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by Hayati Asih

Cost-Volume-Profit Analysis for Uncertain Capacity Planning: A Case Study Paper

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Abstract

Capacity planning under uncertainty is one of the crucial points as it relates on the investment in a company. This research is based on case company in a multinational hard disk drive company in Malaysia. This research is extended on the previous research by Chong and Asih (1) which proposed some scenarios of capacity planning under demand uncertainty towards the number of required testers. These scenarios impact on the investment on expansion planning in order to meet customer demand. Therefore, this research is proposed to develop CVP analysis for multi products to evaluate how many units or dollars must be earned to break-even for capacity planning under demand uncertainty. The result shows scenario 9 has the highest number of products and dollars to break–even because this scenario has high protection level to handle demand uncertainty. In addition, compared to other products, Product B has the lowest number to break-even. It is because this product has the lowest customer demand and the longest testing durations. On the other hand, Product T has the highest number to break-even as it has the highest demand and the lowest testing durations. For managerial insight, this research could assist decision maker in analyzing the different scenarios for capacity planning under demand uncertainty.

Keywords
Cost-volume-profit analysis, capacity planning, uncertainty, break-even point

1. Introduction
Planning the company's activities and events in the future is an important phase in successful management. The Cost-Volume-Profit (CVP) analysis becomes an important tool to predict the cost to be incurred, sales to be made, and profit to be received in order to break-even. According to Larson et al. (2), there are several essential questions why the managers use CVP analysis, such as:

i) What sales volume is required to achieve a target income?
ii) What are the profits if the prices of selling product is declined and the sales volume is improved?
iii) How much does profit improve when the company installs new equipment or decrease the labor cost?
iv) How is the profit affected if the company changes the sales mix of products or services?

In investing the new technology or new resources, the CVP analysis is an essential tool that must be conducted to evaluate the effects of sales volume changes on company's cost, revenue and income.

1.1 Objectives

From the previous researches, there is a few research related on cost-volume-profit analysis of multi products that considering uncertainty. Therefore this research is proposed to evaluate how many units must be sold or how many dollars must be earned for multi products to break–even using cost-volume-profit analysis for all proposed scenarios.

2. Literature Review

Atrill et al. (3) explained that there are some costs that are considered in CVP analysis, namely fixed cost, variable cost, and semi-fixed (semi-variable) cost. Fixed cost is the cost that is not altered by changes in volume of activity within a particular period. On the other hand, variable cost is the cost that could vary with level of the activity. Then, semi-fixed (semi-variable) cost is the cost that involves fixed cost and variable cost components. In interpreting the CVP information, it is important to understand the underlying assumptions, such as: all other variables remain constant; single product or constant sales mix; total cost and total revenue are linear functions of output; the analysis applies only to the relevant range; and the analysis applies only to a short-term time horizon (4).

Xin-gang et al. (5) presented economic analysis for the grate-based waste-to-energy plant and circulating fluidized bed combustion plant in China's waste-to-energy industry. The economic analysis consists of return on investment, net present value, internal rate of return, and sensitivity analysis. This research considered two kinds of technologies or equipment, namely the imported equipment and China-made equipment. The results showed that the China-made equipment has faster payback periods and higher internal rate of return for both grate-based waste-to-energy plant and circulating fluidized bed combustion plant. However, this study does not take into account the quality aspects of those equipment as the quality could affect the plant's performances.

Compare to Testa et al. (6), they proposed economic analysis of the new health technology, namely bedside ultrasonography, which has a better efficacy and a greater efficiency. This research tried to evaluate cost-benefit analysis for bedside ultrasonography in the Internal Medicine department. The result showed that the volume of activity to break-even was around 734 ultrasonography examination, and the money that must be earned € 81,998 with time required was around 406 days.

Then, urban renewal investment projects in the province of Naples (Italy) were proposed by Morano and Tajani (7). They were essential to support Public Administration decisions. This research conducted financial feasibility of the investment in planning urban renewal initiative involving private investors. The results shows the break-even analysis could define the amount of quantity as building products to be realized and sold. Then, Wang et al (8) presented cost reduction and investment required to achieve economic break-even point in China's photovoltaic industry. The result showed that ¥ 1.2 billion of ¥ 2.2 billion is required to achieve the break-even.

Then, Nykamp et al (9) presented break-even analysis of decentralized storage assets as a substitute to conventional reinforcements of photovoltaic in German's power distribution grids. The annual cost for the investment (capital expenditures) and operational expenditures are the main cost to derive break-even point. The results showed that the storage assets to break-even was between 100 and 500 € per kWh of installed capacity. In addition, sensitivity analysis were employed to define the profitability can be improved significantly if not all peaks photovoltaic generation need to be stored.

3. Methods

The basic equations in this approach are as follows.

p	index of product; p = 1, … , 4
IC	Investment cost
TIC	Total investment cost
FC	Fixed cost
TC	Total cost
TCM	Total contribution margin
SPp	Selling price of product p
VCp	Variable cost of product p
TVC	Total variable cost
CMp	Contribution margin per unit of product p
CMRp	Contribution margin ratio of product p

Dp	Monthly demand of product p
T	Total number of additional testers required for both tester stages
SMRp	Sales mix ratio of product p
RISp	Ratio of individual sales of product p
SRRp	Sales Revenue Ratio of product p
WCM	Weighted average contribution margin ratio
WCMu	Weighted average contribution margin ratio in units
BEPD	Total break – even point in dollars
BEPUp	Break – even point in units of product p
BEPDp	Break – even point in dollars of product p

Contribution margin per unit of product p is equal to sales price of product p minus variable cost of product p. The equation can be expressed as:

$$CM_p = SP_p - VC_p \tag{1}$$

Total variable cost refer to the demand of product p multiplied by the variable cost of product p, starting at D1 and VC1, and ending with D4 and VC4 and then summing up them.

$$TVC = \sum_{p=1}^{4} (D_p \times VC_p) \tag{2}$$

Contribution margin ratio of product p is the contribution margin per units of product p divided by sales price of product p. The constraint can be expressed as:

$$CMR_p = \frac{CM_p}{SP_p} \tag{3}$$

Sales mix ratio of product p is the ratio of sales for each product by dividing the demand of product p and sum of the demand of product p. It can be mathematically expressed as:

$$SMR_p = \frac{D_p}{\sum_{p=1}^{4} D_p} \tag{4}$$

Total investment cost is multiplying the investment cost and total number of additional testers required for both tester stages as shown in the equation below.

$$TIC = IC \times T \tag{5}$$

3.1 Multi product break – even point in units

The equation below is used to calculate the weighted average contribution margin per unit. It is calculated by summing up the multiplication contribution margin of product p and sales mix ratio of product p.

$$WCM_u = \sum_{p=1}^{4} (CM_p \times SMR_p) \tag{6}$$

Total cost is the sum of total investment cost and fixed cost. It can be mathematically expressed as:

$$TC = TIC + FC \tag{7}$$

Break – even point in units represents the sales amount that is required to cover total costs, and there is neither profit nor loss. It can be computed by dividing the total cost and total contribution margin as expressed in the equation below:

$$BEPU = \frac{TC}{WCM_u} \tag{8}$$

Breakdown of break – even sales in units is the quantity detail of each product that must be sold to achieve the break – even. It is calculated by multiplying break-even point in units and sales mix ratio of product p.

$$BEPU_p = BEPU \times SMR_p \tag{9}$$

3.2 Multi product break – even point in dollars

The equation below represents the ratio of individual sales of product p that is calculated by multiplying the sales price of product p and sales mix ratio of product p.

$$RIS_p = SP_p \times SMR_p \tag{10}$$

Computation of weighted average contribution margin ratio is by conducted dividing weighted average contribution margin ratio in units and total ratio of individual sales of product p. It can be expressed as:

$$WCM = \frac{WCM_u}{\sum_{p=1}^{4} RIS_p} \quad (11)$$

Break – even point in dollars refers to how many dollars that company must be earn to break-even. It is calculated by dividing the total cost and weighted average contribution margin ratio.

$$BEPD = \frac{TC}{WCM} \quad (12)$$

Sales Revenue Ratio of product p is calculated by dividing the ratio of individual sales of product p and the sum of ratio of individual sales of product p.

$$SRR_p = \frac{RIS_p}{\sum_{p=1}^{4} RIS_p} \quad (13)$$

Breakdown of break – even sales in dollars refers to how many dollars that must be earned for each product to break-even. It is calculated by multiplying break – even point in dollars and Sales Revenue Ratio of product p.

$$BEPD_p = BEPD \times SRR_p \quad (14)$$

4. Data Collection

This research is based on case study on a multinational hard disk drive (HDD) company, especially in the automatic testing process. There are many products produced and these products has short life cycle. In addition, the demand uncertainty in automatic testing process makes the problem very complicated. Therefore, the company must determine the capacity planning that considering this uncertainty. This model has been developed by Chong and Asih (1) which proposed some scenarios of capacity planning under demand uncertainty towards the number of required testers as shown in Table 1.

The parameter Γ is called the degree of conservatism, which reflects the decision makers' attitude toward risk. The higher parameter Γ, the lower risk that decision maker has (10,11). It is interpreted as the maximum number of parameters that can deviate from their nominal values. If Γ = 0 (nominal case), it means the demand is realized as forecasted, there is no protection against uncertainty. If Γ = S (worst case), it means the demand is completely protected against uncertainty, which yields a very conservative solution.

In the automatic testing process, there are two tester stages, i.e. Tester A and Tester B. Each tester stage has their own configuration to test the HDD. For instance, in Table 1 for Tester A, there are five scenarios. The first scenario has the lowest number of required testers but the probability of meeting demand is about 65.35%. Compare to the fifth scenario which is the worst case, this scenario has the highest number of required testers but the demand is 100% met. For managerial insight, these scenarios impact on the investment on expansion planning in order to meet customer demand. Therefore, this research is proposed to develop CVP analysis to know how many units or dollars must be earned to break-even for capacity planning under demand uncertainty.

Table 1. Scenarios of capacity planning under demand uncertainty towards the number of required testers (Source: Chong and Asih (1))

Scenario	Degree Of Conservatism (Γ)	The Number of Required Testers (in Units)	Probability of Meeting Demand
Tester A			
1	0 (nominal case)	28	65.35%
2	1	33	82.63%
3	2	41	91.53%
4	3	44	97.42%
5	4 (worst case)	50	100%
TESTER B			
6	0 (nominal case)	8	40.79%
7	1	17	71.12%
8	2	19	91.21%
9	3 (worst case)	20	100%

Currently, there are 45 units of Tester A and 11 units of Tester B in this company. According to table above, some scenarios needs additional tester in order to meet customer demand. Table 2. presents the required additional testers for all scenarios which will be input in analyzing the CVP. For instance, scenario 1 is no need to add the testers, on the other hand, scenario 5 requires five testers as it is subtraction of the scenario (see on Table 1) and current system, e.g. 50 units – 45 units = 5 units for Tester A.

Table 2. The required additional testers for all scenarios

Scenario	The required additional testers (in units)
Tester A	
1	-
2	-
3	-
4	-
5	5
Tester B	
6	-
7	6
8	8
9	9

Cost – volume – profit (CVP) analysis is proposed to know how many units must be sold or how many dollars must be earned to break – even (means, recover the costs without gaining the profits). The calculation of CVP analysis is more complicated for the multiple products than the single product. In this research, CVP analysis is calculated to all proposed scenarios developed that required additional testers. Table 3. presents the assumption of costs required. There are four different product types, such as Product T, Product S, Product A, and Product B. Each product type has different selling price and variable cost. For instance, for Product T, the selling price is $ 30/unit and variable cost is $ 10/unit. Then, for both tester stages (e.g. Tester A and Tester B), the investment cost is $ 5,000,000 / tester and the fixed cost is $ 450,000.

Table 3. List of costs

Costs	Product T	Product S	Product A	Product B
Selling Price $ / unit	30	70	80	100
Variable Cost $ / unit	10	30	40	50
	Tester A		**Tester B**	
Investment Cost $ / tester	5,000,000		5,000,000	
Fixed Cost $		450,000		

5. Results and Discussion

This section is concerned with analyzing cost–volume–profit for all proposed scenarios developed. It is useful to know how many units must be sold or how many dollars must be earned to break–even (this means recover the costs without gaining the profits). Multi products break-even analysis is more complex in comparison to single product break-even analysis. Some basic equations are proposed to achieve this objective.

5.1 Numerical Results

The sample calculation of scenario 5 is as follows. Table 4. presents the calculation result for total variable cost, contribution margin, contribution margin ratio and sales mix ratio for scenario 5. There are four main products, each having its demand, sales price and variable cost. By referring to Equation (1) – Equation (4), the computing of contribution margin, total variable cost, contribution margin ratio, and sales mix ratio can be conducted, respectively. The result shows that Product T is the biggest sales compare to others (which is about 0.71 or 71%), even though this product is the lowest price. Then, the total variable cost is about $ 2 million.

Table 4. The Calculation Result of Total Variable Cost, Contribution Margin, Contribution Margin Ratio, and Sales Mix Ratio

Product	Demand	Selling Price	Variable Cost	Total Variable Cost (Eq. 2)	Contribution Margin (Eq. 1)	Contribution Margin Ratio (Eq. 3)	Sales Mix Ratio (Eq. 4)
T	83,647	30	10	836,470	20	0.67	0.71
S	16,798	70	30	503,940	40	0.57	0.14
A	13,660	80	40	546,400	40	0.50	0.12
B	4,262	100	50	213,100	50	0.50	0.03
Total	118,367			2,099,910			

Table 5. shows the calculation result of total investment cost and total cost. In scenario 5, the additional testers required are 5 units for Tester A (please refer to Table 2). Because of that, the total investment cost and total cost are computed using Equation (5) and Equation (7), respectively.

Table 5. The Calculation Result of Total Investment Cost and Total Cost

	Tester A	Tester B	TOTAL
Number of Additional Tester	5 units	-	5 units
Investment Cost	5,000,000	5,000,000	10,000,000
Total Investment Cost (Eq. 5)	25,000,000		25,000,000
Fixed Cost		450,000	
Total Cost (Eq. 7)		25,450,000	

After calculating the costs above, the break–even points in units for each product can be provided by computing weighted average contribution margin per unit, break–even point in units and its breakdown using Equation (6), Equation (8), and Equation (9), respectively (as shown in Table 6). By expanding the capacity, the company must sell 742,233 units of Product T; 149,075 units of Product S; 121,227 units of Product A; and 37,824 units of Product B to break–even.

Table 6. The calculation result of multi products break–even point in units

Product	Weighted Average Contribution Margin per unit (Eq. 6)	Break – Even Point in Units (Eq. 8)	Breakdown Break – Even Point in Units (Eq. 9)
T	14.13	1,050,459	742,333
S	5.67		149,075
A	4.62		121,227
B	1.80		37,824
TOTAL	26.22		1,050,459

Besides calculating the break-even point in units, the break-even point in dollar for each product can be provided. Table 7. presents the calculation result of ratio of individual sales, weighted average contribution margin ratio, break–even point in dollars, sales revenue ratio, and breakdown break–even point in dollars through Equation (3.10) – Equation (3.14). The result means how many dollars to sell for each product to break–even. For instance, Product T must be sold at about 38 million dollars, Product S is about 18 million dollars, Product A is about 16 million dollars, and Product B is about 6 million dollars. These are verified by the sales and costs for scenario 5 at this break-event point. It shows that a CVP analysis for a multi-product company can be employed to answer a variety of planning questions. If a product mix is determined, all answers are according to the assumption that the mix remains constant at all relevant sales levels.

Table 7. The calculation result of multi products break–even point in dollars

Product	Ratio of Individual Sales (Eq. 10)	Weighted Average Contribution Margin Ratio (Eq. 11)	Break – Even Point in Dollars (Eq. 12)	Sales Revenue Ratio (Eq. 13)	Breakdown Break – Even Point in Dollars (Eq. 14)
T	21.20			0.48	38,436,979
S	9.94			0.22	18,010,810
A	9.23	59.65	79,714,521	0.21	16,738,568
B	3.60			0.09	6,528,164
TOTAL	43.97			1	79,714,521

After obtaining the expansion planning of the mixed–load testers for the proposed scenarios, the cost–volume–profit analysis in units and in dollars are developed as presented in Table 8. There are several scenarios that do not require additional costs because these scenarios do not need additional testers, such as scenario 1, 2, 3, 4, and 6. On the other hand, the other of scenarios are required additional cost. For example, scenario 7 requires 877,058 units of Product T; 176,131 units of Product S; 143,228 units of Product A; and 44,688 units of Product B to be sold in order to break-even. Or, it can also be stated that scenario 7 needs $ 26,311,736 of Product T; $ 12,329,160 of Product S; $ 11,458,257 of Product A; and $ 4,468,804 of Product B must be earned to break-even.

5.3 Proposed Improvements

This result show that scenario 9 has the highest number of products and dollars to break–even because this scenario has high protection level to handle demand uncertainty. In addition, compared to other products, Product B has the lowest number to break-even. It is because this product has the lowest customer demand. On the other hand, Product T has the highest number to break-even as it has the highest demand and the lowest testing durations. This result can help the managers of the company for making decision on which scenarios that should be chosen.

Table 8. Break-even sales for all proposed scenarios in units and dollars
(a) Break-even sales for all proposed scenarios in units

	Break -Even Sales in Units				
	Product T	**Product S**	**Product A**	**Product B**	**TOTAL**
Scenario 1	No additional testers required				
Scenario 2					
Scenario 3					
Scenario 4					
Scenario 5	742,333	149,075	121,227	37,824	1,050,459
Scenario 6	No additional testers required				
Scenario 7	877,058	176,131	143,228	44,688	1,241,105
Scenario 8	1,146,508	230,242	187,231	58,417	1,622,398
Scenario 9	1,281,233	257,297	209,232	65,282	1,813,044

(b) Break-even sales for all proposed scenarios in dollars

	Break -Even Sales in Dollars				
	Product T	**Product S**	**Product A**	**Product B**	**TOTAL**
Scenario 1	No additional testers required				
Scenario 2					
Scenario 3					
Scenario 4					
Scenario 5	22,269,993	10,435,279	9,698,156	3,782,352	46,185,780

Scenario 6	No additional testers required				
Scenario 7	26,311,736	12,329,160	11,458,257	4,468,804	54,567,958
Scenario 8	34,395,243	16,116,932	14,978,470	5,841,713	71,332,358
Scenario 9	38,436,986	18,010,813	16,738,571	6,528,165	79,714,536

6. Conclusion

This research is based on case company in a multinational hard disk drive (HDD) company, especially in the automatic testing process. There are many products produced and these products has short life cycle. In addition, the demand uncertainty in automatic testing process makes the problem very complicated. Therefore, the company must determine the capacity planning that considering this uncertainty. This model has been developed by Chong and Asih (1) which proposed some scenarios of capacity planning under demand uncertainty towards the number of required testers.

This model proposed several scenarios that impact on the expansion planning for both tester stages, Tester A and Tester B. These scenarios are required to be analyzed on financial problem as considerations for company to make decisions on investment planning. This research has objective to evaluate how many units must be sold or how many dollars must be earned for multi products to break–even using cost-volume-profit analysis for all proposed scenarios.

This research contributes on theory as there are few researches related on cost-volume-profit analysis of multi products that considering uncertainty. Not only theory, this research could assist decision maker in analyzing the different scenarios for capacity planning under demand uncertainty.

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