minimum daily salary rate (203 baht) multiplied by 7 because one machine requires one labor to control and operate and the manufacturer has 7 machines currently deployed. As a result, the additional cost is equal to 1,421 baht per 38,500 bottles or 0.037 baht per bottle.

The calculation is based on the following assumptions:

1. One day normally has 1 working shift, which is equal to 8 working hours[8]
2. A machine can normally produce 38,500 plastic bottles a day (8 working hours)

[8] This means one day can have up to 3 shifts. However, this will cost the manufacturer more for the extra labor cost. Specifically, the manufacturer must pay 2,842 baht a day (24 working hours) for the extra labors needed while the full-time labors already get fixed salary from the manufacturer, which is 726,000 baht a month in total.

Flexible Production Strategy	Objective	Addition Cost Per Bottle
Forwarding Excessive Orders to Manufacturing Partners	To increase overall production capacity by expanding the ability to complete over-capacity orders via partners (Outsourcing)	0.300
Recruit Pay-Per-Day Labors	To increase the ability to produce more in the manufactory (in-house production)	0.037

Table 5: Flexible Production Strategies for Manufacture and Associated Costs

The financial model of the flexible-capacity design

The **financial model of the flexible-capacity design** also focuses only the actual customer orders, which is the main source of the revenue. Since the selling price is set at the competitive price at 1.65 baht a bottle. For that reason, the revenue structure can be calculated as follow.

Revenue Structure
Monthly Total Revenue = Monthly Customer Order * Predefined Selling Price *If the Monthly customer order >= Capacity Limit,* *Then, there are 2 flexible options available for exercise:* • *Recruit Pay-Per-Day Labors only if monthly customer orders <= 23,940,000*   o *The predefined selling price is deducted by 0.037* • *Forwarding Excessive Orders to Manufacturing Partners*   o *The predefined selling price is deducted by 0.3*
Cost Structure
Monthly Total Costs = **Cost of Utility + Cost of Labor + Additional Costs for Setting Flexible Option** • *The additional cost for setting the "Recruit Pay-Per-Day Labors" flexible option = 20,000 baht* • *The additional cost for setting the "Forwarding Excessive Orders" flexible option = 30,000 baht*

Table 6: Financial Structure of Flexible-Capacity System Design

This flexible-capacity system design can be alternatively depicted in the following figure.

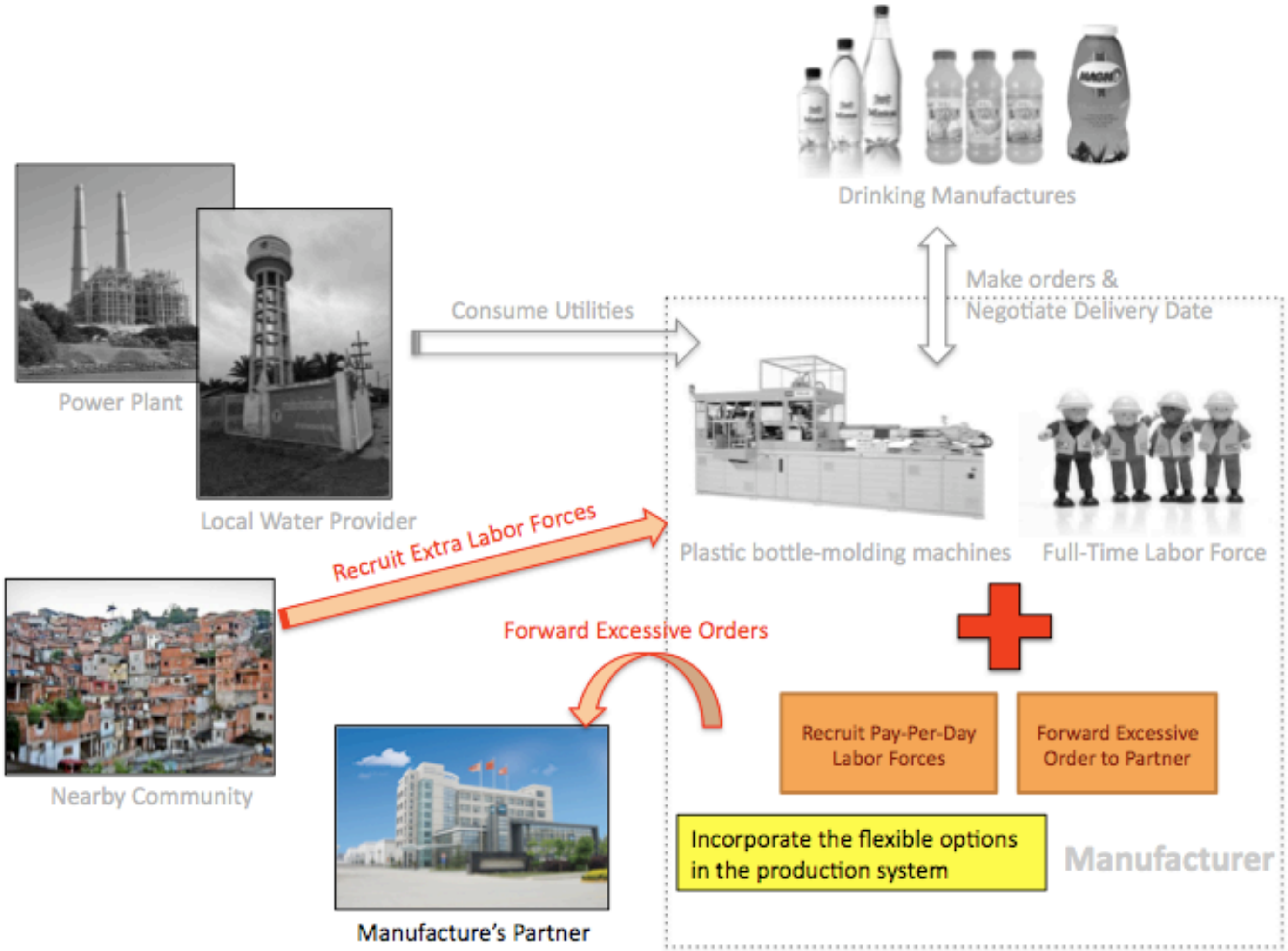


Figure 9: Flexible-Capacity System Design in the Entire Production System

Chapter 4: Two-Period Decision Analysis

A 2-period decision analysis was conducted to assess the optimal sequential decisions that would yield the maximum expected NPV for the manufacturer. In this particular case, each period takes 1 month, corresponding to the monthly company meeting of the manufacturer's management team to discuss about production strategies, which then lead to a course of actions to adjust the current operation practices for maximizing the expected net profit. Normally, the managing director (MD) of the manufacturer, who is the final decision maker, makes a production planning decision based on the following two key factors:

- The final monthly production volume in total

  (obtained from the confirmed purchase orders)

- The current capacity of the machines

As there is an uncertainty in the demand, this model classifies and simplifies demand levels into three distinct ones, which are high, medium and low. Based on the historical customer orders, the approximate production volume for each demand level and its associated probability are developed for this model. It is the manufacturer's "purchase order" database that shows the maximum monthly order is rounded up to 8 millions bottles while the minimum monthly order is about 5 millions bottles, resulting in the approximate production volume for this particular model while the assumption on the probability is defined for each demand level according to the distribution of the monthly demand data.

Demand	Probability	Designated Production Volume
High	0.3	8,000,000
Medium	0.45	6,500,000
Low	0.25	5,000,000

Table 7: Probability of Demand Levels for the First Period

From the table above, it can be seen that the chance of getting medium-to-high orders is much higher than the low demand ones (75% to 25%). However, the current capacity cannot cover the demands of a medium-to-high cases because the 7 machines available in the plant can produce only 5,929,000 bottles per month (22 working days) when excluding extra working shifts. In other words, the manufacturer can normally produce 38,500 bottles a day in total although the extra working shifts are possible. For that reason, either "recruiting temporary labors" or "forwarding orders" is possibly chosen in each decision period to provide a flexibility of production to maximize the manufacturer's expected net profit.

According to the data of historical purchase orders, the demand in the first period and that of the second period seem to have a small negative correlation[9], which come from the local economic problems. As a result, the Monte Carlo simulation is used to populate

[9] Assume that the growth rate is equal to -0.6% per month (See "Sources of Uncertainty" section for justification to use this designated rate)

the expected production volume for the second period as displayed in the following table.

	High Demand Case Period 1	High Demand Case Period 2	Medium Demand Case Period 1	Medium Demand Case Period 2	Low Demand Case Period 1	Low Demand Case Period 2
Starting Demand	**8,000,000**	8,003,897	**6,500,000**	6,455,143	**5,000,000**	4,963,743
Demand Growth Per Period	-0.60%	-0.60%	-0.60%	-0.60%	-0.60%	-0.60%
Volatility	12%	12%	12%	12%	12%	12%
Projected Demand in the period (Average Demand from 1000 simulation)	8,003,897	**7,951,837**	6,455,143	**6,393,435**	4,963,743	**4,894,517**

Table 8: Projected Demand for Second Period Based on Demand Scenario

Note that the probability between periods is the same as before because the time difference between 2 periods is just 1 month, resulting in very small change in probability. So, the same assumptions from the first period are made here for simplification, leading to the projected demand for second period as shown in the table.

Demand	Probability	Designated Production Volume
High	0.3	**7,951,837**
Medium	0.45	**6,393,435**
Low	0.25	**4,894,517**

Table 9: Probability of Demand Levels for the Second Period

The MS Excel spreadsheet is used to develop a financial model (mentioned in the previous section) in order to calculate the net present values among possible paths based on all of the assumptions above.

According to the spreadsheet, the table below shows the NPV of each node in the flexible system design branch.

Period 1	Period 2	Forward Orders	Recruit Labor	Do Nothing
High	High	2,993,520	3,974,021	1,771,350
High	Medium	2,539,341	3,178,559	1,771,350
High	Low	954,699	1,482,197	335,385
Medium	High	2,500,687	3,110,858	1,771,350
Medium	Medium	2,046,507	2,315,396	1,771,350
Medium	Low	461,866	619,034	335,385
Low	High	739,776	1,211,871	194,193
Low	Medium	194,193	285,597	416,408
Low	Low	-1,241,772	-1,299,045	-1,279,954

Table 10: Summary of NPV at the End of Decision Tree for Flexible System Design

From this NPV calculation, the decision tree can be illustrated as follows.

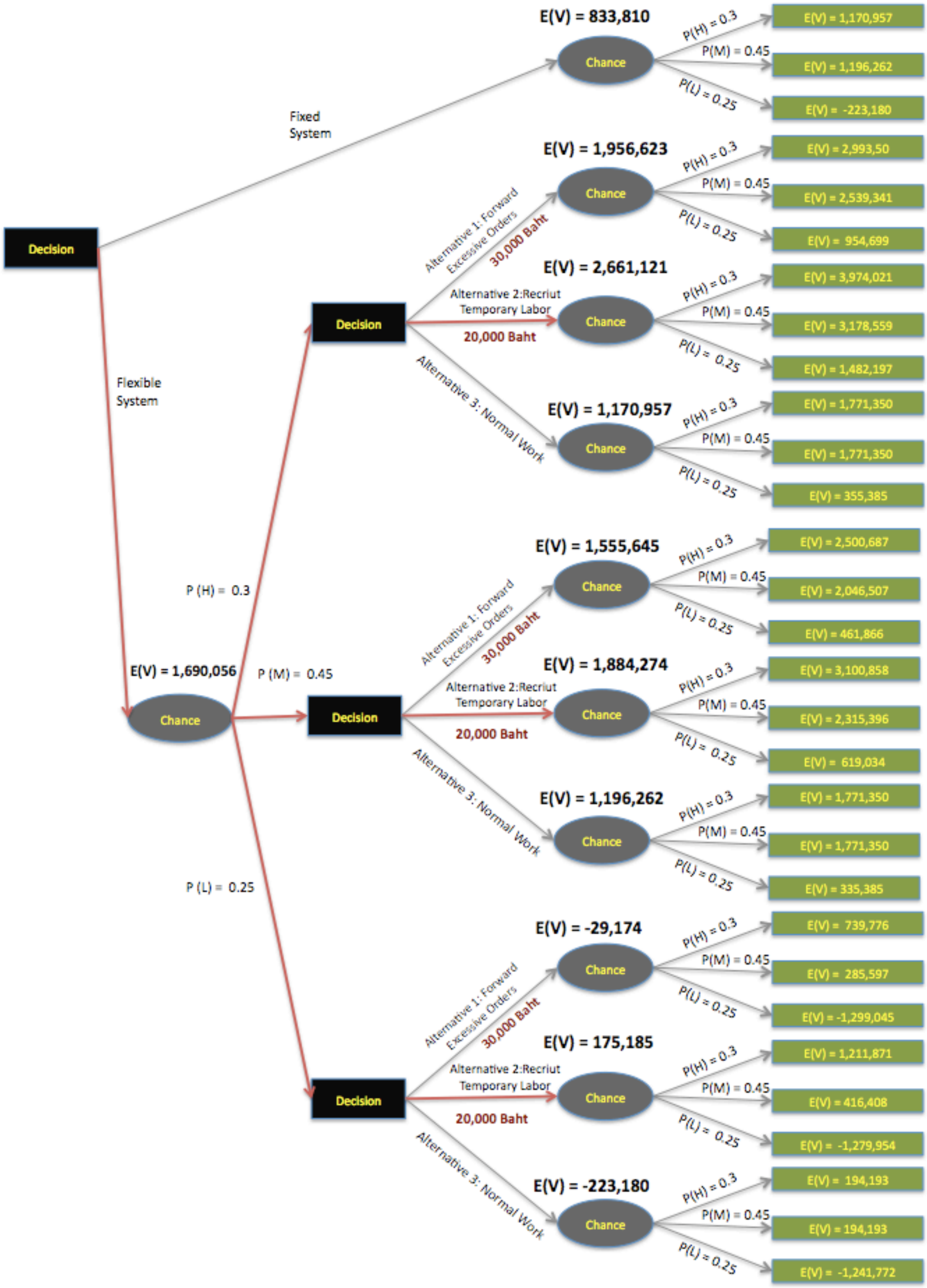
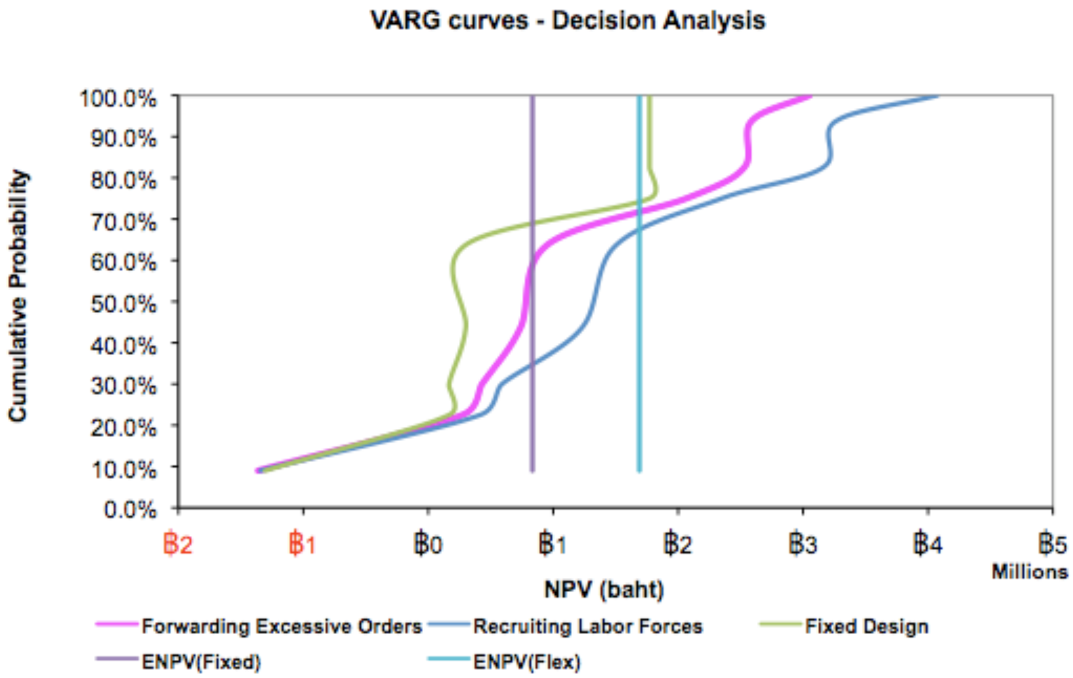


Figure 10: Decision Tree

The Result of Decision Analysis

As shown in the decision tree above, the first-stage decision is to judge whether the flexible system design should be implemented in the manufactory or not. If the decision is to implement, then the second-stage decision on which strategy should be chosen to be implemented will be made to provide a flexible production capacity, leading to the higher expected profit, which significantly depends on the chosen decision path.



It is obvious that **the strategy of recruiting extra labors yields the highest profit when compared to other alternatives** and seem to dominate any other concept in this case study. As a subsequent, the flexible system design is more favorable because it provides the flexibility in production system to a very great extent. Specifically, we can recruit the labor forces when needed and release them[10] when the client demand is not high and can be satisfied by the full-time manufactory's workers within normal working hours. This CALL option IN costs no more than 20,000 baht for the manufacturer because the labor forces are abundant and the machine operator does not need to be a knowledge-worker. So, this flexible option might be appealing for the manufacturer to implement.

Based on the assumptions of the given demand scenarios and the current manufacturing capacity, the flexible system architecture can contribute to 1.6 millions baht or 202.69% higher profit within 2 periods when compared to the fixed system. **So, the flexible strategy appears to be a better choice for the manufacturer in the current system settings.**

E[NPV] for Flexible Strategy	1,690,056 baht
E[NPV] for Fixed Strategy	**833,810 baht**
Value of Option	**856,246 baht**

[10] Note that the layoff the full-time workers is unfavorable due to the manufacture policy

Chapter 5: Lattice Analysis

In this case, binomial lattice analysis is conducted to evaluate the impact of the major uncertainty, which is the evolution of the market demand, to the expected financial outcomes, which are the net profit and the net present value, over the next 10 time periods in which each period is equal to 1-month timeframe. Since customer orders are collected on a monthly basis before the manufacturer executes an appropriate production plan accordingly, the time period is set to a 1-month timeframe.

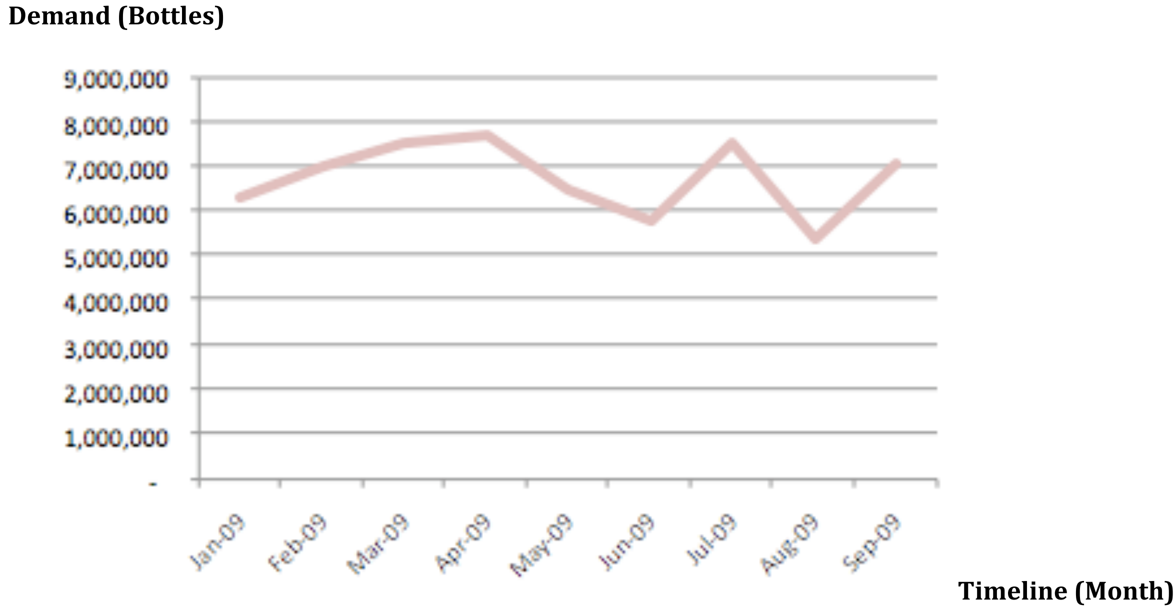


Figure 11: Historical Demand Data Points

Based on the historical demand data, the estimated demand of the production volume at period 0 is about 7 million bottles per month with the expected demand decrease of 1% and the demand volatility of 12.4% as shown in the graph below.

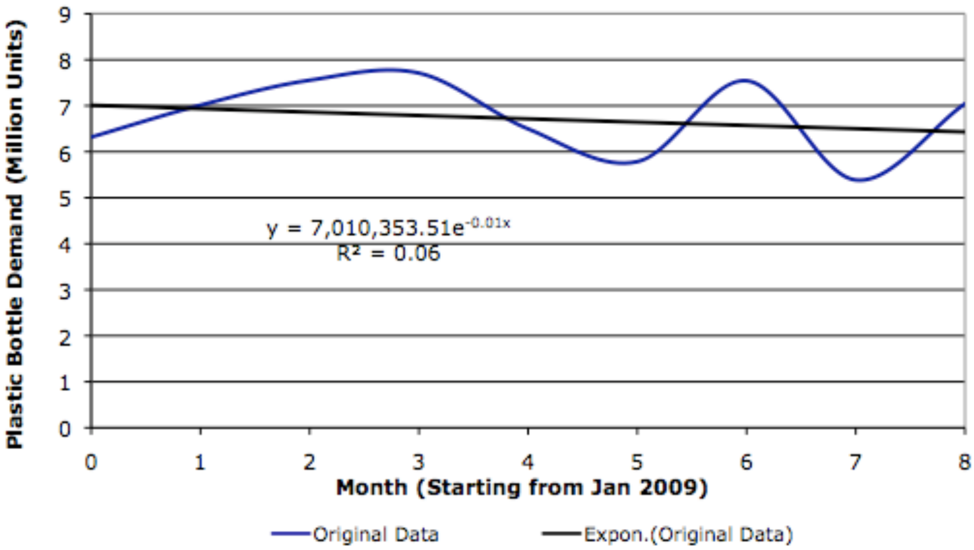


Figure 12: Historical Demand Data Points and Projected Trend of Demand

Once the average demand and volatility are approximated, the binomial upside probability (p), the binomial model upside factor (u), and the binomial model downside factor (d) can be calculated subsequently to initialize the binomial lattice model.

$$p = 0.5 + 0.5\left(\frac{\upsilon}{\sigma}\right)\sqrt{\Delta t} \quad = \quad 0.4597$$

$$u = e^{\sigma\sqrt{\Delta t}} \quad = \quad 1.1320$$

$$d = \frac{1}{u} \quad = \quad 0.8834$$

All the variables for the lattice analysis can be summarized into the table below.

Variable Names	Mathematical Symbol	Value
Initial Production Volume Required	a_i	7,000,000 bottles
Length of a Time Period	Δt	1 month
Volatility	σ	12.4%
Average Demand Drop	υ	-1%
Binomial Upside Probability	p	0.4597
Binomial Model Upside Factor	u	1.1320
Binomial Model Downside Factor	d	0.8834

Table 11: Variables for the Binomial Lattice Analysis

After the lattice model based on those variables is developed, the probability lattice is populated accordingly as shown in the following table while the subsequent table shows the demand outcome lattice.

Probability lattice

Probabilities:	1.00	0.46	0.21	0.097	0.045	0.021	0.009	0.004	0.002	0.001	0.000
		0.54	0.50	0.343	0.210	0.121	0.067	0.036	0.019	0.010	0.005
			0.29	0.403	0.370	0.284	0.196	0.126	0.077	0.046	0.026
				0.158	0.290	0.333	0.306	0.247	0.181	0.125	0.082
					0.085	0.196	0.270	0.290	0.266	0.220	0.169
						0.046	0.127	0.204	0.250	0.259	0.238
							0.025	0.080	0.147	0.203	0.233
								0.013	0.049	0.102	0.157
									0.007	0.030	0.069
										0.004	0.018
											0.002

Table 12: Table of the Probability Lattice

Demand outcome lattice

	t = 0	t = 1	t = 2	t = 3	t = 4	t = 5	t = 6	t = 7	t = 8	t = 9	t = 10
Demand	7,000,000	7,924,000	8,969,968	10,154,004	11,494,332	13,011,584	14,729,113	16,673,356	18,874,239	21,365,639	24,185,903
		6,183,800	7,000,062	7,924,070	8,970,047	10,154,093	11,494,433	13,011,699	14,729,243	16,673,503	18,874,405
			5,462,769	6,183,854	7,000,123	7,924,139	8,970,126	10,154,182	11,494,535	13,011,813	14,729,372
				4,825,810	5,462,817	6,183,909	7,000,185	7,924,209	8,970,205	10,154,272	11,494,636
					4,263,121	4,825,853	5,462,865	6,183,963	7,000,246	7,924,279	8,970,284
						3,766,041	4,263,158	4,825,895	5,462,913	6,184,018	7,000,308
							3,326,920	3,766,074	4,263,196	4,825,937	5,462,961
								2,939,001	3,326,950	3,766,107	4,263,233
									2,596,314	2,939,027	3,326,979
										2,293,584	2,596,337
											2,026,152

Table 13: Table of the Demand Outcome Lattice

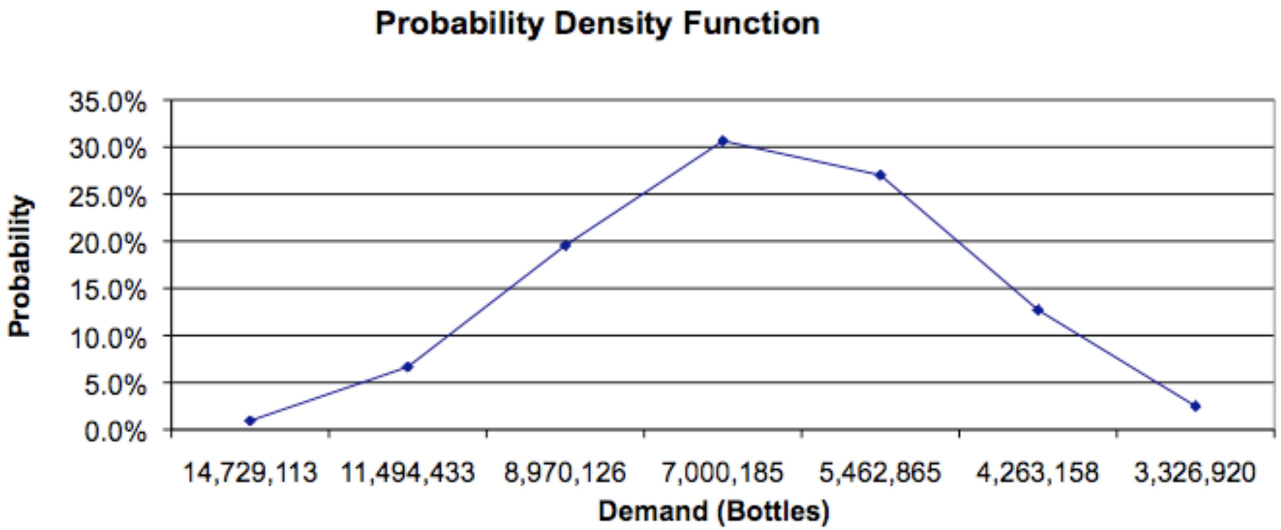


Figure 13: PDF of the Demand Based on the Binomial Lattice Model

Decision Analysis using Lattice

For the fixed system design, the production capacity is fixed at 5,929,000 bottles per month (38,500 per day per machine and the manufacturer has 7 machines operating). For that reason, the manufacturer has no ability to increase the capacity level by any mean when the demand is higher than 5,929,000 bottles. Nevertheless, the manufacturer still needs to pay for the fixed costs no matter what the amount of production is. The main fixed costs come from: 1. Salaries of the full-time labor forces, which are equal to 33,000 baht per day or 726,000 baht per month. 2. Monthly utilities are about 2,200,000 baht per month. As a consequence, the net profit of each period is equal to either case below:

Net Profit = (Expected demand in each period * Selling price per unit) – Fixed Cost; when the expected demand in that period is **less** than or equal to the capacity limit, which is at 5,929,000

Net Profit = (Maximum production at capacity * Selling price per unit) – Fixed Cost; when the expected demand in that period is **more** than the capacity limit, which is at 5,929,000. As the MD estimated the production cost per bottle at 1 baht while the manufacturer sells a bottle at 1.65 baht. So, the profit margin will be equal to 0.65 baht per bottle. So, the net profit for that period is equal to 927,850 baht maximum, resulting from (5,929,000 * 0.65) - 2,926,000

Based on those possible two cases, the net profit in the fixed design system can be calculated as shown in the table below.

Net profit for fixed design system

t = 0	t = 1	t = 2	t = 3	t = 4	t = 5	t = 6	t = 7	t = 8	t = 9	t = 10
927,850	927,850	927,850	927,850	927,850	927,850	927,850	927,850	927,850	927,850	927,850
	927,850	927,850	927,850	927,850	927,850	927,850	927,850	927,850	927,850	927,850
		624,800	927,850	927,850	927,850	927,850	927,850	927,850	927,850	927,850
			210,777	624,831	927,850	927,850	927,850	927,850	927,850	927,850
				154,972	210,804	624,862	927,850	927,850	927,850	927,850
					478,074	154,947	210,832	624,894	927,850	927,850
						763,502	478,052	154,923	210,859	624,925
							1,015,649	763,483	478,030	154,898
								1,238,396	1,015,632	763,464
									1,435,171	1,238,381
										1,609,001

Table 14: Table of the Net Profit Outcome Lattice for Fixed Design

Probability-Weighted Net Profit, Expected Value, Net Present Value for Fixed Design System

To determine each net profit observation, the net profit lattice is multiplied with the probability lattice, resulting in the table below.

Probability	927,850	426,533	196,077	90,137	41,436	19,048	8,756	4,025	1,850	851	391
Weighted		501,317	460,911	317,821	194,803	111,939	61,750	33,118	17,399	8,998	4,596
Cash Flow			182,394	373,545	343,438	263,131	181,442	116,772	71,574	42,303	24,308
				33,245	181,218	309,266	284,339	228,743	168,245	116,014	76,188
					13,207	41,292	168,797	268,849	247,180	204,532	156,705
						22,013	19,678	43,080	156,528	240,393	221,017
							18,994	38,270	22,805	42,806	145,799
								13,652	37,741	48,882	24,271
									8,994	30,516	52,727
										5,631	22,338
											3,411
E [Cash Flow]	927,850	927,850	839,382	814,748	747,688	722,662	666,411	642,667	593,237	570,866	526,258
PV(E[Cash Flow])	927,850	843,500	693,704	612,133	510,681	448,716	376,172	329,790	276,750	242,103	202,895
ENPV over 6 years	**4,412,757**										
ENPV over 10 years	5,464,294										

Table 15: Probability-Weighted Net Profit Table for Fixed Design

As shown in the table above, it turns out that the NPV of this manufacturer in the next 6 periods will worth about 4.5 millions baht while the NPV over 10 periods is about 5.5 millions baht when using the discount rate at 10%. In order to ensure the accuracy of the expected NPV calculated above, the dynamic programming backtracking approach is used for double-checking purpose as shown in the following table.

ENPV (Cash Flow)	**4,412,757**	4,299,679	3,851,374	3,235,276	2,538,168	1,771,350	927,850
NO FLEXIBILITY		3,436,674	3,587,887	3,199,371	2,538,168	1,771,350	927,850
			2,055,071	2,693,484	2,465,069	1,771,350	927,850
Dynamic programming				620,217	1,497,326	1,622,528	927,850
Approach					440,379	395,833	624,862
						917,846	154,947
							763,502

Table 16: Dynamic Programming Table for the Fixed Design

Net profit for flexible design system

For the flexible design system, the production capacity could be expanded with the maximum upper bound at 23,940,000 bottle a month by recruiting labors to operate 7 machines 24 hours everyday in that month (30 working days). Then, if the sum of the customer orders exceeds 23,940,000 bottles, the manufacturer can forward the request to the manufacturing partner although the manufacturer needs to pay for the higher cost of production. However, it is believed that they can still make profits from the rest of the customer orders that the current manufacturer's capacity cannot catch up with. These conditions are summarized in the table below.

Scenario	Profit margin per unit
Expected Demand <= 5,929,000	0.65 baht/bottle
5,929,000 < **Expected Demand** <= 23,940,000	First 5,929,000 bottles get profit margin at 0.65 baht/bottle The rest has profit margin at 0.65-0.037 = 0.613 baht/bottle (The new profit margin excerpts from the two-stage decision analysis section)
Expected Demand > 23,940,000	First 5,929,000 bottles get profit margin at 0.65 baht/bottle Then, the next 18,011,000 bottle can make profit margin at 0.613 baht/bottle The rest has profit margin at 0.65-0.3 = 0.35 baht/bottle (The new profit margin excerpts from the two-stage decision analysis section)

Table 17: Profit Margin for Flexible Design System

Note that this lattice model incorporated the two flexible options together. As the profit margin of the "*Recruit Pay-Per-Day Labors*" is higher than the "*forwarding excessive orders*", the "*Recruit Pay-Per-Day Labors*" option is exercised first. However, if the client order is higher than the capacity, then the "*forwarding excessive orders*" will exercised as a complementary flexible option to allow manufacture to keep up with the over-capacity orders.

Subsequently, the net revenue obtained from the lattice model can be shown in the table below.

t = 0	t = 1	t = 2	t = 3	t = 4	t = 5	t = 6	t = 7	t = 8	t = 9	t = 10
1,584,373	2,150,785	2,791,963	3,517,777	4,339,399	5,269,474	6,322,319	7,514,140	8,863,282	10,390,510	15,689,136
	1,084,042	1,584,411	2,150,828	2,792,012	3,517,832	4,339,461	5,269,544	6,322,399	7,514,230	8,863,383
		624,800	1,084,076	1,584,449	2,150,870	2,792,060	3,517,887	4,339,523	5,269,614	6,322,478
			210,777	624,831	1,084,109	1,584,486	2,150,913	2,792,109	3,517,942	4,339,585
				154,972	210,804	624,862	1,084,142	1,584,524	2,150,956	2,792,157
					478,074	154,947	210,832	624,894	1,084,176	1,584,562
						763,502	478,052	154,923	210,859	624,925
							1,015,649	763,483	478,030	154,898
								1,238,396	1,015,632	763,464
									1,435,171	1,238,381
										1,609,001

Table 18: Table of the Net Profit Outcome Lattice for Flexible Design

Probability-Weighted Net Profit, Expected Value, Net Present Value for flexible design system

Probability	1,584,373	988,716	590,009	341,737	193,788	108,178	59,666	32,599	17,676	9,526	6,612
Weighted		585,708	787,059	736,734	586,186	424,403	288,798	188,085	118,557	72,872	43,904
Cash Flow			182,394	436,441	586,473	609,969	545,989	442,735	334,747	240,255	165,640
				33,245	181,218	361,349	485,564	530,266	506,288	439,865	356,333
					13,207	41,292	168,797	314,136	422,119	474,149	471,570
						22,013	19,678	43,080	156,528	280,894	377,448
							18,994	38,270	22,805	42,806	145,799
								13,652	37,741	48,882	24,271
									8,994	30,516	52,727
										5,631	22,338
											3,411
E [Cash Flow]	1,584,373	1,574,424	1,559,462	1,548,157	1,534,460	1,523,178	1,510,142	1,498,979	1,486,377	1,475,337	1,464,559
PV(E[Cash Flow])	1,584,373	1,431,295	1,288,812	1,163,153	1,048,057	945,774	852,436	769,213	693,406	625,687	564,651
ENPV over 6 years	**8,313,899**										
ENPV over 10 years	10,966,855										

Table 19: Probability-Weighted Net Profit Table for Flexible Design

It appears that the NPV of this manufacturer in the next 6 periods will worth about 8 million baht while the NPV over 10 periods is about 8.3 millions baht when using the discount rate at 10%. In order to ensure the accuracy of the expected NPV calculated above, the dynamic programming backtracking approach is used as shown in the following table.

ENPV (Cash Flow)	**8,313,899**	10,176,049	11,545,091	12,196,569	11,828,763	10,043,093	6,322,319
CAPACITY EXPANDED		5,042,659	6,515,847	7,443,416	7,605,014	6,702,741	4,339,461
			2,515,534	3,706,907	4,304,686	4,095,969	2,792,060
Dynamic programming				695,433	1,677,308	2,053,201	1,584,486
Approach					440,379	395,833	624,862
						917,846	154,947
							763,502

Table 20: Dynamic Programming Table for the Flexible Design (Expand)

The next step is to evaluate the expected NPV **if the manufacturer has an option to increase the capacity** when needed. So, the table below presents the net profit obtained from this flexible CALL IN option, which leads to the NPV of approximately 7.6 million baht.

ENPV (Cash Flow)	7,657,376	8,953,114	9,680,978	9,606,642	8,417,215	5,701,469	927,850
WITH FLEXIBILITY TO EXPAND		4,886,466	5,859,286	6,220,438	5,740,852	4,112,759	927,850
Dynamic programming			2,515,534	3,550,681	3,648,088	2,872,948	927,850
Approach				695,433	1,677,308	1,896,942	927,850
					440,379	395,833	624,862
						917,846	154,947
							763,502

Table 21: Dynamic Programming Table for the Flexible Design (Option to Expand)

Due to the flexibility in this system design, the net revenue and NPV seem higher than those of fixed system design whenever there are flexible options for the MD to decide at each period. Unlike the fixed design system, the excessive customer orders can be taken without any maximum boundary since the manufacturer can either forward orders to industrial partners or expand the working hours. Although the profit margin is smaller in this case when product orders is very large, the overall profit is still higher than the fixed system. By comparing both cases, the time periods that are required to exercise an option to enjoy the benefits of flexible system design are shown below.

Exercise CALL	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
OPTION?		**YES**	**YES**	**YES**	**YES**	**YES**
			YES	**YES**	**YES**	**YES**
				NO	**YES**	**YES**
					NO	NO
						NO

Table 22: Lattice Table Whether Option is exercised

With this analysis, the value of the having the option to recruit more labors and forward the excessive orders to manufacturing partners when the demand cannot be satisfied with the current labor force is 3,244,619 baht for the next 6 periods or 73.53% increase in profit.

E[NPV] for Flexible Strategy	7,657,376 baht
E[NPV] for Fixed Strategy	**4,412,757 baht**
Value of Option	**3,244,619 baht**

Table 23: Value of Option Table

Chapter 6: VARG Curve Analysis

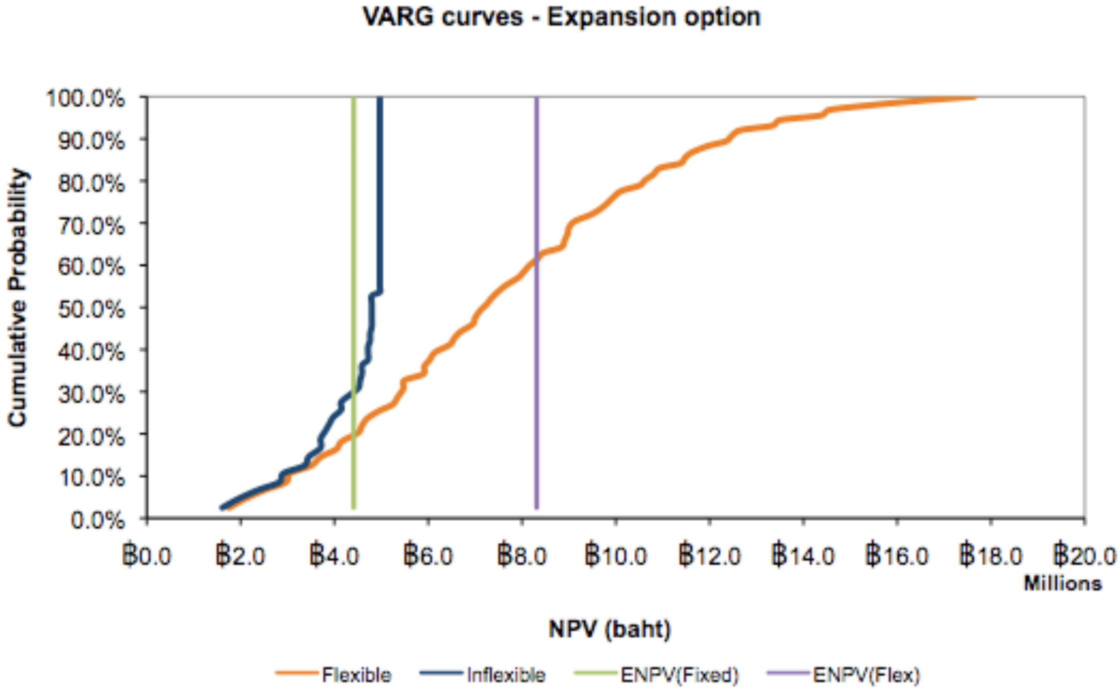


Figure 14: VARG Curve from Lattice Analysis

To provide another viewpoint of the NPV evaluation, the VARG graph is plotted as displayed in the chart above. It obviously shows that the flexible option will allow the manufacturer to gain a higher NPV in all cases in this analysis, which is logical since the manufacturer can firstly take all the customer orders then they figure out whether they have enough capability to produce in-house to get a higher profit or they should forward the request to other manufacturing partners. For the reason, this flexible concept is a **dominance** concept because other alternatives are inferior. However, it is important to note that this result could change if the system settings are different from the current settings in this analysis.

Chapter 7: Multi-Criteria Valuation Table

Although the decision tree analysis and the lattice analysis show that the flexible design is a more appropriate system for this case study so far, whether the fixed design or the flexible design is the most preferred still depends on other evaluation criteria. Hence, the multi-criteria valuation table was created to conduct a better assessment between these two designs. Critical different criteria are chosen to measure the expected values of these two system designs in monetary unit. Interestingly, those evaluation criteria could significantly affect the decision makers to decide another way around. For that reason, this table is a great tool to evaluate what kind of system will be suitable to its surrounded uncertainties from various aspects.

Architectural Value Parameter	**Decision Analysis**		**Lattice Analysis**	
	Fixed Design	**Flexible Design**	**Fixed Design**	**Flexible Design**
CAPEX	-	20,000[11]	-	20,000[12]
Minimum NPV	**-223,180**	-1,299,045	-	-
Maximum NPV	1,196,262	**3,974,021**	-	-
E(NPV)	833,810	**1,690,056**	4,412,757	**7,657,376**
STDEV(NPV)	**805,626**	1,471,579	**777,156**	3,658,344
P10	166,528	**1,452,980**	2,916,270	**3,058,263**
P90	1771350	**3,262,736**	4,968,879	**12,473,789**
Preferred System	**Flexible Design**		**Flexible Design**	

Table 24: Multi-Criteria Evaluation Table

The table shows that the flexible system design is still more preferred than the fixed system design in various aspects although the fixed system is more stable (lower standard deviation). Because the flexible system design can take as many orders as they are available, the standard deviation of the flexible system design is much higher than that of the fixed design. Besides, since the flexible system design just needs a relatively small amount of the initial investment when compared to the expected value that will be gained, the options are more appealing to the manufacturer.

[11] Some of the additional costs (i.e., extra labor costs, extra production costs specified in the partner agreement, job advertisement expenses, etc.,) already included in the profit margin, resulting in the lower profit margins for the case where customer orders are larger than the manufacturer's capacity can take

[12] Same as above

Chapter 8: Conclusion & Lesson Learned

This paper conforms to many case studies explored in the class. The paper explicitly shows that the values of a flexible system design are tremendous. Especially, when the surrounded uncertainties have strong influences on the system being considered and those uncertainties cannot be effectively mitigated by any mean. For instance, the uncertainty about the market demand, which seems to have "surprises" at all times in Thailand. So, keeping a flexible option available would provide a better chance for the manufacture to deal with such a surprise.

Like other manufactory's case study, the main identifiable uncertainty is the market demand. This paper employed two evaluation approaches, which are decision analysis and lattice analysis, to compare and contrast the fixed system design and the flexible system designed to suggest what system design would lead to higher value of the manufacturer. The results between these two approaches are the same, which recommended that the flexible system design is favorable.

In this case study, the lattice seems to be more suitable analyzing tool because the chosen flexible option is not complex and be more like a repetitive work in considered time horizon. The flexible option of recruiting labors force and forwarding excessive orders are usually made in every period. Since the lattice analysis has a standard way of evaluating, this approach leads to more accurate and consistent analyzed result. However, as the data points are not abundant, this can still lead to error in calculation no matter what tools are used. For this reason, one of the great lessons learned to collect sufficient information to archive the more accurate analysis result.

The most challenging part in this paper development is to invent and develop implementable flexible options where they can fit to the current system settings whereas the practicality of these flexible options is viable. This challenge is quite unique based on the case being considered due to the fact that a practice in one system could not be used in another system. Thanks to Prof. Richard, I have a chance to learn how to apply the flexibility concepts and its applications in the other real system designs, which greatly help me to devise implementable strategies for the manufacture in this case study so they can better capture benefits in various circumstances once they decide to implement them. Specifically speaking, the CALL-LIKE options in this system context like flexible labor recruitment and the establishment of the partner agreement on the fixed outsourcing cost allows manufacturer to capture the benefits when the chance comes.

Working on the real problem with the real people and system provides me a great learning experience in this class. Also, the misunderstandings about the concepts were gone once I understand how concepts are pieced together to provide an overall view of the whole picture, which is the flexibility in the design. Last but not least, the experiences in real system taught me how to identify the flaws in the system design, which would help me to become a better system architecture.