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Original Research Article

Evolutionary Game Analysis of PPP Project Constructor's Emergency Strategy Optimization Based on the Perspective of Public Value

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Abstract: Properly and efficiently solving the emergency incidents caused by the negative externalities of the PPP project is a major challenge facing the current construction party. How to optimize the emergency strategy of the project builder in the construction project is the focus of this article. This paper establishes an evolutionary game model and elaborates the evolution of the emergency strategy of the PPP project. The research results show that at this stage, in response to different results in different situations, strengthening the degree of intervention of the project builder and adopting diversified emergency strategies can be timely The public value of bridging the failure. This article provides a new theoretical explanation based on the perspective of public value for optimizing the emergency strategy of the project builder in the PPP project.

Keywords: PPP project; Emergency strategy; Public value; Evolutionary game.

1. Introduction

PPP projects are implemented to solve economic and social problems, but the negative externalities of the projects are often borne by specific groups of residents, resulting in a series of incidents such as the “neighbor avoidance” effect, which require the attention and participation of the construction side. In recent years, with the increase in the number of PPP projects being constructed, the concern and sensitivity of neighboring residents to the environmental issues that may be brought about by the projects have been increasing, resulting in incidents such as the PC Chemical Project in Tianjin, the Molybdenum and Copper Project in Shifang City, and the PX Projects in Ningbo and Kunming, which have had a negative impact on socio-economic factors. Therefore, optimizing the emergency response strategies of project builders in PP projects is an urgent priority.

Public value advocates the creation of public value by public administrators, the expansion of public participation, and the establishment of an open and flexible mechanism for the acquisition and delivery of public services. The mainstream of foreign scholars studying public value theory is to combine public value with public administration and public management from the perspectives of public management, economics and jurisprudence. In recent years, many domestic scholars have introduced public value theory to explore the origins, analytical frameworks and countermeasures of this kind of emergency incident phenomenon. Wang Dianli et al. consider the problem of “neighborhood avoidance” as an integration of public value creation, transmission, failure and regulation, and point out that all parties in society should take action and do something when they can help to compensate for the failure of public value. Under the perspective of public value, Zhong Junqi et al. constructed a “value-process” framework and analyzed and verified it in the context of the Maoming PX project, and put forward a strategic triangle model of “public, cooperation, and legitimacy”, suggesting that a platform for reconciliation and coordination should be created to provide stability and harmony within the framework of legitimacy. It is proposed that a platform for reconciliation and coordination should be created, and a stable and harmonious system should be provided within the framework of legitimacy in order to effectively solve emergency incidents. Yu Peng et al. established the public value set in environmental neighborhood governance and the integration mechanism of environmental neighborhood governance based on the strategic triangle model, and in order to achieve the ultimate goal of maximizing the value of the “public value set”, they proposed that the key to environmental neighborhood governance lies in getting rid of the mindset of stability preservation and compromise, and reshaping the mission of public value of all parties.

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To summarize, the public value theory is a new key that can make up for the shortcomings of the past theories and solve the contingencies of PPP projects. Although the above studies introducing the public value theory have pointed out the important role that the construction party should play in solving the emergency events of PPP projects, as well as given corresponding countermeasures and suggestions for the adjustment of public policies, there is a lack of quantitative research on the public value theory due to the difficulty of reflecting the public value in the contract. PPP projects should essentially provide residents with their corresponding public value, and the generation of externality events has led to the failure and lack of some public value. Therefore, based on the public value perspective to optimize the project constructor's contingency strategy, this paper analyzes the evolution of the contingency strategy of PPP projects to find the breakthrough point of optimization at each stage. The innovation of this study is to introduce public value into the basis of emergency response strategy analysis for emergency events, and provide theoretical guidance for the adjustment and improvement of the emergency response strategy through model calculation and quantitative analysis.

2. Evolutionary Game Analysis of Contingency Strategies of PPP Project Builders

When emergency events caused by construction projects occur, under market economy conditions, residents usually only care about maximizing their own benefits. The emergency strategy of the construction party should also be adjusted accordingly to maximize the public value to compensate for the failure in time. Under the perspective of public value theory, the constructor should play a guiding role in the game between the two sides of the emergency event, build a platform for the transmission of social public value, so that the two sides can fully participate and reach a consensus on the value, and the degree of the constructor's intervention at this time plays an important role. The purpose of this study is to discuss the evolution of the emergency response strategy of PPP projects with the degree of intervention of the construction side as a variable, to enhance the residents' sense of security, to establish an evolutionary game model, to take the decision of the construction side to carry out a strong emergency response strategy (with a strong degree of intervention of the construction side) as a goal, and to measure how to maximize the malfunctioning public value without wasting social resources.

In a market economy, residents are usually only concerned with maximizing their own benefits, while the builder agency is concerned with maximizing the impact of regulations on facilitating the construction of the building project. If the residents choose not to cooperate, then when the builder agency chooses a strong strategy, the initiatives taken by the residents not to cooperate will cost the residents more, such as fines, and the builder agency's profits will increase, such as by gaining recognition from higher authorities. If the residents fully cooperate with the construction project and the construction agency chooses a strong contingency strategy for the building facility, then the residents will receive some subsidies, such as financial compensation such as indemnities or soft compensation such as priority allocation of the remaining resources.

2.1 Model assumptions and parameterization

One of the participants in the evolutionary game model is the construction side, denoted as G_i (i=1, 2, ...), and the other side is the resident group, denoted as E_i (i=1, 2, ...). The construction side has two strategies. The construction side has two strategies, for emergency events choose to develop a strong emergency strategy or choose to develop a weak emergency strategy, were recorded as G_s, G_w .When the compensation strategy is more moderate, the construction side of the weak intervention, the development of the situation of a more laissez-faire attitude; when the compensation strategy is more strong, indicating that the construction side of the strong intervention, when the residents insisted on the expression of dissatisfaction, will pay the cost. There are two strategic choices for the resident group: the residents express cooperation in the construction of the PPP project; or the residents express non-cooperation, which are recorded as E_s and E_t , respectively, and the contingency strategy may fail when the residents choose non-cooperation. The construction party and the resident group randomly choose the strategy to evolve the game, at the t stage of the game, the probability (or share) of the construction party choosing G_s is set as $x(0 \le x \le 1)$, then the probability (or share) of G_w is 1-x. For the same, the probability that the residents express their satisfaction, i.e., E_s is $y(0 \le y \le 1)$ and then the probability that E_t is 1-y. The parameters in the model are defined as shown in Table 1 and the operation matrix is shown in Table 2.

Table 1 Parameterization.

	Construction party
R_G	The reward for choosing to develop a vulnerable emergency strategy.
αR_G	When residents express satisfaction and choose to fully cooperate, it increases the benefits of the construction organization.
C_G	The cost of developing a vulnerable emergency strategy.
βC_G	The additional cost incurred by the construction party when transforming weak emergency strategies into strong emergency strategies.
ωP	The increased profits due to strong emergency strategies when residents express dissatisfaction.
	Residential groups
R_E	The rewards obtained when choosing not to cooperate.
εR_E	The additional profits obtained when choosing cooperation.
C_E	The cost of choosing not to cooperate.
ηC_E	The additional costs incurred when choosing cooperation.
P	When the construction party chooses a strong emergency strategy, the cost of residents not cooperating increases.
R_Q	When the construction party chooses a strong emergency strategy, the return on cooperation among residents increases.

Table 2 Operator Matrix.

$E \quad G$	$E_s y$	$E_t 1-y$
$G_s x$	$\left(\prod_{G_1},\prod_{E_1}\right)$	$\left(\prod_{G_2},\prod_{E_2}\right)$
$G_w 1-x$	$\left(\prod_{G_3},\prod_{E_3}\right)$	$\left(\prod_{G_4},\prod_{E_4}\right)$

$\prod_{G_1}=(1+\alpha)R_G-(1+\beta)C_G$	$\prod_{G_2}=R_G+\omega P-(1+\beta)C_G$
$\prod_{G_3}=(1+\alpha)R_G-C_G$	$\prod_{G_4}=R_G-C_G$
$\prod_{E_1}=(1+\varepsilon)R_E-R_Q-(1+\eta)C_E$	$\prod_{E_2}=R_E-P-C_E$
$\prod_{E_3}=(1+\varepsilon)R_E-(1+\eta)C_E$	$\prod_{E_4}=R_E-C_E$

2.2 Evolutionary game modeling calculations

Calculate the expected returns (or utilities) of the participants choosing strategies G_s, G_w, E_s, E_t and the weighted average expected returns of groups G and E, denoted $\bar{U}_C and \bar{U}_E$, respectively.

$$U_{G_{(s)}}=y\cdot\prod_{G_1}+(1-y)\prod_{G_2}, U_{G_{(w)}}=y?\prod_{G_3}+(1-y)\prod_{G_4}, \bar{U}_G=x?U_{G_{(s)}}+(1-x)U_{G_{(w)}}$$

$$U_{E_{(s)}}=x\cdot\prod_{E_1}+(1-x)\prod_{E_3}, U_{E_{(t)}}=x\cdot\prod_{E_2}+(1-x)\prod_{E_4}, \bar{U}_E=y\cdot U_{E_{(s)}}+(1-y)U_{E_{(t)}}$$

The dynamics equation when the builder adopts a strong compensation strategy and residents show willingness to cooperate in taking cooperative measures is:

$$f_G(x,y)=x(U_{G_{(s)}}-\bar{U}_G)=x(1-x)[y?(\prod_{G_1}-\prod_{G_3})+(1-y)(\prod_{G_2}-\prod_{G_4})] \quad \text{(Eq.1)}$$

$$f_E(x,y)=x(U_{E_{(s)}}-\bar{U}_E)=y(1-y)[x?(\prod_{E_1}-\prod_{E_3})+(1-x)(\prod_{E_2}-\prod_{E_4})] \quad \text{(Eq.2)}$$

$\vartriangle$ It is used to describe the success of a strategy and is expressed as the difference between the expected return and the weighted average return. Eq. (1) and (2) are:

$$f_G(x,y)=x(1-x)[y(\Delta_{G_{13}}-\Delta_{G_{24}})+\Delta_{G_{24}}] \tag{Eq.3}$$

$$f_E(x,y)=y(1-y)[x(\Delta_{E_{12}}-\Delta_{E_{34}})+\Delta_{E_{34}}] \tag{Eq.4}$$

It is calculated that:

$$\Delta_{G_{13}}=-\beta C_G,\Delta_{G_{24}}=\omega P-\beta C_G,\Delta_{E_{12}}=\varepsilon R_E+R_Q+P-\eta C_E,\Delta_{E_{34}}=\varepsilon R_E-\eta C_E$$

Apparently, $\Delta_{G_{13}}<0,\Delta_{G_{13}}\le\Delta_{G_{24}},\Delta_{E_{12}}\ge\Delta_{E_{34}}$.

Six possible scenarios are summarized in Table 3.

Table 3 Six possible scenarios.

	ΔG_{13}	ΔG_{24}	ΔE_{12}	ΔE_{34}
Scenario 1	-	+	+	+
Scenario 2	-	+	-	-
Scenario 3	-	+	+	-
Scenario 4	-	-	+	+
Scenario 5	-	-	-	-
Scenario 6	-	-	+	-

Make

$$\begin{cases} f_G(x,y)=x(1-x)[y(\Delta_{G_{13}}-\Delta_{G_{24}})+\Delta_{G_{24}}]=0 \\ f_E(x,y)=y(1-y)[x(\Delta_{E_{12}}-\Delta_{E_{34}})+\Delta_{E_{34}}]=0 \end{cases} \tag{Eq.5}$$

Because of $(x,y)\in[0,1]\times[0,1]$, it is possible to determine the equilibrium point A(0, 0), B(1, 0), C(1, 1), D(0, 1) of the pure strategy.

The calculated balance point of the mixed strategy is $V(x^*,y^*)=\left(\frac{-\Delta_{E_{34}}}{\Delta_{E_{12}}-\Delta_{E_{34}}},\frac{-\Delta_{G_{24}}}{\Delta_{G_{13}}-\Delta_{G_{24}}}\right)$, among $0\le\frac{-\Delta_{E_{34}}}{\Delta_{E_{12}}-\Delta_{E_{34}}}\le1,0\le\frac{-\Delta_{G_{24}}}{\Delta_{G_{13}}-\Delta_{G_{24}}}\le1$. For the equilibrium point, we need to analyze its stability to find the ESS, and the Jacobian matrix of partial equilibrium point stability analysis is used to evaluate the evolutionary equilibrium stability. The Jacobian matrix is $I=\begin{bmatrix}\frac{\partial f_G}{\partial x} & \frac{\partial f_G}{\partial y}\\ \frac{\partial f_E}{\partial x} & \frac{\partial f_E}{\partial y}\end{bmatrix}$, and its corresponding trace and determinant are:

$$Tr(I)=\frac{\partial f_G}{\partial x}+\frac{\partial f_E}{\partial y}=(1-2x)[y(\Delta_{G_{13}}-\Delta_{G_{24}})+\Delta_{G_{24}}]+(1-2y)[x(\Delta_{E_{12}}-\Delta_{E_{34}})+\Delta_{E_{34}}]$$

$$\begin{aligned} Det(I)&=\frac{\partial f_G}{\partial x}?\frac{\partial f_E}{\partial y}-\frac{\partial f_G}{\partial y}\cdot\frac{\partial f_E}{\partial x} \\ &=(1-2x)[y(\Delta_{G_{13}}-\Delta_{G_{24}})+\Delta_{G_{24}}]?(1-2y)[x(\Delta_{E_{12}}-\Delta_{E_{34}})+\Delta_{E_{34}}]-x(1-x)(\Delta_{G_{13}}-\Delta_{G_{24}})?(1-y)[y(\Delta_{E_{12}}-\Delta_{E_{34}})\end{aligned}$$

A partial stability analysis method based on the Jacobi matrix:

(1) Tr(I)<0, Det(I)>0, then the corresponding equilibrium point is asymptotically stable and the point is an ESS;

(2) Tr(I)>0, Det(I)>0, then the corresponding equilibrium point is the unstable fixed point;

(3) Tr(I)=0, Det(I)>0then the corresponding equilibrium point is the center point;

(4) Det(I)<0, then the corresponding equilibrium point is the saddle point.

Analyzing the six cases listed in Table 3 separately, we can obtain the characteristics of the equilibrium points, as shown in Table 4.

According to Table 4, we can obtain the dynamic image of the evolutionary game. When this point is unstable, it is not an optimal solution in either x or y direction. When this point is a saddle point, it is a maximum in one direction and a minimum in the other. When this is an ESS, it is the best solution in all directions. The results are shown in Figure 1.

Table 4 Analysis of equilibrium points

Scenario 1					
	A(0,0)	B(1,0)	C(1,1)	D(0,1)	$V(x^*, y^*)$
$Tr(I)$	+			-	
$Det(I)$	+	-	-	+	
point	Instability point	saddle point	saddle point	ESS	$x^* < 0$
Scenario 2					
	A(0,0)	B(1,0)	C(1,1)	D(0,1)	$V(x^*, y^*)$
$Tr(I)$		+	+		0
$Det(I)$	-	+	+	-	+
point	saddle point	ESS	Instability point	saddle point	Center point
Scenario 3					
	A(0,0)	B(1,0)	C(1,1)	D(0,1)	$V(x^*, y^*)$
$Tr(I)$					0
$Det(I)$	-	-	-	-	+
point	saddle point	saddle point	saddle point	saddle point	Center point
Scenario 4					
	A(0,0)	B(1,0)	C(1,1)	D(0,1)	$V(x^*, y^*)$
$Tr(I)$		+		-	
$Det(I)$	-	+	-	+	
point	saddle point	Instability point	saddle point	ESS	$x^*, y^* < 0$
Scenario 5					
	A(0,0)	B(1,0)	C(1,1)	D(0,1)	$V(x^*, y^*)$
$Tr(I)$	-		+		
$Det(I)$	+	-	+	-	
point	ESS	saddle point	Instability point	saddle point	$y^* < 0$
Scenario 6					
	A(0,0)	B(1,0)	C(1,1)	D(0,1)	$V(x^*, y^*)$
$Tr(I)$	-	+			
$Det(I)$	+	+	-	-	
point	ESS	Instability point	saddle point	saddle point	$y^* < 0$

Figure 1 shows the evolutionary paths and equilibrium stability of the strategic interactions between builders and residents in the six scenarios. In case 1, the probability of x continues to increase, converging to 1 when y < y* and decreasing from 1 to 0 when y > y*. For residents, $\Delta_{E_{34}} > 0$ implies that they are fully satisfied with the compensation strategy given by the builder as a tightly controlled strategy, and thus y keeps growing until it converges to 1, independent of changes in the builder's strategy. In case 2, the trend of x share is almost the same as in scenario 1. The difference is that the trend of y changes in the opposite direction. The strategic choices of the construction side eventually converge to a strong compensation strategy, but the strategic choices of the residents eventually manifest themselves in measures to express dissatisfaction. In case 3, the strategic choices of one participant depend on the strategic choices of the other. When x < x*, y decreases, and vice versa, y increases. When y < y*, x increases, and conversely, x decreases. This suggests that the path of strategic evolution between the builder and the residents is so cyclical that it never reaches a steady state, leading to uncertain system evolution. In case 4, both the builder and the residents adopt a strictly dominant strategy and their strategies do not interact with each other in this scenario. As a result, the system evolves an ESS that adopts a weak contingency strategy and a strategy that fully cooperates with the construction. In case 5, the vulnerable contingency strategy strictly becomes the dominant strategy of the builder since $\Delta_{G_{13}}$ <0 and $\Delta_{G_{24}}$ <0. Both the builder and the residents have strictly dominant strategies, so the ESS for system evolution is the vulnerable contingency strategy and the residents' choice not to cooperate. In case 6, the residents' strategy choice depends on the builder's choice. When x < x*, y decreases and vice versa. Due to the lack of strong contingencies, there is no relative advantage in choosing to fully cooperate with the construction of the project, so the system evolution tends to weak contingency strategies and residents choosing not to cooperate.

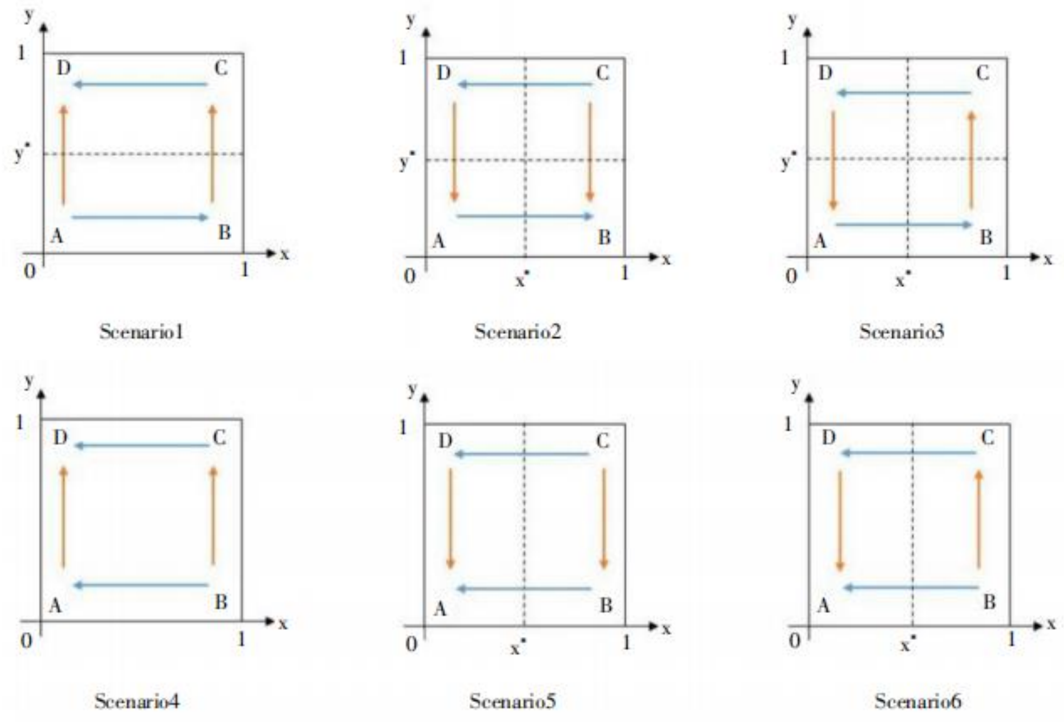

Figure 1 System dynamics diagram for six cases

2.3 Analysis of model results

Based on the above six scenarios, the evolution of the PPP project builder's contingency strategy can be categorized into the fledgling stage, the growth stage and the maturity stage (as shown in Figure 2), specifically:

(1) In case 2 and case 5, no matter what strategy the builder takes, residents are reluctant to cooperate, which means that the impact of the building is far greater than the compensation that residents can get through the emergency strategy, which fully shows that the formulation of emergency strategy does not meet the needs of residents for a better life. From the perspective of emergency strategy formulation, the possible causes of situation 1 and situation 5 are as follows: First, the single economic compensation strategy that appears in many cases at present does not consider the soft compensation strategy that residents need today. For example, waste incineration stations only pay compensation for the environmental pollution caused by the surrounding area, but do not take measures to improve the ecological environment of the site. To solve such problems, different emergency strategies and other systems can be organically combined according to different projects, the local

environment can be improved by investing in the construction of basic public facilities, and the stereotype of residents in risk perception can be eliminated through early publicity work. Second, the process of emergency strategy formulation is not open and transparent, the public participation rate is low, and the construction side does not formulate corresponding emergency strategies according to the "public heart", and its rationality is questioned by residents. For example, in the case of Beijing-Shenyang passenger dedicated Line, the construction department takes economic benefits as the primary goal of the construction department's performance, which fails to achieve the fair interaction expected by the public. In this case, the construction party should play an active guiding role in the game process, the working principle should be guided by public value, fully listen to public opinion, and take the initiative to assume the responsibility of building a common communication platform between the construction party and the residents. From the results, situation 2 and situation 5 can be classified into the same category of results, and the influence is prominent and the public value fails.

(2) In case 3 and case 6, the compensation strategy of the builder is the main driving force to make up for the public value, and the perfect emergency strategy can bridge the public value failure to the greatest extent. From the perspective of public management theory, this kind of situation mostly occurs in the transition period from the traditional public management theory to the public value theory as the leading public strategy. When the public value fails, by constantly improving the emergency strategy of the construction side, the public value of the failure can be bridged to varying degrees and the external impact brought by the construction project can be reduced, which is a period of continuous learning, exploration and practice. For example, in the three waste incineration plant treatment incidents cited by Tan Shuang, the decision of the project all triggered the dissatisfaction of local residents, but in the latter two cases, the construction agency chose to cooperate with the practice of garbage classification, the establishment of kitchen waste transportation lines, the establishment of "green house" facilities and other measures through consultation with residents, which not only reduced the negative impact of the establishment of waste incineration plants. Moreover, it promotes the optimization of the city's garbage management strategy, solves the anxiety of residents through multiple emergency compensation strategies, and solves the externalities caused by construction projects, bridging the public value of the failure.

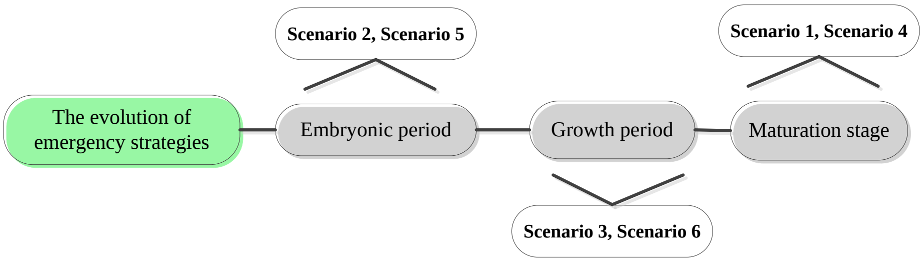

Figure 2 Evolutionary path of contingency strategies for PPP project builders

(3) In case 1 and case 4, when $\Delta_{E_{34}} = \varepsilon R_E - \eta C_E > 0$, regardless of whether the builder's strategy is weak or strong, residents' benefits from choosing cooperation exceed the costs paid. The result of evolutionary game is consistent with cognition, which also means that social risks are fundamentally solved, and the externalities of construction projects to surrounding residents are eliminated by advanced technologies. Either the emergency strategy develops to the optimal stage, avoiding the loss of public value through the most advanced technology, or the optimal emergency strategy can maximize the bridging of public value. At this time, if the construction party implements the strong strategy, it will cause a certain degree of waste of social resources, and residents will also choose cooperation under the weak strategy.

3. Conclusion

It is an important task for the constructors to effectively resolve the emergency events caused by construction projects through multiple emergency strategies. At present, the optimization of the emergency strategy of the construction side is a hot research topic, and the introduction of public value management theory is a new exploration.

In the evolution of emergency strategy, whether residents express cooperation depends on whether the strategy is dominant in the decision-making scheme. Therefore, in order to maximize the public value of failure, it is necessary to ensure that cooperation is the preferred strategy of residents under the premise of effective use of resources, and the intervention degree of the construction party is crucial at this stage, and it can not use weak emergency measures to fall into the vicious circle of “balance – compromise”, nor can it be too tough to cause the loss of “public heart” and make public value fail. This study divides six different results into three categories and gives explanations and suggestions based on actual cases. Examples prove that at the present stage, when different results are caused by emergency events in construction projects, diversified emergency strategies can effectively bridge the public value of failure, which requires local builders to grasp the intervention intensity on the basis of comprehensive emergency response capability and risk assessment. The cooperation rate among residents will be increased. This also proves that the construction side pays attention to public value management and combines emergency strategies with democratic construction, which plays an important role in resolving emergency incidents caused by construction projects in advance. In future studies, we can also combine more game theoretic models, such as the classical model of psychological game theory, to consider more emotional factors of residents.

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