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# *Research on the Application of Non-cooperative Game Theory in Construction Engineering Management*

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***Abstract:*** With the increasing scale and complexity of construction projects, managers face challenges in decision-making, and non-cooperative game theory becomes an effective management tool. This paper studies its application in construction engineering management. A literature review and case study approach explores its applications in competitive bidding, supply chain management, regulatory platforms, and builders' games and its advantages and disadvantages. It is found that the game theory model performs well in optimizing decisions and improving management efficiency to maximize benefits. However, there are some limitations to the application of these models that require particular attention to adaptation. The paper explains that the application of non-cooperative game theory has been demonstrated in certain areas, and therefore, introducing non-cooperative game theory into the engineering management process would provide broader and deeper insights to help us make more informed decisions and improve management efficiency. To further enhance the efficiency and quality of engineering management, we need to explore in depth the more expansive application areas of non-cooperative game theory in engineering management.

***Keywords:*** non-cooperative game, construction engineering management, game theory

## 1. Introduction

With the intensification of market competition and the increasing demand of customers for engineering projects, how to maximize benefits becomes a crucial goal for enterprises in engineering projects. For this reason, game theory, as a mathematical model for studying the mutual influence of participants in decision-making, is widely used in engineering management. In this field, a non-cooperative game theory further enhances the economic efficiency of engineering project management by analyzing the strategies of each financial agent in decision-making and determining the optimal solution. Compared with the cooperative game, the non-cooperative game is more in line with the relative independence of the interests of each party in the engineering project and has more practical significance. The purpose of this paper is to study the application of non-cooperative game theory in engineering management, analyze its advantages and disadvantages and specific model theory in conjunction with relevant literature, explore its importance, and provide references for enterprises to maximize benefits in engineering management projects.

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## 2. Overview of Game Theory and Non-Cooperative Game Theory

Game theory is a method of finding the best decision through competition or cooperation and is applicable to the fields of economics, sociology, political science, and management science. Different types of game theory, such as dynamic and static games, zero-sum and non-zero-sum games, each with different game rules that can lead to different optimal strategies for players. In practical applications, game theory can be used to solve non-cooperative game problems in construction management, such as cooperation and conflict between customers and main contractors and between main contractors and subcontractors. Through a game-theoretic approach, the best solution can be found to achieve the maximum benefit for the system and all players [1]. In construction project management, game theory is a practical tool that can be used to analyze and optimize the interaction of decisions at all stages. An important branch of game theory is the non-cooperative game, which assumes that each player pursues their own best interests and will not cooperate with other players.

In "Research on the application of game theory non-cooperative equilibrium game in construction engineering management," Jiang Ziqiang introduces three types of non-cooperative equilibrium states in non-cooperative games, including non-cooperative equilibrium of strategic game with incomplete information, non-cooperative equilibrium of strategic game and non-cooperative equilibrium of mixed strategy. In the non-cooperative equilibrium of the strategic game with incomplete information, each player can only judge the other player's action strategy based on the information they have gathered and then choose the optimal action plan.In a non-cooperative equilibrium of a strategic game, there is competition and decision-making between players, and one player's choice may not be as good as the other player's choice, so that player needs to consider the other player's action plan to choose the best action strategy. In a non-cooperative equilibrium with mixed strategies, each player is given a probability for each combination of actions, and the optimal action plan is chosen by calculating the corresponding probability size based on each action strategy [2].

In the management of construction projects, game relationships exist between multiple stakeholders, including construction units, supervision units, design units, and others, as proposed by Ren Guoqiang and Zhang Hongyan. The interactions and negotiations among these stakeholders can significantly impact the progress and quality of construction projects. The stakeholders may have different priorities and goals, leading to conflicts and competition, which require effective management strategies such as clear communication, negotiation, and compromise [3].Therefore, in engineering management, non-cooperative game theory needs to be used to help decision-makers formulate optimal strategies to optimize the construction project management process and improve the effectiveness of the project. For example, in the bidding process of a construction project, there is fierce competition among contractors. Each contractor wants to win the contract and thus gain more profit. In this case, non-cooperative game theory can be used to analyze the strategic choices of individual contractors, find the Nash equilibrium, and determine the best bid price to increase the probability of winning and gaining more profit.

In summary, non-cooperative game theory is a very important tool in construction engineering management, which can help decision-makers to formulate optimal strategies, optimize the construction engineering management process and improve the effectiveness of the project.

## 3. Application of Non-Cooperative Game Theory in Engineering Management

Taking typical engineering management problems as examples, such as bidding, contract negotiation, and resource allocation, Zhu Gaoming et al. analyzed the game mechanism behind these problems and put forward corresponding game models and solutions. They argue that game theory can help engineering managers better understand the interactions between decision-makers and the links between decision outcomes so as to formulate more reasonable management strategies [4]. It is thus

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concluded that non-cooperative game theory has a wide range of applications in engineering management. The following describes the application of game theory to bidding for engineering projects, supply chain management of building materials, and the game between supervisors and constructors based on the punishment mechanism.

## 3.1. Bidding for Engineering Projects (Strategic Game Between Bidders and Tenderers)

In construction projects, project bidding is the link between economic subjects based on whether they choose to cooperate in the pursuit of economic benefits under the assessment of their own interests. It is assumed that the subjects on both sides of the negotiation are economically rational, i.e., the economic behavior adopted is to try to obtain their own high economic benefits at their own low economic cost. In the process of bidding for engineering projects, the interests of the two parties are opposing, the bidder aims to obtain the management rights of the project as far as possible under profitable circumstances, and the bidder aims to take the project at a lower price, so the game between the two is a non-cooperative game. In order to ensure the stability of the capital chain, the company sets a cost budget in advance and bids for the project on the basis of that budget at a price lower than that. In order to keep the cost price low, the enterprise's expected cost price will not be informed to the bidders, so there is no problem of mutual collusion between the two parties; during the negotiation process, the bidders need to make a quick price strategy adjustment according to the bidders' reaction to different cost prices and other bidders' strategies, the non-cooperative game belongs to the application of static game with incomplete information.

### 3.1.1. Specific Analytical Model.

When non-cooperative game theory is applied in the bidding of engineering projects, it involves the analysis of the competitive strategies and final results of the two participants, the bidders, and the tenderers. In this competition, the bidders usually only consider the price factor and choose the lowest cost way to complete the project. However, if bidders consider other factors, such as the experience and skills of the bidder and the financial benefits at a later stage, they may choose the non-lowest-priced bidder. However, if there is fierce competition among bidders, they may resort to a vicious competitive strategy and choose excessively low bid prices to win the contract. Such a practice may lead to a decline in quality or failure to maintain sustainability, thereby compromising the success of the project. In such cases, bidders and tenderers can avoid unhealthy competition by adopting reasonable competition policies and contract terms. Non-cooperative game theory can therefore help bidders and tenderers in bidding for engineering projects to analyze competitive strategies, assess optimal prices and partner selection, and ensure project success. Also, this analytical approach can be used to improve communication and cooperation between bidders and tenderers to maximize project efficiency and quality.

Through reading the literature, the authors found that non-cooperative game theory has some research results in engineering bidding, and Chen Shirong concluded that in engineering project bidding, the use of non-cooperative game theory could analyze the game relationship and strategy choice between parties, revealing the conflict of interest and game strategy. The analysis of non-cooperative games and static games with incomplete information can help bidders to develop optimal bidding strategies and achieve successful bids. This analysis and discussion provide bidders with references to address the challenges and opportunities in the bidding process [5]. Song Wen Dart concludes that the analysis of the non-cooperative game in bidding for engineering projects can help bidders develop optimal bidding strategies to improve the probability of winning bids, reduce costs and gain more benefits. At the same time, it can also reveal the conflict of interests between bidders

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and tenderers, enabling all parties to negotiate and play more rationally and achieve a win-win situation [6].

### 3.2. Building Materials Supply Chain Management (Price Games Between Primary and Secondary Contractors and Building Materials Suppliers)

In building materials supply chain management through previous studies, articles by both Li Longlong (2014) and Liu Bo (2017) discuss the problems in construction project management and how to use supply chain management ideas and game theory to solve these problems. The study by Li Longlong (2014) focuses on supply chain challenges in the building materials industry, resulting in increased costs and disruptions. To address these issues, a gaming approach utilizing supply chain management concepts is proposed to improve coordination and cooperation between suppliers and contractors. This approach presents a promising solution for the existing research gap in this field [7].Liu Bo (2017) is concerned with the game theory problems in construction project management, such as contract negotiations between contractors and owners and price games between construction material suppliers and contractors. The authors propose a theory of game-theoretic non-cooperative equilibrium to address these problems. In negotiations and fun, both parties must consider each other's interests and motivations to achieve a non-cooperative balance to achieve their goals better [8]. There are complex supply chain and game theory problems in construction project management. To solve these problems, supply chain management ideas and game theory need to be applied to achieve better coordination and cooperation. Different suppliers of building materials compete in the market with differing information, leading to different prices made by suppliers and, therefore, other purchasing decisions made by contractors. This process requires the coordination of multiple suppliers and subcontractors to ensure that materials and services arrive on-site on time.

In a study conducted by Li Xiaoyuan in 2015, it was found that the building materials retail industry commonly deals with a vast number of suppliers varying in size. Additionally, trade order strategies and promotions are standard practices within the industry, particularly for bulk orders. Furthermore, cost control functions are utilized to maximize cost advantages [9].Game theory can be used to analyze the decision-making processes and interactions in a supply chain and to find the optimal coordination strategy. For example, the game approach can be used to find the optimal cooperation strategy to optimize the supply chain in a construction project with conflicting interests between the main contractor and subcontractors in a construction project with contradictory claims between the main contractor and subcontractors.

#### 3.2.1. Specific Analytical Model.

Consider a non-cooperative game with a conflict of interest between the main contractor and subcontractors. A non-cooperative game model needs to be used to find the optimal strategy. A non-cooperative game model typically includes multiple players, each of whom will take specific actions to influence their interests and those of other players.

In the case between the main contractor and a subcontractor, if the subcontractor adopts a high bid strategy, the main contractor must consider whether to accept that price and allocate the contract. If the main contractor rejects the high cost, the subcontractor may be able to reduce the price to be awarded the contract. However, if the main contractor accepts the high price, this can lead to increased costs and reduced profits, affecting the project's profitability.they need to find the optimal non-cooperative strategy between them by employing techniques from game theory. The most commonly used methods include the Nash equilibrium and game tree strategies.

In a tender case, a Nash equilibrium strategy could be that the subcontractor submits a medium-price bid, and the main contractor accepts that price and allocates the contract.

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In the case of a tender, a game tree strategy could be where the main contractor and the subcontractor consider each other's possible actions and products to choose the optimal design. For example, the main contractor may consider whether the subcontractor will reduce its price if it rejects the high bid and what impact the reduction will have on the project's profitability to make the optimal decision.

Using non-cooperative game models and strategies, the main contractor and subcontractors can find the optimal non-cooperative strategy to maximize their interests while avoiding the adverse effects of conflicting interests.

### 3.3. Game Between the Supervisor and the Constructor

As an essential part of construction project management, project quality is the key to the success or failure of the project. The supervisory party and the construction party have opposing interests, and the two are non-cooperative game. When the construction party uses inferior materials and is not detected by the supervisor, it can make high profits from the construction cost, which increases the supervision cost of the supervisor; if the supervisor sees that the quality of the project is not up to standard, it will be punished by the supervisor, i.e., the cost of punishment of the construction party increases, and the supervisor receives the benefit of its punishment cost. For the game of the supervisor and the construction unit, you can set up a static game model of complete information based on non-cooperative game theory to find out whether the construction unit is constructed according to the design and whether the supervisory team is supervised so that the construction unit is built according to the invention and the supervisory team is run as a result of Nash equilibrium [10]. The amount of penalty and the construction unit's concealment of profit and the cost of inspection by the supervisor must reach a certain balance for the two to interact positively and ensure the smooth implementation of the project [11].

#### 3.3.1. Specific Analytical Model.

Assuming that both the constructor and the supervisor are rational persons, the purpose of the constructor in project management is to reduce costs as much as possible to earn a high price difference; the purpose of the supervisor is to supervise the constructor and to punish the constructor for substandard project quality to gain revenue to reduce the loss of supervision costs, i.e., to reduce the cost of supervision. The use of poor-quality materials can reduce the cost of construction. Therefore, to ensure the quality of the project, the supervisor can apply the "threat" in the non-cooperative game theory to supervise the construction party, i.e., clarify the punishment mechanism, strengthen the supervision of the construction party, and eliminate the construction party's fluke to the greatest extent.

For example, before the construction company is ready to purchase materials to start construction, the supervisor informs the construction company about the penalty cost of not meeting the quality standards and arranges for professional staff to supervise it and "threaten" it with increased penalty costs. In this static game of complete information, the contractor will weigh the cost of being tested for substandard quality against whether the benefits of using inferior materials are already outweighed by the cost of being tested for substandard quality. If the price of penalties outweighs the benefits, the builder will inevitably choose the more economically efficient decision. In this regulatory process, increasing the cost of penalties also allows the regulator to gain benefits, thus maintaining the effectiveness of the regulatory effort. Thus, the 'threat' of non-cooperative game theory enables the game's participants, the project management's constructors, to predict the outcome of the following action after the decision is made and whether the result is a Nash equilibrium. If not, the decision to take action is modified until the two sides reach Nash equilibrium, then the game is over.

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## 4. Advantages and Limitations of Non-cooperative Game Theory in Engineering Management, Suggestions and Improvements

The advantages and disadvantages of the non-cooperative game in construction management are described as follows:

### 4.1. Advantages

(1) More careful interest consideration

As analyzed above, in bidding for engineering projects, the non-cooperative game model can help managers determine the optimal bidding strategy and benefit distribution and advise the construction and supervision units in their decision-making. Maximize their interests.

(2) Predicting decision outcomes

The non-cooperative game model can help managers predict each party's decision work to optimize the decision and improve management efficiency. For example, in construction project management, the non-cooperative game model can help managers determine the optimal way to allocate resources and schedule to improve project progress and cost-effectiveness.

(3) Developing risk management strategies

The non-cooperative game model can help managers predict the possible decision outcomes of the parties, formulate corresponding risk management strategies and reduce project risks. For example, the non-cooperative game model can help managers develop optimal risk prevention strategies and reduce project risks in construction project management.

### 4.2. Disadvantages

(1) Hypothesis limitation

Non-cooperative game models are usually based on certain assumptions, such as a fixed payoff matrix and a limited decision space. However, in practical engineering management, these assumptions may not be entirely consistent with the actual situation, thus affecting the accuracy of the non-cooperative game model.

(2) Data limitations

Non-cooperative game models require a large amount of data support, and in engineering management, some data may be challenging to obtain or estimate accurately. This can also affect the accuracy of the non-cooperative game model.

(3) Modeling deficiencies

In the engineering management literature involving game theory, the use of specific numerical modeling is a minority, more on the one hand for theoretical knowledge so that it will affect the reference and application of other scholars and the analysis and judgment of enterprises.

### 4.3. Suggestions and Improvements

In engineering management applications, to overcome the shortcomings of the non-cooperative game model, the following suggestions and improvements can be considered.

(1) Combine the model with the actual situation

The non-cooperative game model should be adjusted and improved with the actual situation, for example, by building the model based on the actual benefit matrix and decision space. At the same time, the model's assumptions should be evaluated and revised to make the model more accurately reflect the actual situation.

(2) Improve data acquisition and estimation methods

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To address the issue of data limitations, data accuracy can be improved by improving data acquisition methods and estimation techniques. For example, more advanced techniques can be used to obtain more accurate data, or procedures such as simulation and prediction can be used to estimate missing data.

(3) Optimise the calculation and analysis process

Optimised algorithms and calculation techniques can be used to speed up and reduce the cost of calculations for problems with high calculation complexity. At the same time, visualization techniques and decision support tools can be used to simplify the analysis process and improve the efficiency of decision-making.

(4) Combine with other methods

Non-cooperative game models can be combined in different ways, such as multi-objective planning and decision tree analysis, to consider the problem more comprehensively and obtain more accurate decision results.

The non-cooperative game model must fully account for the actual situation and data accuracy in the engineering management application and adopt optimization algorithms and additional decision-making tools to improve the calculation efficiency and decision-making effect.

## 5. Conclusion

This paper has studied the application of non-cooperative game theory in engineering management, and its advantages and disadvantages have been analyzed. By introducing the application of non-cooperative game theory in project bidding, supply chain management of building materials, and the game of supervisory platforms and builders, we found that non-cooperative game theory has great potential in engineering management. Game theory models can help project managers consider all parties' interests more comprehensively and optimize decision-making and management efficiency. Thus Maximizers are some limitations of non-cooperative game theory in engineering management, such as the need to make assumptions about the participants' behavior. The uncertainty of the actual situation is sometimes difficult to model accurately. Therefore, when applying game theory models in practice, it is essential to be aware of these limitations and make reasonable adjustments to account for the actual situation.

In the future, further research and exploration can be conducted to explore the more expansive application areas of non-cooperative game theory and game theory in engineering management, such as applications in engineering decision-making, collaborative leadership, and resource allocation, as well as combining game theory with other tools and methods to form better and more accurate decision support systems. This research will help promote the development of engineering management, improve the efficiency and quality of engineering management, and further realize the goal of maximizing corporate benefits.

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