Research on quality cost decision between owner and general Contractor

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Abstract: In the increasingly fierce competition in the construction industry, the supply is greater than the demand of the market environment, the way of winning the project procurement at a low price has increased the test of how to deal with the contradiction between cost and quality. The amount of the appraisal cost of the owner's quality cost affects its probability of success in the process of supervision and inspection, and the amount of the prevention cost of the general contractor's quality cost affects its probability of project quality qualification in the process of construction. Based on the quality cost theory, this paper takes the owner and the general contractor as the game parties, establishes the game matrix of the quality cost of both parties, and obtains the optimal quality cost decision of both parties through the game matrix analysis, that is, both the owner and the contractor need to invest in quality improvement to improve the quality of building products.

Keywords: Quality Cost; Game model; the Owner; the General Contractor

1 INTRODUCTION

In the process of production by the construction unit and consumption by the owner, the construction enterprise may make use of a certain degree of information asymmetry between the two parties and blindly compress the quality cost to produce construction products whose quality cannot reach the level agreed in the contract, so as to obtain high profits. It is a loss in a sense for the owner to pay the price but not get the corresponding level of construction products. The construction products produced do not meet the contract standard but are qualified, at best, only affect the service life of the building [2]. If there is a serious shoddy, false report of quality level phenomenon, resulting in safety risks, will be very likely to cause serious impact on the subsequent construction production or use after completion, once the accident occurs, the loss is immeasurable.

This paper will discuss the quality cost decision game between the owner and the general contractor. It is assumed that the project is contracted by the owner to the general contractor, who is responsible for completing the construction tasks of the project. Upon completion of the project, the owner will sell or transfer the entire project.

The discussion is divided into consideration of reward and punishment and consideration of quality improvement.

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2 THE QUALITY COST GAME CONSIDERING REWARD AND PUNISHMENT

Considering the system composed by the owner and the general contractor, the development of the engineering project is abstracted into a process in which the general contractor organizes the construction and the owner supervises the inspection and acceptance [1].

The general contractor is mainly responsible for the project prevention and control, resulting in corresponding prevention costs; The owner is mainly responsible for the supervision and inspection of the project, and the corresponding appraisal cost is generated.

The external loss cost of the project is shared by the owner and the general contractor in proportion α : 1-α.

The prevention level of the general contractor and the supervision level of the owner are emphatically discussed.

If the amount of work completed by the general contractor meets the requirements of the owner, the general contractor shall pay the price of the work, otherwise he shall be punished, including ordering rework.

2.1 Establishment of the game model

Assumption 1: The game between the owner and the contractor about the cost of quality is discussed without considering the non-quality cost.

Assumption 2: Quality problems in construction can be remedied through rework, repair and other measures to achieve conformance quality and pass inspection.

Assumption 3: If quality problems occur in the construction process and are not found until the completion acceptance, these problems must be found by the later users.

Assumption 4: The qualified project must pass the acceptance, and the probability of finding quality problems is P_L, which is the error level of the owner.

The owner receives the accepted project and sells it to obtain revenue L, and the price to the general contractor is T.

After completion, the specific quality level e of the project shall be given according to the acceptance, and the quality level that the project must reach is f as agreed by both parties in the contract. e and f are a number between 0 and 1.

When the owner inspects the quality problem with probability β, the penalty to the general contractor shall be W, and if the acceptance result reaches the quality level f stipulated in the contract, the reward shall be R. In this case, the owner pays C(β) for supervision and inspection, and the general contractor pays C(e) for preventive evaluation.

The internal loss cost of repair and rework for failure to meet the specified quality level f found in the completion acceptance is C_1(f-e); The total external loss cost caused by unqualified quality but not detected is C_2(f-e), and the proportion borne by the owner and the general contractor for this part of external loss is α: 1-α.

The quality cost and profit level of the owner and the general contractor are C_A, U_A and C_B, U_B respectively [4].

Table 1 shows the game between the success of the inspection carried out by the owner and the qualification of the works delivered by the general contractor.

Table 1 Owner and general contractor game matrix

General contractor / Owner	Quality qualified probability is P_T	The probability of unqualified quality is $(1- P_T)$
The inspection success probability is P_L	L－T－R－C(β), T＋R－C(e)	L－T＋W－C(β), T－W－C(e)－C_1(f－e)
The inspection failure probability is $(1-P_L)$	L－T－R－C(β), T＋R－C(e)	L－T－R－C(β)－αC_2(f－e), T＋R－C(e)－(1－α)C_2(f－e)

2.2 Analysis and solution of the model

The revenue model of owner revenue is as follows.

$$U_L= L－T－R－C(\beta)＋P_L(1－P_T)(W＋R)－(1－P_L)(1－P_T)\alpha C_2(f－e) \tag{1}$$

The revenue model of the general contractor is as follows.

$$U_T = T＋R－C(e)－P_L(1－P_T)[W＋R＋C_1(f－e)－(1－\alpha)C_2(f－e)]－(1－P_T)(1－\alpha)C_2(f－e) \tag{2}$$

The owner's successful inspection probability P_L and the general contractor's qualified project quality probability P_T are the embodiments of their respective efforts to manage the project quality.

As rational economic men, the owner and the general contractor always pursue the maximization of profits, and the efforts of both sides in quality management are mutual to a certain extent. The owner may adjust his quality management efforts appropriately when he observes a higher quality compliance rate. Similarly, the general contractor may reduce P_T due to a lower P_L. Therefore, (P_L, P_T) is a discrete array, that is to say, the actions of the owner and the general contractor are a set of limited arrays, and the decision of their respective quality management efforts is a strategic game between P_L and P_T. Therefore, the sufficient conditions for the maximization of returns for both parties are:

$$\begin{cases} \partial U_L / \partial P_L = 0 \\ \partial U_L / \partial P_T = 0 \end{cases} \tag{3}$$

$$\begin{cases} \partial U_T / \partial P_L = 0 \\ \partial U_T / \partial P_T = 0 \end{cases} \tag{4}$$

I. Maximize the owner's income

According to Equation (3), we can obtain:

$$\begin{cases}(1-P_1)\left[\mathrm{W}+\mathrm{R}+\alpha \mathrm{C}_2(\mathrm{f}-\mathrm{e})\right]=0 \\ \alpha \mathrm{C}_2(\mathrm{f}-\mathrm{e})-P_L\left[\mathrm{W}+\mathrm{R}+\alpha \mathrm{C}_2(\mathrm{f}-\mathrm{e})\right]=0\end{cases} \tag{5}$$

The solution is:

$$\begin{cases}P_T=1 \\ P_L=1-\dfrac{W+R}{W+R+\alpha C_2(f-e)}\end{cases} \tag{6}$$

When the qualified rate of the project is 100%, the owner's profit is maximized [3], so the owner must develop certain reward and punishment system, and promote the improvement of P_T through the improvement of P_L.

On the other hand, the greater the external loss $\alpha C_2(f-e)$ caused by the inspection of quality problems that the owner has to bear, the more enthusiasm the owner will have to improve their quality management level, so as to improve the P_L.

Ⅱ. Maximize the general contractor's income

According to Equation (4), we can obtain:

$$\begin{cases}\left(1-P_{\mathcal{D}}\right)\left[\mathrm{W}+\mathrm{R}+\mathrm{C}_1(\mathrm{f}-\mathrm{e})-(1-\alpha)\mathrm{C}_2(\mathrm{f}-\mathrm{e})\right]=0 \\ \left(1-P_L\right)\alpha \mathrm{C}_2(\mathrm{f}-\mathrm{e})-P_L(\mathrm{W}+\mathrm{R})=0\end{cases} \tag{7}$$

The solution is:

$$\begin{cases}P_T=1 \\ P_L=\dfrac{\alpha C_2(f-e)}{W+R+\alpha C_2(f-e)}\end{cases} \tag{8}$$

$P_T=1$ indicates that when the unqualified rate of the project quality is 0, both parties can obtain the maximum profit. In other words, in order to obtain the maximum profit, the general contractor must make enough efforts to ensure that the quality of the project reaches the specified level. Therefore, the general contractor itself has the motivation to ensure the quality of the project. It can be deduced that with or without R, the rational general contractor will strive to achieve the quality of the project at level f [5]. For the owner, the incentive R for the contractor can be controlled at a certain level, not too high, because the existence of R is not a necessary condition for the general contractor to complete qualified quality projects.

According to the derived P_L formula, when the external loss to be borne by the owner increases, P_L will approach 1, that is, the management strength of the owner will adjust with the change of the external loss to be borne by the owner. This is consistent with the P_L formula from the perspective of maximizing profit for owners.

2.2 Game of quality cost considering quality improvement

The reason why the quality improvement of the owner and the construction is influenced by the supplier quality capability improvement plan initiated by Volkswagen, which is a plan to upgrade and improve the technology and management of the current suppliers by means of training and third-party assistance. In other industries, the impact of the quality of products and services provided by suppliers on the final product has been paid attention to, while the quality improvement of other participants' work in the production and construction process of the project has not been paid attention to.

Generally speaking, in the process of production and construction of a project, the owner chooses a construction unit that meets the requirements based on their qualification level and previous project experience. However, after the construction starts, even if certain supervision and inspection costs are paid, it is only for the quality management of the project under construction or already under construction. Basically did not consider the construction skills to improve the part, that is, the quality of the part. If the owner can also make some contribution to the training and skill training of the construction unit's personnel, it will greatly promote the reduction of the rework rate of the project and the better completion of the whole project. In turn, in the quality inspection, if the construction side can do some cooperation, the quality inspection of the owner's level of success will have a role in promoting.

The relationship between the owner and the general contractor is simplified to the general contractor producing the subdivision item by item, and then handing over to the owner item by item, who receives the goods after inspection. Each sub-project is equivalent to a semi-finished product, which eventually makes up the entire project. Previous discussions did not consider quality improvement. They were all aimed at controlling the repair rate of necessary prevention cost input by the general contractor during construction, while the owner mainly invested in necessary appraisal cost to control the passing level of engineering inspection. After considering the quality improvement, in addition to the original prevention cost and appraisal cost input, we also add the additional quality input cost caused by the efforts made to reduce the project rework rate and the efforts made to improve the quality detection level. In general, their respective quality costs include quality assurance cost, quality failure cost and supply chain quality improvement cost.

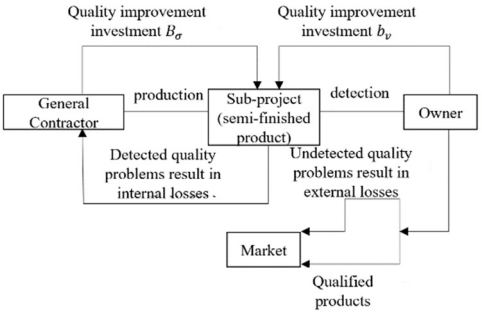

Figure 1: Consider quality improvement in the supply chain

The rate of nonconforming products is σ.The Detection level is $1-v$.The rework rate of the general contractor in the construction process is the same as the unqualified rate of the project in the previous section ($1\text{-}P_T$), which is abbreviated as σ here. The inspection level to be improved by the owner is the probability of unsuccessful inspection ($1\text{-}P_L$), which is measured by ν. If the qualified rate and the probability of successful inspection are selected as variables, the difficulty of determining the upper limit will cause difficulties for the research, so the rework rate of the project and the probability of unsuccessful inspection are selected as variables. The reduction of these negative probabilities is also the expression of quality improvement, which is more convenient for the expression of the formula of the cost of quality improvement.

The contract price of the project signed by the general contractor and the owner is L, and the income the owner can get if he transfers or sells the completed project is T. Quality failure cost includes internal loss and external loss cost. The internal loss cost of this two-level supply chain is the cost of reworking the nonconforming works that have been inspected by the owner, expressed as X. External loss cost refers to the loss caused by the existence of quality problems that are not detected by the owner until they are discovered by other relevant departments or users, represented by Y, the owner is responsible for the part of λY, the general contractor is responsible for (1-λ)Y, where 0<λ<1. We also assume that the cost of external losses is much higher than the cost of internal losses.

The quality improvement cost of the owner and the general contractor is respectively:

$$B_\sigma \ln\left(\frac{\hat{\sigma}}{\sigma}\right) \text{and } b_\nu \ln\left(\frac{\hat{\nu}}{\nu}\right)$$

When the purpose of the owner's quality improvement investment is to help reduce to σ, if, then the owner has no quality improvement investment; The purpose of the general contractor's quality improvement investment is to help reduce to ν, if, then there is no improvement investment in the probability of unsuccessful checks. And are respectively the value of the investment coefficient of the owner and the general contractor for quality improvement, which refer to the derivation method in literature and will not be repeated here.

2.2.1 Centralized decision-making considering quality improvement

The profit function of the whole supply chain is

$$U' = \mathrm{L} - \mathrm{C}(\nu) - \mathrm{C}(\sigma) - \sigma(1-\nu)\mathrm{X} - \sigma\nu\mathrm{Y} - B_\sigma \ln\left(\frac{\hat{\sigma}}{\sigma}\right) - b_\nu \ln\left(\frac{\hat{\nu}}{\nu}\right) \tag{9}$$

In this formula, σ(1-ν)X represents the internal loss caused by the probability that the unqualified works of the general contractor are checked by the owner, σνY represents the external loss caused outside the system under the probability that the unqualified works of the general contractor are not checked by the owner.

Ask U 'maximum, Let $\partial U' / \partial\sigma = 0$, $\partial U' / \partial\nu = 0$.

$$\partial U' /\partial \sigma = -C'(\sigma) - (1-\nu)X - \nu Y + \frac{B_\sigma}{\sigma} \tag{10}$$

$$\partial U' /\partial \nu = -C'(\nu) + \sigma X - \sigma Y + \frac{b_\nu}{\nu} \tag{11}$$

Through calculation, the optimal solution (σ^*, ν^*) of the centralized supply chain is obtained, which satisfies:

$$\begin{cases} \sigma^* = \dfrac{B_\sigma}{C'(\sigma^*) + (1-\nu^*)X + \nu^* Y} \\ \nu^* = \dfrac{b_\nu}{C'(\nu^*) + \sigma^*(Y-X)} \end{cases} \tag{12}$$

The decision-making mode of centralized supply chain considers the cost and profit of both sides in one function, and obtains the optimal solution to maximize the interests of both sides through the common profit function of both sides.

2.2.2 Distributed decision-making considering quality improvement

Under what circumstances will owners and contractors increase their investment in quality improvement? The analysis is made from the Angle of profit maximization of both sides.

The owner's profit function is:

$$U'_L = \text{L-T-C}(\nu)\text{-}\sigma\nu\lambda Y - B_\sigma \ln\left(\frac{\hat{\sigma}}{\sigma}\right) \tag{13}$$

The general contractor's profit function is:

$$U'_T = T - C(\sigma) - \sigma(1-\nu)X - \sigma\nu(1-\lambda)Y - b_\nu \ln\left(\frac{\hat{\nu}}{\nu}\right) \tag{14}$$

I. According to the basic theory of Nash equilibrium game, because the decision factor of the employer is ν, it will calculate the first derivative of σ when making decision, so that it is equal to 0, namely:

$$\nu = \frac{B_\sigma}{\sigma\lambda Y} \tag{15}$$

It can be seen from equation (15) that ν and σ are in the opposite direction. When there is a higher rework rate σ, there will be a lower value of ν from the perspective of the owner, that is, there will be a higher probability of inspection success, because in order to meet the requirements of project quality, the owner will not leave high rework rate alone. When such a high rework rate phenomenon, rational owners will actively take measures to reduce the ν value, which is in line with the actual requirements.

The derived expression is as follows:

$$B_{\sigma} = \nu\sigma\lambda Y \tag{16}$$

■ From Equation (16), it can be seen that the owner's quality improvement investment increases with the increase of ν. When the owner chooses whether to improve the quality, when there is a higher owner inspection unsuccessful level, the investment to reduce the rework rate will also increase, that is, when the owner finds himself weak in the usual supervision and inspection, he can pay some additional quality improvement costs.

■ With the increase of λ, the larger the value of λ is, the more part of the owner to bear the external loss.

■ With the increase of σ, it is easy to understand that a higher rework rate will cause the owner to worry about the quality of the project

Ⅱ. According to the basic theory of Nash equilibrium game, because the decision factor of the general contractor is σ, it will make the decision by calculating the first derivative of ν and making it equal to 0, namely:

$$\sigma = \frac{b_{\nu}}{\nu\left[(1-\lambda)Y - X\right]} \tag{17}$$

It can be seen from equation (17) that σ and ν are in the opposite direction. When there is a low probability of unsuccessful inspection ν, that is, the general contractor has a slight mistake in the quality of the project, the owner can check and form a higher rework rate. From the point of view of the general contractor, if the owner shows a higher probability of unsuccessful inspection, the owner's concern about the quality of the project is not very high, there are some quality problems can not be found, then the general contractor can be lazy, shoddy? The answer is no. From the perspective of his profit function, a rational general contractor should maximize his profit when the quality of the project is qualified. In order to achieve the overall goal of the project and the profit maximization goal of the general contractor, he should consciously improve the construction quality level to reduce the rework rate, which is in line with the actual requirements. The derived expression is as follows:

$$b_{\nu} = \sigma\nu\left[(1-\lambda)Y - X\right] \tag{18}$$

■ As can be seen from Equation (18), the quality improvement input of the general contractor increases with the increase of σ. When the general contractor chooses whether to carry out quality improvement or not, if there is a high rework rate σ of the general contractor, then the investment on reducing the probability of inspection failure will also increase [6]. That is, when the general contractor finds that he is weak in the execution of qualified construction, he can pay some extra quality improvement costs.

■ It increases with the increase of, that is, the greater the external loss the general contractor has to bear, the smaller the internal loss. This indicates that many engineering problems are exposed outside the system because they are not checked out in time, and the cost of bearing external losses is high.

■ With the decrease of the ν will be reduced, that is, when the ν is low, there is a higher probability of inspection success, reflecting the high level of supervision and inspection of the owner, then the total contractor quality improvement investment can be slowed down.

3 CONCLUSIONS

In the analysis of the quality cost game model between the owner and the general contractor, the following conclusions are drawn.

■ The general contractor can make up for the deficiency of low inspection level through quality improvement to reduce the rework rate. The method can be to ask the general contractor to hold regular skills and knowledge training classes for workers to improve their professional skills. The owner shall be responsible for part of the corresponding expenses, which is the quality improvement input of the owner to reduce the rework rate. A higher proportion of external loss can urge the owner to consciously carry out quality improvement investment to avoid bearing high external loss costs.

■ By improving the quality of the inspection success probability of the owner to make up for their own high rework rate shortage, the method can be that the general contractor to a certain reward system to encourage the staff fine work, strengthen the self-inspection work, these measures increase the labour cost of the general contractor, this part of the cost is the general contractor to help improve the probability of success of the quality improvement investment. On the other hand, it is necessary for the general contractor to invest in quality improvement to help improve the probability of inspection success so as to avoid bearing high external loss costs. If the level of supervision and inspection of the owner is high, the total contractor quality improvement investment can be slowed down.

■ The owner shall invest in quality improvement to help the general contractor complete the established project quantity with quality and quantity. The general contractor shall pay quality improvement investment to cooperate with the supervision and inspection carried out by the owner, and both parties shall invest in quality improvement to improve the quality of building products.

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