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Stepwise Kaizen Parameters Improvement via the Path of Steepest Ascent

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***Abstract*—Kaizen has been widely accepted as a continuous process improvement with the gradualist approach. This paper presents research carried out to explore a pattern of an investment in Kaizen to enhance overall profit. System dynamics-based simulation has been employed with an optimization technique, a Steepest Ascent approach, to improve experimental variables e.g. the amount of spending on prevention and appraisal activities, the time and the amount to reduce the investment which results in maximum Net Present Value (NPV) of profit. The simulation model in this study is based on a Thai automobile manufacturer as a case study company. The result suggests that the investment in Kaizen should be reduced economically when the process is under controlled. It can be named as the 'Stepwise Kaizen', which was proved in this study that it provides greater overall profit than the constant spending. This study also presents the behavior of quality costs and profit against time scale along the Stepwise Kaizen implementation.**

***Index Terms*—Investment in Kaizen, Quality economics, Steepest Ascent, Stepwise Kaizen**

I. Introduction

In 1986, the Japanese philosophy 'Kaizen' which is the continuous process of work improvement was proposed. It is now used and has been universally accepted as the low cost and unsophisticated work improvement approach, which pays off gradually in the long run. Reference [1] suggested that Kaizen dose not need a large investment, and an optimum quality level is found at 100% conformance from relatively low-cost changes to reduce waste. Reference [2] presented a continuous improvement model as fig. 1. This model shows that the quality costs can be reduced to a low level when the production is assured as it is under controlled conditions. However, the amount of the investment to reach an optimal overall profit is abstruse to determine in practice.

Reference [3] proposed a variation of criterion used to determine the economic quality level in which a profit was recommended instead of the total quality costs because profit is the normal goal of doing business, not minimum cost. In that work, a system dynamics simulation was employed to expand the consideration of the quality costs to the market condition. Nevertheless, an optimal spending on prevention and appraisal activities in that study was determined as constant along the quality improvement program which did not support the model in fig. 1.

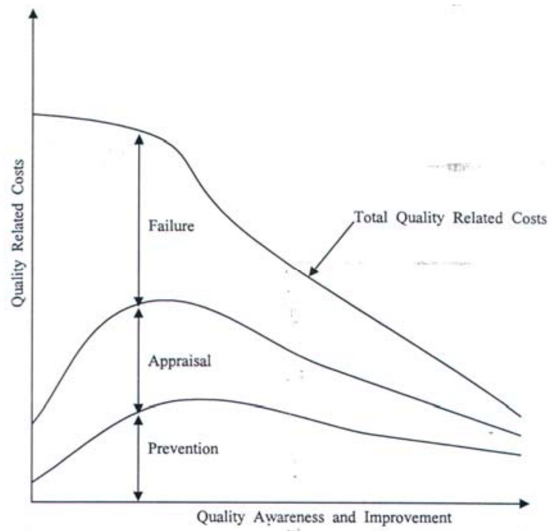

Fig. 1 The continuous improvement model from [2]

This paper describes a quantitative investigation into the 'Stepwise Kaizen', which an ongoing investment in prevention and appraisal activities is reduced at an appropriate point of time. The behavior of costs and profit along this approach is clarified. The results are compared with the previous work which the investment in Kaizen is constant.

II. The Research Methodology

This work used a system dynamics simulation model of the economics of quality improvement (see fig. 2). This model was adapted from [4] which the constant investment in Kaizen was improved to be variable. The model was constructed by using real data gathered from a case study company, a leader automobile manufacturer in Thailand. The quality improvement mechanisms as well as the market mechanisms are represented in the model.

The variables for experimentation were identified as Prevention spending (P_1), Appraisal spending (A_1), Reduced prevention spending (P_2), Reduced appraisal spending (A_2), and Time to reduce P_1 and A_1 to P_2 and A_2 following the concept of 'Stepwise Kaizen'. The outcomes from the simulation were considered in terms of quality costs, product demand, price, and profit against a two years time scale.

An optimization technique, the method of Steepest Ascent as in [5] was employed to improve all variables from the current operating condition to the visible region of the optimal overall profit.

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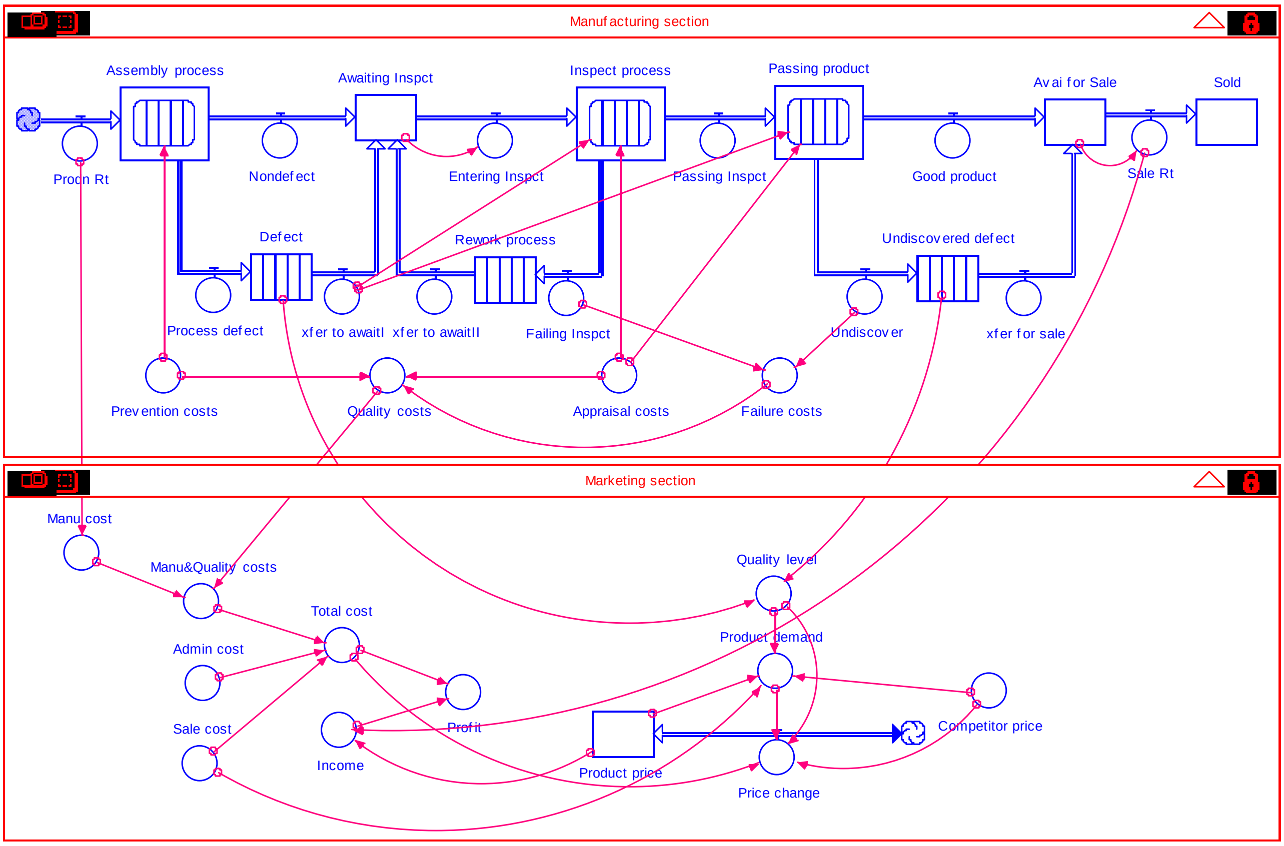

Fig. 2 Simulation model

III. Experimentation and Experimental Results

Considering the experimentation presented in Table 1, multiple simulation runs at the current operating condition were operated. Factorial design can detect the nature of the relationship between the outcomes and all variables. These could lead to the concept of the Path of Steepest Ascent. However, the procedure to determine an actual optimum could be applied via the second order experiment. Table 2 shows a statistical test between variables and simulated outcomes which were the profit. The p-value less than 0.05 means the variables affected the profit. The variable which had the greatest coefficient was improved toward an optimum. Fig. 3 shows the results by varying t from 13 to 24. At t=21, it provided greatest outcome. It was then identified as a new current operating condition. Simulation and Statistical test were employed again.

This experiment improved all variables for four sequential procedures as shown in Table 3. In fig. 4, the averages of profit were enhanced while the variation in sequential procedure seems to be reduced. In this study, we would implement the latest operating condition received from the fourth iteration, this could be closed to the optimum due to the reduction of the variance of the outcomes.

From the experimental results, variables were improved to P_1 = 3,100,000 Baht/month, A_1 = 670,000 Baht/month, P_2 = 1,250,000 Baht/month, A_2 = 300,000 Baht/month, and t = 21st month. These variables provided the preferable outcome which was the Net Present Value (NPV) of profit over two years = 1,783,858,123 Baht.

Comparing these experimental results with the previous work in [4], the constant investment in Kaizen for greatest profit were preventive spending for 2,975,000 Baht/month and appraisal spending for 665,000 Baht/month, and the NPV of profit over two year was 1,775,206,983 Baht. The outcomes from the constant investment in Kaizen are compared with the investment in Stepwise Kaizen as presented in table 4.

IV. Discussion

A major objective of this study was to investigate the pattern of an ongoing investment in Kaizen. The experiment shows that the method of Steepest Ascent can be employed to determine an amount of the investment in Stepwise Kaizen along time scale effectively. The experimental results indicate that if a company, by implementing the ‘Stepwise Kaizen’,

1. The spending on prevention activities of 3,100,000 Baht/month from the initial month to the twentieth month could reduce all process defects which dropped the internal failure cost to zero in the seventh month. Due to the characteristics of the case study company system, there is a delay of two months in prevention activities implementation. Hence the effects started to occur in the third month.
2. The spending on appraisal activities of 670,000 Baht/month from the initial month to the twentieth month could detect all process defects. So the undiscovered defect and the external failure cost were zero.

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Table 1 The simulation results at the current operating condition

Variables					Outcomes
t (Month)	P_1 (Baht)	A_1 (Baht)	P_2 (Baht)	A_2 (Baht)	NPV of Profit (Baht)
13	2,000,000	500,000	1,000,000	200,000	1,468,845,455
				400,000	1,540,143,346
			1,500,000	200,000	1,566,798,283
				400,000	1,609,696,868
		1,000,000	1,000,000	200,000	1,557,578,712
				400,000	1,628,858,632
			1,500,000	200,000	1,655,527,228
				400,000	1,698,436,007
	3,000,000	500,000	1,000,000	200,000	1,591,164,955
				400,000	1,637,415,604
			1,500,000	200,000	1,671,024,999
				400,000	1,693,524,171
		1,000,000	1,000,000	200,000	1,649,047,817
				400,000	1,695,295,628
			1,500,000	200,000	1,728,903,045
				400,000	1,751,400,898
15	2,000,000	500,000	1,000,000	200,000	1,535,113,500
				400,000	1,583,552,555
			1,500,000	200,000	1,595,861,146
				400,000	1,626,942,392
		1,000,000	1,000,000	200,000	1,627,293,635
				400,000	1,675,740,222
			1,500,000	200,000	1,688,038,965
				400,000	1,719,128,299
	3,000,000	500,000	1,000,000	200,000	1,653,951,384
				400,000	1,679,451,346
			1,500,000	200,000	1,697,420,800
				400,000	1,709,416,866
		1,000,000	1,000,000	200,000	1,711,250,255
				400,000	1,736,748,682
			1,500,000	200,000	1,754,717,115
				400,000	1,766,712,499

Table 2 The Statistical test between variables and simulation outcomes

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	854,522,615.53	47,564,073.34	17.97	0.0000
t	19,302,437.91	2,921,837.80	6.61	0.0000
P_1	84.37	5.84	14.44	0.0000
A_1	148.04	11.69	12.67	0.0000
P_2	120.26	11.69	10.29	0.0000
A_2	187.48	29.22	6.42	0.0000

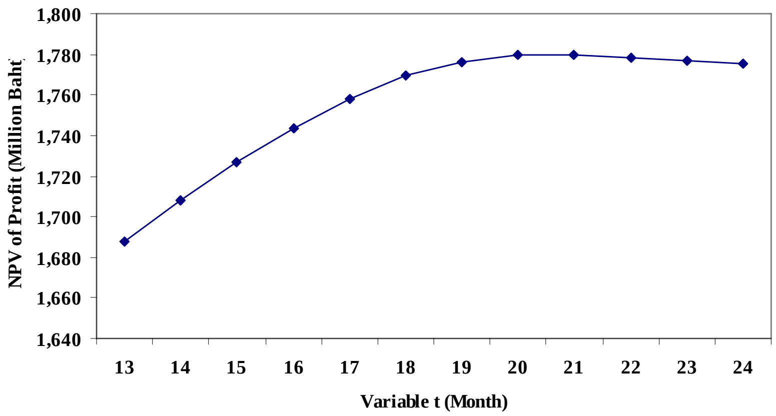

Fig.3 The simulation results by varying t

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Table 3 The improvement of variables

Iteration	Variable	Minimum	Maximum	P-Value	Coefficients	Improvement
First	t	13	15	0.0000	19,302,437.91	**21**
	P_1	2,000,000	3,000,000	0.0000	84.37	2,500,000
	A_1	500,000	1,000,000	0.0000	148.04	750,000
	P_2	1,000,000	1,500,000	0.0000	120.26	1,250,000
	A_2	200,000	400,000	0.0000	187.48	300,000
Second	t	20	22	0.7581	728,650.06	21
	P_1	2,000,000	3,000,000	0.0000	47.10	2,500,000
	A_1	500,000	1,000,000	0.0000	157.25	**700,000**
	P_2	1,000,000	1,500,000	0.7479	-3.04	1,250,000
	A_2	200,000	400,000	0.6673	10.18	300,000
Third	t	20	22	0.0856	1,193,546.22	21
	P_1	2,000,000	3,000,000	0.0000	26.10	2,500,000
	A_1	650,000	750,000	0.0000	68.95	**670,000**
	P_2	1,000,000	1,500,000	0.2651	-3.04	1,250,000
	A_2	200,000	400,000	0.1394	10.18	300,000
Fourth	t	20	22	0.0594	1,259,397.16	21
	P_1	2,000,000	3,000,000	0.0000	23.98	**3,100,000**
	A_1	665,000	675,000	0.8059	31.73	670,000
	P_2	1,000,000	1,500,000	0.2446	-3.04	1,250,000
	A_2	200,000	400,000	0.1231	10.18	300,000

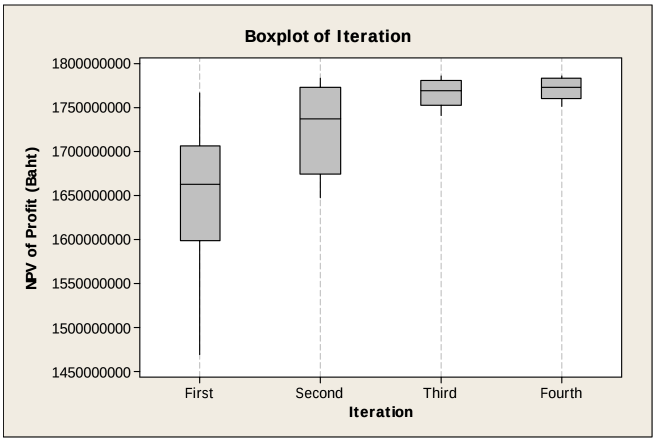

Fig. 4 The average and the variance of the outcomes

It means that the preferable levels of prevention and appraisal spending to approach the optimal overall profit should be at the level of 100% conformance along time scale. It advocates the comment in [6], [7] that defects are prohibited to the customers for the late 20th century. The results also indicate that the zero defect production could be reached by implementing Stepwise Kaizen approach.

3. Following the concept of the Stepwise Kaizen, the results show that the investment in prevention and appraisal activities could be reduced for 59.68% and 55.23% respectively in the twenty-first month. It supports the continuous improvement model in fig. 1. It can be explained that at the first phase, the prevention and appraisal costs as in [8] e.g. the costs of quality planning, quality design, quality assurance, quality training, quality inspection and testing, and the costs of inspection and test equipment were spent to eliminate and detect all defective products, the failure costs started to reduce. After the effective prevention and appraisal activities reduced failure costs to zero and the production was in the steady state, which was named in [9] as the 'wisdom phase', the prevention spending could be reduced to the low level to further the quality analysis and maintain the continuous improvement program. Some prevention activities about planning, designing, and training can be discontinued. The appraisal costs, the spending on laboratory and test equipment can be dropped. It should be spent just for inspection and testing to ensuring that the production was under controlled conditions. Therefore, the total quality costs were dropped to a low level as commented in [10].
4. The Stepwise Kaizen which increased the quality level by dropping defective products did not only reduce the quality costs, but also increased the product demand and the product price. These benefits increased the profit and did not decline when the prevention and appraisal spending were reduced at the wisdom phase because there was no undiscovered defect to the market due to the under controlled process.
5. Comparing these experimental results with the constant investment in Kaizen as presented in [4], the Stepwise Kaizen provided greater NPV of profit for 8,651,140 Baht in two years because the constant investment in Kaizen did not spent economically when the process reached the wisdom phase. The results also show that the constant investment in Kaizen did not eliminate and detect all defects in the early phase because it needed more investment that the process could not reach optimal overall profit, whereas the Stepwise Kaizen could invest for 100% conformance along the program because the investment could be reduced at the wisdom phase.
6. Reference [3] suggested the profit as the criterion to determine prevention and appraisal spending in quality improvement program instead of the total quality costs. Fig. 5 displays the behavior of quality costs and their effect to profit along the implementation of the Stepwise Kaizen. This graph amends the model in fig.2 which

Table 4 The comparison between the Stepwise Kaizen and the constant investment in Kaizen

	The Stepwise Kaizen	The constant investment in Kaizen
Prevention costs	3,100,000 Baht/month until the 20th month, then reduce to 1,250,000 Baht/month	2,975,000 Baht/month
Appraisal costs	670,000 Baht/month until the 20th month, then reduce to 300,000 Baht/month	665,000 Baht/month
Internal failure costs	Start to reduce in the 3rd month, then reduce to 0 in the 6th month until the end	Start to reduce in the 3rd month, then reduce to 0 in the 6th month until the end
External failure costs	Zero Baht/month	Start to reduce in the 3rd month, then reduce to 0 in the 6th month until the end
Total quality costs	Start to reduce in the 3rd month to 3,770,000 Bath/month, reduce to 1,550,000 Baht/month in the 21st month until the end	Start to reduce in the 3rd month to 3,640,000 Baht/month, then constant
Product demand	Increase to 1,987 unit/month in the 6th month, then constant	Increase to 1,987 unit/month in the 6th month, then constant
Product price	Increase to 438,284 Baht/unit in the 10th month, then constant	Increase to 438,251 Baht/unit in the 10th month, then constant
Profit	Increase to 77,086,499 Baht/month in the 10th month until the 21st month, increase to 79,306,499 Baht/month until the end	Increase to 77,165,360 Baht/month in the 10th, then constant
NPV of Profit	1,783,858,123 Baht	1,775,206,983 Baht

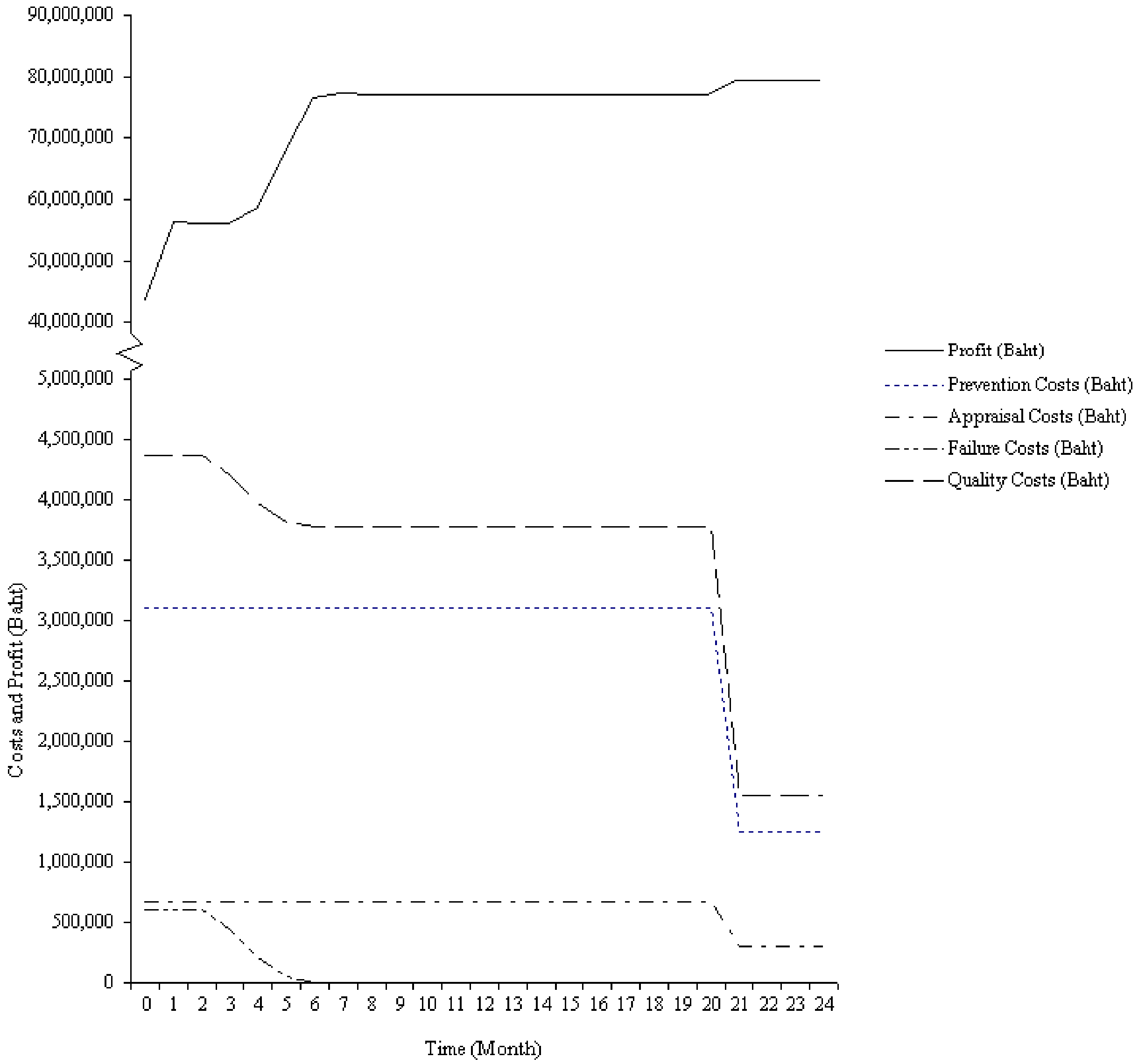

Fig. 5 The behavior of quality costs and profit along the implementation of the Stepwise Kaizen

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displays costs without profit. This graph indicates that the investment in Kaizen should be reduced when the process reached the wisdom phase. The outcome which is the profit increased when the effects of prevention spending occurred. At the wisdom phase, the profit increased again because of the reduction of the investment in prevention and appraisal activities whereas all benefits did not decline.

V. Conclusion

This paper describes an application of the method of Steepest Ascent to determine the economic investment in Kaizen. The results indicate that the company should spend on activities to eliminate and detect all defects in the early phase and then reduce the spending wisely to the low level when process is under controlled conditions, as called the 'Stepwise Kaizen'. It was found that this approach is able to reach 100% conformance economically along time scale and provides greater over all profit than the constant investment in Kaizen because the constant investment cannot detect all defect in the early phase and it spends exceeding the economic level when the process is under controlled.

The appropriate amount of spending on prevention and appraisal activities for each month to reach the optimal overall profit is recommended for further experimentation. An expansion of the simulation time scale and the other criterions such as the internal rate of return (IRR), or the payback period are also interesting to study.

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