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The sensitivity analysis of construction cost for cleaner production

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Abstract. It is important to analyze how the implementation of cleaner production affects the whole life cycle cost(LCC) of building, that is, identify the impact factors on the life cycle cost. In this paper, we analyze the sensitivity of key cost drivers for building life cycle cost LCC, and determine the degree of influence of various cost drivers involved in the implementation of cleaner production, so as to guide the selection of cleaner production implementation plan.The result of research, the material unit cost c_2 (sensitivity coefficient 55.7%) is the most sensitive factor, the Second sensitive factor is the labor cost, and then is is equipment unit cost and design unit cost.So, these factors will be consider to improve in implementation scheme of cleaner production.

Key words. Cleanero production, sensitivity analysis, construction cost, lcc.

1. Introduction

It is important to analyze how the implementation of cleaner production affects the whole life cycle cost of building, that is, identify the impact factors on the life cycle cost. In previous studies, used sensitivity analysis is used to study the sensitivity of uncertain factors to cost estimation, so as to improve the accuracy of cost estimation and reduce the risk of decision-making[1] The multivariate sensitivity analysis is used to evaluate the cost-effectiveness changes of biological variables in the selection of biological specimen diagnostic strategies, so as to determine its economic feasibility[3]. The sensitivity analysis is also used to identify the key factors that affect the whole life cycle cost (LCC) in the process of bioenergy production, so as to select the best algal culture method[4]. Sensitivity analysis has been widely used to identify key cost factors and provides guidance for the best cost estimate[5]. For domestic and foreign scholars, the definition of sensitivity is derived from the derivation of deterministic relations. However, under uncertainty, it is difficult to achieve sensitivity analysis in this way. Therefore, there were many ways to solve uncertain problems[6]. The most common method is Monte Carlo simulation[7][8],

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and the rank correlation coefficient is introduced to study sensitivity analysis Sensitivity analysis is used to solve the economic problems, can determine the sensitivity for the large key factors[9]; estimation of uncertain parameters arising from changes in range of economic indicators, to measure the risk; in addition, can also be used for scheme selection, to implement the scheme with lower sensitivity. Therefore, the sensitivity analysis has been widely used in various fields, especially in the evaluation of the economic benefits of investment projects.

In this paper, we analyze the sensitivity of key cost drivers for building life cycle cost LCC, and determine the degree of influence of various cost drivers involved in the implementation of cleaner production, so as to guide the selection of cleaner production implementation plan. The sensitivity analysis mainly consists of three steps:

(1)Determining the key cost drivers: the impact factors of building life cycle cost are selected: the design unit cost c_1 equipment unit cost c_3 labor unit cost c_4, demolition unit cost c_7??processing unit cost c_8 Material regeneration quantity Q_2 processing quantity Q_8 Waste quantity Q_9. It Includes the cost factors improving the economic performance of cleaner production, and the comprehensive factors reflecting the economic benefits of cleaner production.

(2)Establishing the cost estimation formula: according to the mathematical model and the cost factors above. Assumption that the cost factors is independent of each other, determining the estimation formula of the building life cycle cost LCC (Note: in this paper, the operation and the maintenance cost is not as cost drivers, so the LCC estimation is not to involve the two cost):

$$C_{\mathrm{lcc}}' = \int_{t=0}^{T-1} \frac{C_5+C_6}{(1+R\ )^t} + \frac{C_7+C_8}{(1+R)^T} + C_9\left(\frac{1+\lambda_9}{1+\mathrm{R}}\right)^T - C_{10}\left(\frac{1+\lambda_2}{1+\mathrm{R}}\right)^T$$

$$= m + \frac{(c_7 * m + c_8 * Q_8)}{(1+R)^T} + (c_9 * Q_9)\left(\frac{1+\lambda_9}{1+\mathrm{R}}\right)^T - (c_2 * Q_2)\left(\frac{1+\lambda_2}{1+\mathrm{R}}\right)^T$$

c_i Is unit cost for various parts, such as c_2 is material unit cost; $\mathrm{Q}_8$is processing quantity; Q_9 is processing quantity; Q_2 is material regeneration quantity.

(3)The sensitivity analysis using the Monte Carlo simulation and Spielman correlation coefficient: Setting the probability function and the value of each parameter. In the actual situation, the probability distribution of different factors may be different. In the LCC sensitivity analysis, the architectural life T shows the discrete distribution; all the others show continuously distribution. According to the related research and the current distribution types, three types of probability distribution are selected he: triangular distribution, normal distribution and uniform distribution. Determining the probability distribution of cost drivers usually requires a lot of historical data and data. However, for construction industry in China, the lack of data is very common, and there are many uncertainties. In this regard, the probability distribution of the parameters is determined by consultation and discussion with the relevant experts in the paper. Finally the simulation is implemented by Matlab software.

2. Discussion

In this paper, it takes high-rise concrete residential building in Shanghai as an example, the cost parameters of the reference value is from related literature, authority and Statistics of organization (Table 1), and per cubic meter of construction waste is set 1.9t, the average annual increase rate of 5%, prices and other auxiliary data projections to determine the main parameters (table2)

Table 1 estimation data of related parameters

Item	**Data**	**Sorce**
Construction cost	Shanghai area high-rise 2561yuan/m2 small high-rise 2384yuan/m^2 multilayer 1984yuan/m^2	Construction cost information network of China construction project 2013
The proportion of each cost	high-rise labor cost 23.9% material cost 63.94% equipment cost 3.4%	The price and index of construction engineering in Shanghai 2012
dismantlion cost	dismantling 6yuan/m^2 disassembly 20yuan/m^2	The technology research of building deconstruction &building materials reuse Gong Xiaolei 2010
site sorting,collection and transportation cost of construction waste	site sorting 20yuan/t collection and transportation 50yuan/t	Research on Cost Compensation Model for Construction and Demolition Waste Management Liu Jiangkuang 2013
processing cost,income of recyling\regenerated materials	processing cost 30yuan/t regerated cost 21.3yuan/t recycling material income 65yuan/t	Ditto

Table 2 Distribution function and parameter value of various cost factors

Cost factor		**Distribution function**	**Parameter value**
Cost parameter	Design unit cost c_1 yuan/m^2	Normal distribution	70.35 7.13
	Equipment unit cost c_3 yuan/m^2	Normal distribution	81.05,5.82
	Labor unit cost c_4 yuan/m^2	Normal distribution	(569.77,54.17)
	Demolition unit cost c_7 yuan/m^2	Trigonometric distribution	42.16,52.16,68.37
	Processing unit cost c_8 yuan/m^3	Normal distribution	40.47,5.8
Parameter of economic performance	Processing quantity Q_8 m^3/m^2	Trigonometric distribution	0.1516 0.2166 0.2816
	Waste quantity Q_9 m^3/m^2	Trigonometric distribution	0.2026 0.2532 0.3038
	Material regeneration quantity Q_2 m^3/m^2	Trigonometric distribution	0.1094 0.1367 0.1640
Others	Material unit cost c_2 yuan/m^2	Normal distribution	1524 33,100.24
	Land-filling unit cost c_9 yuan/m^2	Trigonometric distribution	36,57,65
	Building life T(year)	Discrete uniform distribution	40,65
	Annual increase of material price λ_{10}	Uniform distribution	4% 10%
	Annual increase of processing price λ_9	Uniform distribution	5% 12%
	Rate discount R	Uniform distribution	10% 25%

The Monte Carlo simulation and the calculation of Spielman's correlation coefficient are carried out with Matlab. The result of Monte Carlo simulation (10000 times) for LCC was shown in Figure 1 and the interval of LCC is [1788.6 million, 2642.4.4 million]. The labor unit cost unit as an example to illustrate the results of correlation coefficient: for the normal distribution of the labor unit cost was input (shown in figure 2), The result of Monte Carlo simulation (10000 times) is found in figure 3. It is found that there is positive relation between the labor cost and the LCC. The correlation coefficient is obtained as shown in table3. As a result of normalization, the results of sensitivity analysis can be obtained(Figure 4).

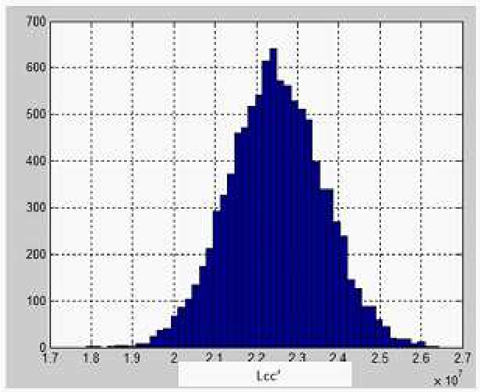

Fig. 1. The results of the monte carlo simulation for lcc '(except for operation and maintenance cost))

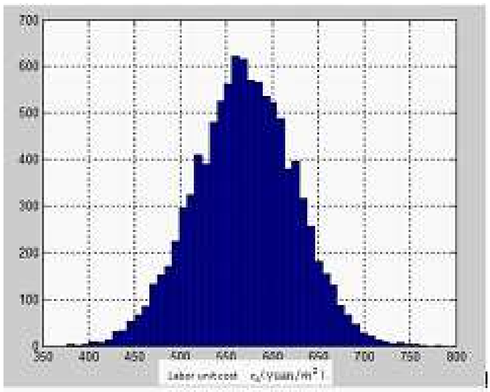

Fig. 2. Statistical results of labor cost

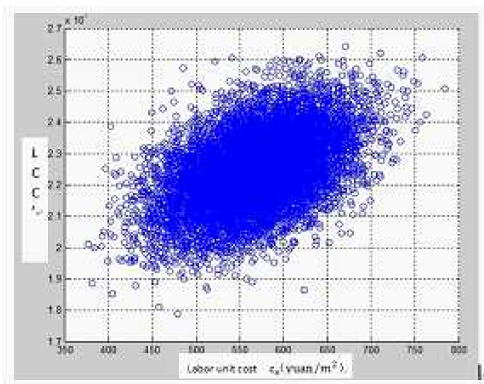

Fig. 3. The relationship between labor cost and lcc(positive correlation)

Table 3 Correlation coefficient and significant level of each cost factors and LCC

Cost factors	Correlation coefficient r	Significant level p	Cost factors	Correlation coefficient r	Significant level p
Design unit cost c_1	0.0518	3.77E-48	Demolition unit cost c_7	0.0174	0.0017
Material unit price c_2	0.8620	0	Processing unit cost c_8	0.0181	0.0013
Equipment unit cost c_3	0.0624	0	Material regeneration quantity Q_2	-0.0322	0.0070
Labor unit cost c_4	0.4565	0	Processing quantity Q_8	0.0280	0.0051
			Waste quantity Q_9	0.0175	0.0055

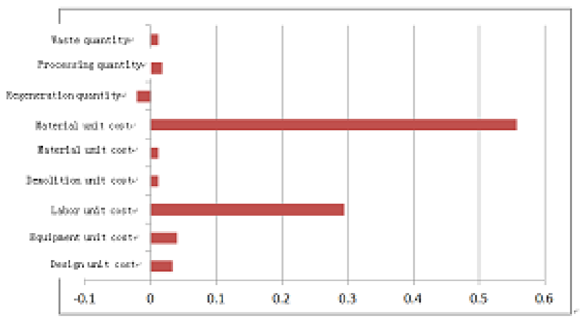

Fig. 4. The sensitivity coefficient of each cost factors and lcc

In order to further analyze the importance of each cost driver, the following formula is used to calculate the LCC share of a cost driver:

$$S_i = |r_i * P_{imax}| - |r_i * P_{imin}|$$

Among them, S_i is the share of cost factor i; r_i is the sensitivity coefficient of cost factor i; $P_{imax}$and P_{imin} is the extremes of the cost factors.The final results of Normalization is shown in Figure 5.

3. Conlusiong

From the sensitivity coefficient, the cost driver of design unit cost c_1, equipment unit cost c_3, labor unit cost c_4 and material unit cost c_2 are most sensitive. Through normalization, it know that material unit cost c_2 (sensitivity coefficient 55.7%) is the most sensitive factor to LCC, and its share is also large. Therefore, material unit cost is the most important factor in life cycle cost estimation. The Second sensitive factor is the labor cost c_4 (sensitivity coefficient 29.5%). The third sensitive factor

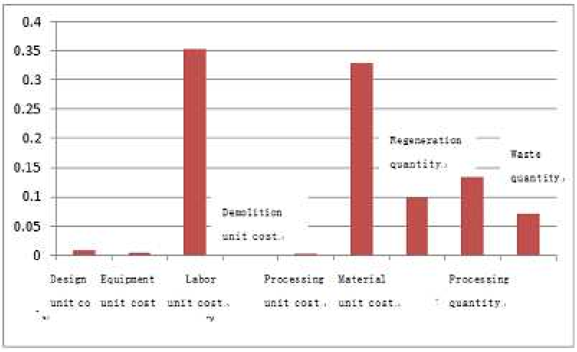

Fig. 5. The share of LCC for each cost factors

is equipment unit cost c_3 and design unit cost c_1,their sensitive coefficients were respectively 3.4% and 4.4%, but because they share less, therefore the sensitivity is small. The sensitivity coefficient of other cost factors is less than 1%, but the processing quantity Q_8, material regeneration quantity Q_2 and waste quantity Q_9 occupy big share, so their sensitivity to LCC should also be considered. Therefore, in the decision making of cleaner production implementation, the insensitive factors, such as design unit cost, equipment unit cost, demolition unit cost and processing unit cost, are first considered. By improving these factors, we can improve the economic performance of cleaner production and minimize the fluctuation of LCC as well. It is important to consider more sensitive factors of clean production benefit (materials regeneration quantity). In the implementation of cleaner production, it can be considered firstly to implement with the scheme related with the priority level of dismantling and processing level r; and to a certain extent, can also be considered to improve the design level and equipment level in implement scheme, and level of staff is at least considered in the implement of cleaner production.

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