International Journal of Civil Engineering and Infrastructure
Vol. 1, No. 1, March 2023

WHY WOULD A CONTRACTOR SKIP A WORK? - A GAME-THEORY APPROACH

Rachmad Irwanto
[1]Civil Engineering Study Program, Muhammadiyah Jakarta University, Jl. Cempaka Putih Tengah 27, Indonesia
Correspondence email: rachmad.irwanto@umj.ac.id

Received: December 24, 2022 | Accepted January 29, 2023

ABSTRACT

There is almost always or at least a disorder phase in construction project. This paper elaborates a game theory review of a real case where a contractor decides to skip a work phase willfully. The review discusses the case through zero-sum and non-zero-sum scenarios to observe what possible ways in terms of the best payoffs through Nash equilibria. So far, despite the skipped work, the real project is undergoing well and will likely to catch the deadline. The game theory analysis on the real case project has found that the payoffs are measured through specifically described strategies and to some extents, could provide insights on decision making process during construction phase.

Keywords: *zero-sum, non-zero-sum, payoff, Nash equilibria, construction projects.*

1. PRELIMINARY

Construction projects involve complex decision-making processes influenced by various stakeholders and their competing objectives. To understand these dynamics, game theory could provide a valuable framework for analyzing strategic interactions and decision-making in cases commonly happens in the construction industry. This paper is inspired by a real case project supervised by the author. The project belongs to South Mayoral Office of South Jakarta and handled by the Water Resource Department. It is about box culvert installation as part of drainage maintenance scheme in the city of South Jakarta. During the production of this paper, the project is still ongoing and expected for final handover by end of November 2023.

This paper intends to review a case from the project by applying game theory to examine the case from two points of view. One is involving a zero-sum game and the other is a non-zero-sum game. Both cases explore the behavior of contractors when deciding to skip a work procedure willfully during construction phase.

Game theory is explicable as an inquiry into social reasoning concepts during conflict situations [1]. In the zero-sum case, the focus is on the competitive dynamics occurring between contractors as they strive to gain an advantage over their rivals. The decision to skip a work procedure becomes a strategic move where one contractor's gain is directly offset by the other's loss. The analysis examines the strategies, payoffs, and potential consequences of such decisions, providing insights into the competitive landscape of the construction industry and optimizing individual contractor success.

In the non-zero-sum case, the emphasis shifts to the collaborative interactions among project stakeholders, including contractors, the government as the owner, and supervising and design consultants. Here, the decision to skip a work procedure involves balancing cost considerations and project quality. The analysis explores the incentives, payoffs, and potential trade-offs faced by each stakeholder, highlighting the need for cooperation and aligning incentives to ensure project success and adherence to work procedures.

Project success is a combination of many equations wherein risk management through a project scheduling covering uncertainties as implicitly explained in [2]. Among efforts of assessing uncertainties is by curbing known applicable possibilities. By employing game theory in both cases, this paper aims to uncover the underlying decision-making processes in construction projects later expected to improve project performance. With certain prescribed boundary conditions, this paper intend to offer an understanding of the factors influencing contractors' decisions, the dynamics among stakeholders, and the implications for project management. The findings could later provide valuable insights for improving decision-making practices, contractual frameworks, and project execution strategies in the construction industry.

The following sections will present the fundamental principles and concepts of game theory, outline the case scenarios, define the strategies and payoffs specific to each case, and analyze the decision-making dynamics. Furthermore, it is to explore a potential range of strategies and incentives to stimulate cooperation and optimize project outcomes.

2. LITERATURE REVIEW

Cristóbal [3], in his paper in 2015 explains a good use of game theory to analyze conflicts may arise due to complexity within construction projects. The paper makes a good review on the matter using game theory to conclude that managing leaders should have better social skills such as negotiation to manage the conflicts by understanding the source. Both zero sum and non-zero-sum cases may have a Nash equilibrium. A Nash equilibrium is defined as a state where no player can improve their payoff by unilaterally changing their strategy, given the other players' strategies. In non-cooperative case environments, both zero-sum and non-zero-sum games, as explained by Gharesifard *et al*. in his paper in 2013, may have multiple Nash equilibria [4]. The view could be from a worst-case scenario wherein the Nash equilibria provides a maximum loss in terms of social objective compared to the cooperative solution. This paper intends to view the following given cases from a concession point of view. Later it turns out that our non-zero-sum case has two Nash equilibrium.

There have been critics about the use of game theory such as a paper by Rubinstein [1]. Its deficiencies in prediction accuracy due to limited covering in the prescribed course of conducts available to the involved players have been the reasons behind. A paper by Bonau [5] elaborates the use of game theory from behavioral perspective. It argues that traditional game theory would only present a single alternative solution to a problem often without providing information on the underlying assumption. Meaning that players are set to not act rationally, thus behavioral game theory is introduced to approach real life situation better. The authors of this paper consider that there is however, a type of game such as Bayesian games involving asymmetric information of players' strategy to address the critics.

Ariel Rubinstein, in his extensive paper [1] describes an alternative to get the concept as a set of consequences of non-specified payoff irrelevant exogeneous factors. However, if the games are on the unit square with two players non-zero-sum case, continuous payoff function and satisfy weaker condition of concavity, then, according to Ziad [6], the non-zero-sum two-person games may possess a pure strategy Nash equilibrium. Fabrikant *et al.* [7], in their paper elaborates the complexity of pure Nash equilibria from the computational point of view. Another fine article by de Cursi [8] discusses the topic deeper by quantifying uncertainty in game theory application through several illustrative situations. The proposed uncertainty quantification methods help understanding to other situations. Related to complexity setup, a comprehensive explanation by Vetta [9], however, suggests that games complexity in the presence of mixed strategy will not have a pure strategy Nash equilibrium.

Zero-Sum Games

In game theory, a zero-sum game refers to a situation where the gains of one player are exactly balanced by the losses of another player. The major measure tool in this scheme is constant payoff sum to be distributed among players. Since the total payoff in the game remains constant, any increase in one player's payoff will be offset by an equivalent decrease in the other player's payoff. Zero-sum cases are typical to negative-sum games where the scenario prescribes potential loss for each player. A Nash equilibrium as explained above along with minimax will typically be the solution for zero-sum games.

In the context of construction projects, a zero-sum game occurs when contractors directly compete for limited resources, contracts, or benefits. The decision to skip a work procedure can be seen as a strategic move by one contractor to gain a competitive advantage over their rival. By doing so, they may save costs, accelerate the project timeline, or achieve other benefits expected at the expense of the other contractor, who experiences a corresponding loss.

In zero-sum games, the strategies of each player are typically antagonistic, and their interests are directly opposed to each other. The goal of each player is to maximize their own payoff while minimizing the opponent's payoff. This leads to a competitive dynamic where one player's gain is directly offset by the other player's loss. Zero-sum game scheme is among simple situation descriptions of a close competition environment assuming no external influences occurring during the whole process.

In a zero-sum game payoff matrix, the sum of the payoffs for all players is always zero, as required for a zero-sum game. It's important to note that this is just one possible way to represent a zero-sum game with three players and that the specific payoffs would depend on the details of the situation.

Non-Zero-Sum Games

In contrast, a non-zero-sum game refers to a situation where the gains and losses of the players are not balanced. In this case, the total payoff can vary, and it is possible for all players to achieve positive payoffs simultaneously.

This paper also intends to simulate the aforementioned project with non-zero-sum cases using three-player games. This can usually be complicated to analyze due to its matrix dimension which will be greater than a usual two-dimension matrix. The ideal way to display the intended simulation would be a three-dimensional array, wherein each cell containing three payoffs. However, a three-dimensional matrix may be difficult to write down on two-dimensional paper. So typically, the $[\boldsymbol{n} \ \boldsymbol{x} \ \boldsymbol{m} \times \boldsymbol{l}]$ array is displayed as an $\boldsymbol{l}$ with different $[\boldsymbol{n} \times \boldsymbol{m}]$ matrices. Payoff matrix represents gains from a certain point of view for each player. The more players and considered possible courses of actions, the bigger the matrix dimension, thus its analysis complexity. One way to look at multi-dimensional matrix is through displaying the matrix as several two-dimensional matrices classified according to the considered number of the players' gains. As at table 1, player 1 (P1) can choose the possible strategies from the columns and player 2 (P2) can choose its possible strategies from the rows. Meanwhile, player 3 (P3) will have the possible strategies from the upper matrix **A** and lower matrix of **A'**. Further section in this paper will discuss on how to find out the best strategies for each player that may use methods such as maximin and minimax along with derivative methods from Nash Equilibria. Further analysis of maximin and minimax strategies with certain prescribed situation such as oligopoly is discussed by Satoh *et al*. [10]. The values assigned within the matrices' cells [***a, b, c, d***] are subjective according to how the gains are scaled with respect to real conditions. The gains represented could be anything and even a combination of multiple gains at once. The setup would depend on how the things are translated into the matrices.

In our case, the construction industry, non-zero-sum games are often characterized by collaborative decision-making scenarios where stakeholders have shared objectives or interdependent outcomes. The decision to skip a work procedure involves considering multiple factors such as cost savings, project quality, and long-term benefits. The payoffs in non-zero-sum games can be diverse and include considerations beyond direct competition, such as project success, reputation, or regulatory compliance.

Table 1. Payoff matrices for 3 players with 2 possible courses of action

P3 - A

$$\begin{bmatrix} & & P1 & P1 \\ & & A & A' \\ P2 & A & a,b,c & b,c,a \\ P2 & A' & c,b,a & a,c,b \end{bmatrix}$$

P3 - A'

$$\begin{bmatrix} & & P1 & P1 \\ & & A & A' \\ P2 & A & a,c,d & b,c,d \\ P2 & A' & b,a,c & c,b,d \end{bmatrix}$$

In non-zero-sum games, the strategies and interests of the players can be mutually aligned, leading to opportunities for cooperation and collaboration. The goal is to find mutually beneficial solutions that maximize the overall payoff for all players involved. In this case, the players may, willfully or not, engage to each other in a strategic decision-making phase, seeking outcomes that optimize the collective interest while managing potential conflicts or trade-offs.

Referenced from Bonau [5], non-zero-sum games can either be positive-sum or negative-sum. The positive-sum games will have a positive-sum payoff, meaning possible "win-win" solutions for players. The situation can be described as multiple interests exist among players that may benefit to each other. Whereas negative-sum games may be described as a potential conflicting situation where the only way for a player to maintain the status quo is to take something out from another player. This type of scenario likely creates competitions among players rather than a mutual concession.

While competitive elements may still exist in non-zero-sum games, the focus shifts towards finding ways to balance individual interests with collective objectives and achieving overall positive-sum outcomes. Collaborative communication (though not necessarily involving all stakeholders all the time during the engagement phase) along with information sharing, and incentive structures are often key components in fostering cooperation among stakeholders.

Understanding the distinction between zero-sum and non-zero-sum games is important in analyzing decision-making dynamics and determining the appropriate strategies and incentives for different scenarios in the construction industry. In the real-world construction projects however can involve various shades of zero-sum and non-zero-sum dynamics. The application of game theory allows for a more nuanced analysis of decision-making strategies and outcomes.

3. ZERO-SUM CASE: CONSTRUCTION PROJECT AND WORK PROCEDURE SKIPPING

In this section, a scenario is prescribed to illustrate a zero-sum case. Let us consider a construction project where there are two players, Contractor A and Contractor B, are competing one another for the project. They have been given a fixed budget and timeline to complete their respective tasks. One critical work procedure, Strauss pile installation under pile cap for the box culvert base, is necessary to ensure compliance with design safety procedures.

In this example, the rows represent the strategies available to the contractor (Skip Work or Complete Work), and the columns represent the strategies available to the consultant and owner (Enforce Contract, Renegotiate Contract, or Accept Work Skipping). The payoffs in each cell represent the gains or losses for each player (Contractor, Consultant, Owner) for each combination of strategies.

For example, if the contractor chooses to Skip Work and the consultant and owner choose to Enforce Contract, then the payoffs for each player would be (-10, 5, 5), representing a loss for the contractor and a gain for the consultant and owner. If the contractor chooses to Complete Work and the consultant and owner choose to Accept Work Skipping, then the payoffs for each player would be (0, 5, -5), representing no gain or loss for the contractor, a gain for the consultant, and a loss for the owner.

Table 2. Payoff matrix zero-sum case

	Enforce contract	Renegotiate contract	Accept Work skipping
Skip	-10, 5, 5	5, -5, 0	10, -5, -5
Complete	0, 5, -5	0, 5, -5	0, 5, -5

In a zero-sum game, the minimax and maximin strategies for each player are the same. The minimax strategy for a player is the one that minimizes their maximum possible loss, while the maximin strategy is the one that maximizes their minimum possible gain. In a zero-sum game, these two strategies are equivalent because one player's loss is the other players' gain.

The payoff matrix in the zero-sum game as illustrated at table 2 above, we can notice the minimax/maximin strategy for the contractor is to choose Complete Work. This strategy guarantees the contractor a payoff of at least 0, regardless of the strategies chosen by the consultant and owner. If the contractor were to pick Skip Work strategy, their payoff could be as low as -10 if the consultant and owner insist to Enforce Contract.

Let us consider the minimax/maximin strategy for the consultant is to choose Accept Work Skipping. This strategy guarantees the consultant a payoff of at least 5, regardless of the strategies chosen by the contractor and owner. However, if the consultant were to go with Enforce Contract or Renegotiate Contract, their payoff could be as low as -5 if the contractor chooses to Skip Work.

Meanwhile, for the owner, the possible minimax/maximin is also to allow Accept Work Skipping strategy. This strategy guarantees the owner a payoff of at least -5, regardless of the strategies chosen by the contractor and consultant. If the owner were to Enforce Contract or Renegotiate Contract, their payoff could be as low as -5 should the contractor obeys to Complete Work.

It is important to note that these minimax/maximin strategies represent each player's best strategy in a worst-case scenario, where they assume that the other players will choose strategies that result in the worst possible outcome for them. Also, in this specific case, external influences coming from any players out of the described players including options other than the prescribed available strategies are excluded. In practice, players may choose different strategies based on their expectations of how the other players will behave.

In a non-cooperative game context, each contractor can independently choose a strategy without mutual coordination or cooperation. This scenario actually better translated in a situation such as during tender phase. It is where a contractor is confident that the soil bearing capacity (SBC) is sufficient even without Strauss pile. There has been an intention to skip the piling works since the beginning knowing significant cost could be eliminated. A measure in this matter would then be prepared to redirect the project for CCO (Contract Change Order) scheme by submitting a technical justification report, proposing work-over and later volume adjustments to cover the missing piling works yet still profitable. Assuming the owner and the consultant will eventually come along, by skipping one procedure which will save cost and time, giving extra flexibility room for the contractor and probably could make a lower offering to win the project without losing too much of profit margin.

4. NON-ZERO-SUM CASE: CONSTRUCTION PROJECT AND COST-SAVING DILEMMA

For non-zero-sum case, let us consider a similar scenario with the earlier one. It is a public funded construction project where the awarded contractor is responsible for constructing public infrastructure project handling box culvert installation as part of city drainage project. The project involves multiple phases, including excavation, foundation, structural assembly works, and finishing works. The Water Resource Department represents the South Jakarta City Mayoral Office as the project owner, and there is a supervising and design consultant overseeing the project. In this case, there will be three players in the game. They are the contractor (player 1), the government representative (player 2), and supervising and design consultant (player 3).

Simulation #1

For non-zero-sum scheme, this paper runs two different simulations. Simulation #1 sets a scenario where player 1 has two options while the rest of two players set into three options as a couple.

Simulation #1 above, the rows represent the strategies available to the contractor Skip Work or Complete Work, and the columns represent the strategies available to the consultant and the owner Enforce Contract, Renegotiate Contract, or Accept Work Skipping. The payoffs in each cell represent the financial gains or losses for each player (Contractor, Consultant, Owner) for each combination of strategies.

Table 3. Payoff matrix non-zero-sum case: simulation #1

	Enforce contract	Renegotiate contract	Accept

			Work skipping
Skip	-10, -5, -20	5, 0, -10	10, -5, 0
Complete	0, 5, 10	0, 5, 10	0, 5, 10

For example, if the contractor chooses to Skip Work and the consultant and owner choose to Enforce Contract, then the payoffs for each player would be [-10, -5, -20], representing a financial loss for all players. If the contractor chooses to Complete Work and the consultant and owner choose to Accept Work Skipping, then the payoffs for each player would be [0, 5, 10], representing no financial gain or loss for the contractor, a small financial gain for the consultant, and a larger financial gain for the owner.

It's important to note that this is just one possible way to represent the described scenario and that the specific payoffs would depend on the details of the situation. Additionally, this matrix only considers financial gains or losses and does not take into account other factors such as reputation, legal consequences, and future business opportunities.

There is one Nash Equilibrium concluded from the simulation. The combination that represents Nash Equilibrium is Complete Work - Accept Work - Skipping, where the contractor chooses to Complete Work and the consultant and owner choose to Accept Work Skipping. In this case, the payoffs would be [0, 5, 10]. No player can improve their payoff by changing their strategy alone. For example, if the contractor were to switch to Skip Work while the other players kept their strategies, their payoff would decrease from 0 to 10.

It's important to note that this is just one possible Nash Equilibrium for this specific payoff matrix and that the actual Nash Equilibria for the described scenario above would depend on the specific details of the situation and the payoffs for each player.

Simulation #2

In the scenario previously described in simulation #1, there are 3 players: the contractor, the consultant, and the owner. Since the consultant and the owner have the same set of strategies Enforce Contract, Renegotiate Contract, or Accept Work Skipping, their strategies can be represented in a single payoff matrix with one dimension for each player's strategies.

In simulation #2, let us consider the consultant and the owner had different sets of strategies, then it might be necessary to use multiple payoff matrices to represent the game. For example, if the consultant had two strategies (Enforce Contract or Renegotiate Contract) and the owner had two different strategies (Accept Work Skipping or Reject Work Skipping), considering the same strategies (at previous zero-sum simulation) are kept the same for the contractor, then it would need two different payoff matrices to represent the game, one for each combination of strategies for the consultant and the owner. In general, the number of payoff matrices needed to represent a game depends on the number of players and the number of strategies available to each player. If all players have the same set of strategies, then a single payoff matrix can be used to represent the game. If different players have different sets of strategies, then multiple payoff matrices may be needed.

In this example, the contractor has two strategies Skip Work or Complete Work, the consultant has two strategies. They are either Accept Skipping or Reject Skipping, while the owner may either take Enforce Contract or Renegotiate Contract. Since the consultant and the owner have different sets of strategies, two payoff matrices are needed to represent the game.

Table 4. Payoff matrices – simulation #2

Matrix A		Player 2	
		Accept skipping	Reject skipping
Player 1	Skip work	-10, -5, -20	5, 0, -10
	Complete work	0, 5, 10	0, 5, 10

Matrix B		Player 3	
		Enforce contract	Renegotiate contract
Player 1	Skip work	-20, -10, -5	10, -5, 0
	Complete work	10, 0, 5	10, 0, 5

Matrix A represents the payoffs when the consultant chooses Accept Skipping and Matrix B represents the payoffs when the consultant chooses Reject Skipping. The rows in each matrix represent the strategies available to the contractor and the columns represent the strategies available to the owner. For example, if the contractor decides to Skip Work, the consultant can take Accept Skipping, but the owner sticks to Enforce Contract, then the payoffs for each player would be [-10, -5, -20], as shown in Matrix A. Whereas, if the contractor is willing to Complete Work, the consultant chooses to Reject Skipping, and the owner does not mind to Renegotiate Contract, then the payoffs for each player would be [10, 0, 5], as shown in Matrix B.

In the game represented by the two payoff matrices, it turns out there are here two applicable Nash Equilibria. Let us first, take a look at the strategy combination of Complete Work - Accept Skipping - Renegotiate Contract. This is where the contractor decides to Complete Work, the consultant approves to Accept Skipping, but the owner suggests to Renegotiate Contract. In this case, the payoffs would be [0, 5, 10] as shown in Matrix A. Meanwhile, we can also pay an attention to a combination of [Complete Work, Reject Skipping, Enforce Contract], where the contractor opts for Complete Work, the consultant stands with Reject Skipping, and the owner prefers to Enforce Contract. In this case, the payoffs would be [10, 0, 5] as shown in Matrix B.

In both of these Nash Equilibria, no player can improve their payoff by changing their strategy alone. For example, let say if the contractor were to switch to Skip Work strategy while the other players kept same their preferred strategies in the first Nash Equilibrium, their payoff would decrease from 0 to -10.

5. DISCUSSIONS AND CONCLUSION

Skipping a certain work as part of agreed work sequences during construction is not always a fraud when procedures of skipping the work are well justified and mutually acknowledged. Further fraud descriptions that affect construction are well described by Sohail *et al*. [11]. The project success matters more in our case. However, what interesting is the reasons behind skipping work during construction and how the decision affects the system within the project management. Skipping work as it is seen from scheduling, financial gains or even further to the overall project risk assessment, could put significant potential disorder within bad management. Understanding the decision-making process and its possible responds among players in a construction project has provided good insight. The model evaluation of combined applied strategies through set scenarios will then be another clue to approach the reality closer.

Above illustrations of zero-sum games with three players can provide us some findings. Starting with minimax/maximin strategies, as described in its theory, each player has a minimax/maximin strategy that represents their best possible strategy in a worst-case scenario. Strict boundary conditions applied here, to most extent, set to have no external interference at all. The payoffs of the opponent will negate the first player. These strategies depend on the payoffs for each player and can provide insights into how each player might behave in the game.

As a matter of strategic interactions, the zero-sum case above illustrates how the strategies chosen by one player can affect the payoffs for all players. Analyzing these strategic interactions can provide insights into how the players might behave in the game and how their actions might affect each other. Objective setups on this scenario explain better on a rather close competition environment.

As expected in many cases of non-zero-sum games, both examples above have multiple Nash Equilibria. These Nash equilibria, as per the theory, represent stable states where no player can improve their payoff by changing their strategy alone. A specific Nash Equilibria depends on the payoffs for each player and can provide insights into the possible outcomes of the game.

The non-zero-sum payoffs for each player depend on the specific details of the situation and can include financial gains or losses as well as other factors such as reputation, legal consequences, and even probably, future business opportunities. Since they are described as non-zero-sum games, the total payoffs are not zero. This means the models implicitly allow external factors interfering the decision-making process through the prescribed players through the prescribed strategy options. Analyzing the payoffs can provide insights into the incentives and motivations of each player. The type of competition of non-zero-sum games could actually be easily concluded. A negative-sum game has a tendency to be a zero-sum game where players are leaning to win over the other players. In our case, we likely to avoid negative-sum scenario. The whole system in the project will likely turn disorder and no player will take positive payoff. The project success matters more.

REFERENCES

[1] A. Rubinstein, "Comments on Interpretation of Game Theory," *Econometrica,* vol. 59, no. 4, pp. 909-924, 1991.

[2] R. Irwanto, "What Actually Drive Construction Project Performance from Operations Management Perspective," *International Journal of Civil Engineering and Infrastructure (IJCEI),* vol. 2, no. 1, 2022.

[3] J. R. S. Cristóbal, "The use of Game Theory to solve conflicts in the project management and construction industry," *International Journal of Information Systems and Project Management,* vol. 3, no. 2, pp. 43-58, 2015.

[4] B. Gharesifard and J. Cortés, "Distributed convergence to Nash equilibria in two-network zero-sum games," *Automatica,* vol. 49, pp. 1683-1692, 2013.

[5] S. Bonau, "A Case for Behavioural Game Theory," *Journal of Game Theory,* vol. 6, no. 1, pp. 7-14, 2017.

[6] A. Ziad, "Pure strategy Nash equilibria of non-zero-sum two-person games: non-convex case," *Economic Letters,* vol. 62, pp. 307-310, 1999.

[7] A. Fabrikant, C. Papadimitriou and K. Talwar, "The Complexity of Pure Nash Equilibria," *Proceedings of the thirty-sixth annual ACM symposium on Theory of computing (STOC '04).*

Association for Computing Machinery, 2004.

[8] E. S. de Cursi, "Uncertainty Quantification in Game Theory," *Chaos, Solitons & Fractals,* 2021.

[9] A. Vetta, "Nash equilibria in competitive societies, with applications to facility location, traffic routing and auctions," *The 43rd Annual IEEE Symposium on Foundations of Computer Science,* 2002.

[10] A. Satoh and Y. Tanaka, "Maximin and minimax strategies in symmetric oligopoly: Cournot and Bertrand," *Munich Personal RePEc Archive (MPRA),* vol. MPRA Paper No. 75837, 2016.

[11] M. Sohail and S. Cavill, "Corruption in construction projects," *Research Repository of Loughborough University,* 2019.