

ESTIMATING DEFECT RECTIFICATION BUDGET USING TWO-DIMENSIONAL MATRIX AND MONTE CARLO SIMULATION

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Abstract

The defect rectification budget at the post-handover stage remains an uncertainty in the developer's estimations. At the primary stage, the traditional estimation method used a specific percentage of the total project cost based on the average defect rectification cost in the calculation. However, this practice still provided an unreliable result in the estimation of the budget requirement for handling the defect rectification work. To overcome the limitation, this paper aimed to propose a hybrid estimation method to study the behaviour of the defect rectification cost of each contractor and lead to determining the defect rectification budget more accurately. In this research study, the hybrid estimation method was integrated with a two-dimensional matrix method and Monte Carlo simulation. First, the two-dimensional matrix method was developed by considering 2 main factors, the number and the severity of the defects encountered at the post-handover stage. Both factors could influence the behaviour of the defect rectification cost of each contractor. Secondly, a Monte Carlo simulation was applied in the estimation and could reflect the real situation of the defect rectification cost occurrence in each defective house. The research methodology was defined as a qualitative research approach. The case study of a housing project was used to develop and verify this concept. As a result, the paper found that the hybrid estimation method could provide a better result by using an accuracy level compared with the traditional estimation method. Thus, this hybrid estimation method is useful for determining the defect rectification budget in residential housing projects.

Keywords: Defect rectification budget, two-dimensional matrix, Monte Carlo simulation, residential housing project

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Introduction

Homeowners usually encounter defective problems in new residential housing projects at the post-handover stage. Based on a survey of customer satisfaction in new homes in the United Kingdom by the Home Builders Federation (HBF) (2017), it was found that 84% of respondents were satisfied with the overall quality of their new homes but that 98% of respondents reported problems to their builders. Moreover, Rotimi *et al.* (2015) suggested that defects are prevalent in new residential homes in New Zealand and 72% of new homeowners have to call back their developers to rectify these defects. Forcada *et al.* (2013a) discovered that defects are not encountered in some housing components such as foundations, earthworks, or structural components. The reason for this is the improvement of inspection work by builders and engineers during the construction process. However, defects from other housing components are still discovered by the homeowners at the post-handover stage. Normally, at the post-handover stage, if the defect is discovered by the homeowner under the warranty period, the responsibility for the defect rectification service lies with the developer; it might be out of the warranty period with the contractor, but it is still under the warranty period with the homeowner. Thus, the developer needs to prepare a budget for handling the defect rectification work effectively at an early stage of the project. Moreover, the traditional estimation method of the defect rectification budget has remained uncertain because it lacks available information. Lastly, to begin the defect rectification budget estimation, the sources of defect occurrence at the post-handover stage should be primarily understood by the estimator.

Literature Review

Previous research studies identified 4 main sources influencing the defect occurrence at the post-handover stage comprising design, materials, workmanship, and protection

(Forcada *et al.*, 2013b). However, as poor design, poor quality materials, and poor protection would have already been detected and eliminated mostly during the construction process, poor workmanship remains as the most influencing factor of defects at the post-handover stage (Karim *et al.*, 2006). This workmanship source is caused by the poor performance of the contractor's management in terms of communication or coordination with the multiple tiers and variety of subcontractors. By recognizing the important role of the contractor in construction management, this study focused on the contractor level to determine an appropriate estimation method for the defect rectification budget at the post-handover stage.

Traditionally, the estimation of the defect rectification budget was determined by using various percentages from different research studies. The budget of the defect rectification work in residential housing projects ranged from 3 to 5% of the total project cost (Josephson and Hammarlund, 1999). Taggart *et al.* (2014) suggested that the defect rectification budget was estimated around 5% or more of total project cost. By using the percentage of total project cost, this method was easy to determine because it did not require a high knowledge of statistics. However, those percentage values could be considered as a single point estimation. This traditional estimation method provided an unreliable result and did not reflect the real situation of defect rectification cost occurrence. A Monte Carlo simulation was considered as an appropriate method for overcoming the single point estimation (Elkjaer, 2000). This method could randomly select the defect rectification cost in the simulation and was expected to provide a better result than the traditional estimation of the defect rectification budget.

Usually, different contractors have a different approach relating to the defect rectification cost based on their performances for achieving house quality. This approach suggests that different categories of defect

rectification cost should occur based on the number and severity of the defects encountered. Since the defect occurrence is a physical phenomenon, the defect rectification cost should be considered for 2 factors. First, Wyatt (1980) mentioned that some houses cost more to rectify than others due to the different numbers of defect occurrences. Next, Georgiou *et al.* (1999) classified the defects: a minor defect which costs less than Australian \$800 for rectification, and a major structural defect that causes a rectification cost of more than Australian \$800. Thus, the number and severity of the defects could impact the different categories of the defect rectification cost by using a two-dimensional matrix.

In this study, to reflect the real situation of the defect rectification cost occurrence, the number and severity of defects were considered for classifying the defect rectification cost categories of each contractor. Then, a Monte Carlo simulation was applied to estimate the defect rectification budget of the housing project.

Methods

To achieve the objective of the study, 3 main stages for estimating the defect rectification budget was developed; these were outlier checking of data, a two-dimensional matrix, and a Monte Carlo simulation. Then, the historical data was collected from the customer complaint reports for housing projects of the developer company in Thailand. Finally, the result of the estimation method was proofed by

comparing the accuracy level of the mean percentage error.

Data Outlier

Initially, the historical data were checked to identify the outlier. Usually, an outlier is an extreme value that is much less than or much greater than the other data values. This outlier was removed to protect the error of the experiment result in the data set. The outlier of the sample data was determined by using the box plot method. This method used the median value. The lower quartile (Q_1) referred to the 25th percentiles and the upper quartiles (Q_3) referred to the 75th percentiles. The difference ($Q_3 - Q_1$) was called the interquartile range or IQ. The extreme values were determined by the following Equations 1 and 2. The outlier value was any value bigger than the upper value or smaller than the lower value:

$$\text{Upper value: } Q_3 + (1.5 \times \text{IQ}) \quad (1)$$

$$\text{Lower value: } Q_1 - (1.5 \times \text{IQ}) \quad (2)$$

Two-Dimensional Matrix

In this matrix, the severity of the defect was represented by the average defect rectification cost of each defective house, whereas the number of defects referred to the numbers of defective points in the house. Both factors were applied to determine the categories of the defect rectification cost by using the two-dimensional matrix and classified into 5 quadrants; very high (VH), high (H), medium (M), low (L), and very low (VL). Figure 1 shows the category of defect rectification cost in different grids.

Next, in the matrix analysis, x was defined as the average defect rectification cost, whereas y was defined as the numbers of defect points in the house. Each factor has minimum and maximum values. Then, the intervals were presented by k , t . Both interval values were determined by subtraction between the maximum and minimum values and divided by 5. Each category of the defect rectification cost had a range value from minimum to maximum of the defect rectification cost and presented into the grid. For example,

VL-VH	L-VH	M-VH	H-VH	VH-VH
VL-H	L-H	M-H	H-H	VH-H
VL-M	L-M	M-M	H-M	VH-M
VL-L	L-L	M-L	H-L	VH-L
VL-VL	L-VL	M-VL	H-VL	VH-VL

Figure 1. Different category of defect rectification cost by using two-dimensional matrix

the calculation of a grid, which was named VL-VL, was presented by Equations 3 and 4. In Equation 3, the minimum defect rectification cost was calculated by multiplying the minimum value of the average defect rectification cost and the numbers of defect points in the house. Moreover, in Equation 4, the maximum defect rectification cost was calculated by multiplying the maximum value of the average defect rectification cost and the numbers of defect points in the house. After that, this calculation was also applied with the other grids for determining the range of the defect rectification cost. The estimators could apply this matrix analysis with the previous project in order to identify the range of the defect rectification cost of a specific grid that has cluster data. The result of the grid findings, which have the range of the defect rectification cost, could apply in the Monte Carlo simulation.

The minimum value of the defect rectification cost = $x_{\min} \times y_{\min}$ (3)

The maximum value of the defect rectification cost = $x_{\min} + k \times y_{\min} + t$ (4)

where

- $x_{\min}$ = Minimum value of the average defect rectification cost
- $y_{\min}$ = Minimum value of the numbers of defect points in the house
- k = Interval value of the average defect rectification cost
- t = Interval value of the numbers of defect points in the house.

Monte Carlo Simulation

The grid, which had the cluster data, was selected to estimate the defect rectification cost of the defective houses for the next project by using the Monte Carlo simulation. Uniform distribution was chosen as a suitable type of distribution for application in the simulation because this distribution required only the minimum and maximum values. Thus, Equation 5 shows the uniform distribution simulation for estimating the defect rectification cost:

$$Y = X_{\min} + (\text{Rand} (X_{\max} - X_{\min})) \quad (5)$$

where

- Rand = Random selection of the defect rectification cost from the probability function
- $X_{\min}$ = Minimum value of the defect rectification cost
- $X_{\max}$ = Maximum value of the defect rectification cost
- Y = Estimated defect rectification cost of each category

Next, the weight of each defect rectification cost category was determined by dividing the numbers of defective houses in the particular grid with all the defective houses under each contractor group. Then, the estimator could determine the numbers of defective houses for the next project by multiplying the numbers of constructed houses in the next project with the weight of the particular defect rectification cost category. After that, the defect rectification cost in the particular category was randomly generated by the Monte Carlo simulation and multiplied by the numbers of defective houses in the next project; the total defect rectification cost of each contractor was summed by the categories of the defect rectification cost that have the cluster data. Equation 6 shows the total defect rectification cost of each contractor. Lastly, the defect rectification budget was the sum of the total defect rectification cost of all the contractors who worked in the next project and its calculation was run for 1,000 iterations:

$$T = (D_{(VL-VL)} \times Y_{(VL-VL)}) + (D_{(L-VL)} \times Y_{(L-VL)}) + \dots + (D_{(VH-VH)} \times Y_{(VH-VH)}) \quad (6)$$

where

- T = Total defect rectification cost of each contractor
- D = Numbers of defective houses for the next project
- Y = Estimated defect rectification cost of each category

Accuracy Measurement of the Estimation Result

The accuracy measurement was applied by using the mean percentage error (MPE).

This MPE allowed us to understand how much of a difference there is between the estimated and actual defect rectification budgets. A smaller MPE presented that the estimated result of the defect rectification budget is close to the actual defect rectification budget. Equation 7 shows the accuracy measurement by using the MPE. This study compared the result of the MPE from the hybrid estimation method with the traditional estimation method. In addition, the estimated result was also compared with the AACE standard for the feasibility study of the project (Christensen and Burton 2005). The expected accuracy of this stage ranged from -15% to -30% for the lower level, whereas it was +20% to +50% for the higher level.

$$\text{MPE (mean percentage error)} = \frac{\text{Sum of PE}}{\text{Number of data}} \quad (7)$$

Results

Initially, the box plot method of the data outlier was applied with 175 defective houses built by 6 different contractors. Each contractor had a contract with the developer for different numbers of constructed houses. Table 1 shows the weight of the contracted and defective houses. This box plot method could determine that 8 out of 175 datasets were the outliers. Moreover, by following the 70/30 rule, the data of each contractor group were divided into developing and testing samples. As a result, 120 datasets were used for developing and 47

datasets were used for testing the proposed estimation method.

Next, the two-dimensional matrix was developed by categorising the average defect rectification cost and numbers of defective points in a house into 5 quadrants. Moreover, the interval value of both factors was determined and the result of first contractor is shown as an example in Table 2. Then, the categories of the defect rectification cost were calculated by following Equations 3 and 4. The weight of a particular category of the defect rectification cost could be defined by identifying the grids that have the cluster data in the two-dimensional matrix. Figure 2 shows the two-dimensional matrix of the 6 contractor groups in the modelling samples. After that, the numbers of defective houses for the next project were determined and multiplied with the estimated defect rectification cost from the Monte Carlo simulation. Lastly, the total defect rectification cost of each contractor was calculated and presented in Table 3.

In this study, the numbers of defective houses in the next project is the same as the previous project and the average value of the defect rectification cost is around 14,074.08. Due to the hybrid estimation method, the results of the defect rectification budget and accuracy measurement from the modelling and testing samples are shown in Table 4. For the modelling samples, the estimated result of the MPE between the actual and traditional method ranged from -43% to 53% whereas the result of the MPE between the actual and hybrid estimation method ranged from 1% to

Table 1. Weight of contracted and defective houses

Contractor group	Numbers of contracted houses	Weight of contracted houses	Defective houses	Weight of defective houses
Contractor 1	48	19%	37	21%
Contractor 2	20	8%	18	10%
Contractor 3	50	20%	32	18%
Contractor 4	36	15%	33	19%
Contractor 5	30	12%	14	8%
Contractor 6	63	26%	41	23%
Total	247	100%	175	100%

Table 2. The interval values and categories of average defect rectification cost and numbers of defective points in the house of the first contractor

The intervals of the average defect rectification cost was $k=\frac{30-1}{5} = 5.8$		
Minimum value	Maximum value	Categories of average defect rectification cost
1	6.8	VL (very low)
6.8	12.6	L (low)
12.6	18.4	M (Medium)
18.4	24.2	H (High)
24.2	30	VH (Very high)
The intervals of numbers of defective points in the house was $t=\frac{4387.5-500}{5} = 777.5$		
Minimum value	Minimum value	Minimum value
500.0	500.0	500.0
1277.5	1277.5	1277.5
2055.0	2055.0	2055.0
2832.5	2832.5	2832.5
3610.0	3610.0	3610.0

Table 3. Total defect rectification cost of the first contractor

Categories of defect rectification cost	X_{min}	X_{max}	P	W	D	Y	T
VL-VL	500.00	8687.00	1	4%	1	1043.51	1043.51
VL-L	3400.00	16096.50	1	4%	1	11762.74	11762.74
VL-M	6300.00	23506.00	0	0%	0	0.00	0.00
VL-H	9200.00	30915.50	0	0%	0	0.00	0.00
VL-VH	12100.00	38325.00	0	0%	0	0.00	0.00
L-VL	1277.50	13974.00	1	4%	1	13952.82	13952.82
L-L	8687.00	25893.00	6	24%	6	22375.85	134255.09
L-M	16096.50	37812.00	2	8%	2	28464.06	56928.13
L-H	23506.00	49731.00	0	0%	0	0.00	0.00
L-VH	30915.50	61650.00	3	12%	3	37086.44	111259.33
M -VL	2055.00	19261.00	4	16%	4	17123.05	68492.20
M -L	13974.00	35689.50	3	12%	3	25402.69	76208.06
M -M	25893.00	52118.00	0	0%	0	0.00	0.00
M -H	37812.00	68546.50	0	0%	0	0.00	0.00
M -VH	49731.00	84975.00	0	0%	0	0.00	0.00
H -VL	2832.50	24548.00	1	4%	1	20973.58	20973.58
H -L	19261.00	45486.00	1	4%	1	35593.78	35593.78
H -M	35689.50	66424.00	0	0%	0	0.00	0.00
H -H	52118.00	87362.00	0	0%	0	0.00	0.00
H -VH	68546.50	108300.00	0	0%	0	0.00	0.00
VH-VL	3610.00	29835.00	1	4%	1	19381.63	19381.63
VH-L	24548.00	55282.50	1	4%	1	37880.77	37880.77
VH-M	45486.00	80730.00	0	0%	0	0.00	0.00
VH-H	66424.00	106177.50	0	0%	0	0.00	0.00
VH-VH	87362.00	131625.00	0	0%	0	0.00	0.00
Total			25	100%	25	271040.93	587731.64

Note: X_{min} Minimum value of defect rectification cost
 X_{max} Maximum value of defect rectification cost
P Numbers of defective houses in previous housing project
W Weight of each defect rectification cost category
D Numbers of defective houses in next housing project
Y Estimated defect rectification cost of each category
T Total defect rectification cost of each contractor

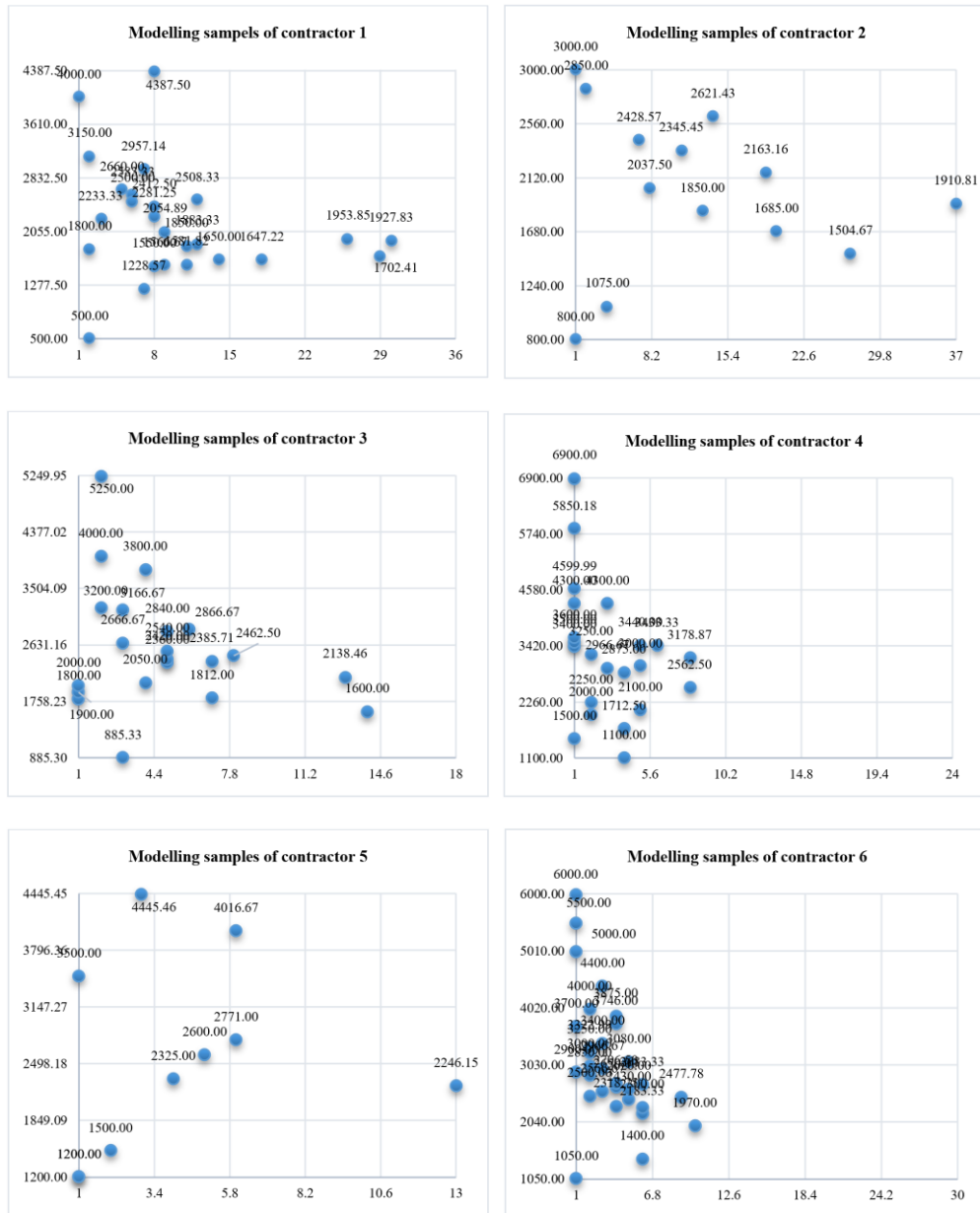


Figure 2. Two-dimensional matrix of six contractor groups in modelling samples

24%. Moreover, this research also applied the samples for testing the proposed estimation method. The estimated result of the MPE between the actual and traditional method ranged from -34% to 126%, whereas the result of the MPE between the actual and hybrid

estimation method ranged from 3% to 32%. Thus, the hybrid estimation method also has a lower percentage of error compared with the traditional estimation method of the defect rectification budget. In addition, both the results of the modelling and testing samples

Table 4. Results of MPE with modelling and testing samples

Types of sample	Contractor group	Number of samples	Total actual budget	Total estimated budget (Traditional estimation method)	Total estimated budget (Hybrid estimation method)	MPE (Actual-Traditional)	MPE (Actual-Hybrid)
Modelling samples	Contractor 1	25	513,549.0	351,851.98	587,731.64	-31%	7%
	Contractor 2	13	319,776.0	182,963.03	324,405.45	-43%	1%
	Contractor 3	21	241,440.0	295,555.66	270,971.20	22%	12%
	Contractor 4	22	202,431.1	309,629.74	244,623.15	53%	21%
	Contractor 5	10	114,462.4	140,740.79	129,862.27	23%	13%
	Contractor 6	29	297,230.9	408,148.30	367,465.45	37%	24%
	Total	120	1,688,889.5	1,688,889.50	1925059.16	0%	12%
Testing samples	Contractor 1	11	200,033.9	154,814.87	214,514.2	-23%	7%
	Contractor 2	5	105,870.0	70,370.40	108,532.1	-34%	3%
	Contractor 3	10	117,626.0	140,740.79	134,460.3	20%	14%
	Contractor 4	9	93,050.4	126,666.71	98,360.9	36%	6%
	Contractor 5	4	24,900.0	56,296.32	32,878.3	126%	32%
	Contractor 6	8	58,669.9	112,592.63	73,798.3	92%	26%
	Total	47	600,150.4	661,481.72	662,790.3	10%	10%

were acceptable compared to the percentage at the feasibility stage which ranged between -30% and +50%.

Conclusions

Previous studies and the traditional estimation method have provided unreliable results in the estimation of the defect rectification budget for the developer. These estimation practices used a certain percentage of the total project cost and could lead to an excessive over-estimated or under-estimated budget requirement. This study proposed a hybrid estimation method by combining the two-dimensional matrix which took into consideration the number and severity of defect occurrences and the Monte Carlo simulation which was applied for estimating the defect rectification budget. The historical data were collected from housing projects of the developer company. Finally, based on the estimated results of the modelling and testing samples, the defect rectification budget was determined and the percentage error of the hybrid estimation method is lower than the traditional estimation method. Moreover, the result of the proposed estimation method

was also acceptable in comparison with the percentage at the feasibility stage of the project. Finally, the hybrid estimation method will be able to help in the estimation of the defect rectification budget for residential housing projects more efficiently.

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