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Decision - Making Process in Business Using Game Theory

Ana Maria GERMAN[1], Alexandru Codrin IONESCU[2]

Abstract

These days, the business environment is dynamic, volatile, uncertain and with multiple self-interested agents interacting, leading to various opportunities for both conflict and cooperation to appear. Gaining and sustaining competitive advantage on market became important capabilities of a company. The aim of this paper is to investigate the efficiency of game theory in the decision-making process of companies from automotive industry. Game theory is a topic of modern applied mathematics. It uses mathematical techniques for analyzing situations when managers/competitors in the same segment make decisions that influence one another's interests/business. A key element in a game is to discover which strategy is a decision maker's best response to the strategies chosen by the others. The concepts of game theory involve the need to formulate, analyze and understand strategic scenarios of companies from various fields. The study's methodology is based on literature review, case studies and mathematical methods. After a suggestive literature review framework, the study presents applications which use different types of games in various conditions. The findings prove that game theory represents an important tool for decision-makers from the automotive industry in the field of strategic planning. The results are useful both in the market, for decision-makers and managers of companies, as well as in the academic field, for students. Game theory is inspiring because the terms and ideology are simpler than those of other theories in this segment. Game theory uses mathematical models to look at how conflict and cooperation work together.

Keywords:
Game theory; strategy; decision-making; competitive environment; company.

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1. Introduction

Globalization has developed the world as a playground for many companies. Given that each company is part of a system, any business action implemented by a company impacts multiple entities that interact with or within that organization. Not paying attention to these interactions may lead to unexpected and very undesirable outcomes [8]. Each decision-maker is a player in the game of business. In the process of decision-making or choosing a strategy, the player must consider the potential choices of other players/competitors.

Game theory (GT) aims to find an optimal solution for all the players. The key element in game theory strategy is to identify which strategy is one decision-maker's best response to the strategies chosen by the other decision-makers. This involves studying "the mathematical models of conflict and cooperation between intelligent and rational decision-makers" [3]. Companies make investment decisions. In this case, the investments are made in a context where the company should take into account the reaction of other players, as well as its dynamic capabilities [4, 5]. Important topics in game theory include strategies, equilibrium concepts, classes of games and theorems [3].

The paper is structured as follows. In the problem statement part, concepts regarding game theory, games and their importance are explained in depth. Afterwards, the research questions and its aim are stated. In the research methods and findings part, the case studies that demonstrate the relevance of GT as a useful decision-making tool are presented. The paper concludes with discussions regarding validity, generalizing the data, the responses to the research questions and further research.

2. Problem Statement

The bases of GT lay in economic models which assume rational behavior by individuals and companies when interacting in the decision-making process. Mathematical systems have been advanced to analyze and predict the behavior of decision-makers in strategic situations [1]. According to the literature, GT can be defined in different ways. Game theory is "the formal study of decision-making where several players must make choices that potentially affect the interests of the other players" [11]. Game theory is "the mathematical study of interaction among independent, self-interested agents" [2,10] or "an intellectual framework for examining what various parties to a decision should do given their possession of inadequate information and different objectives" [2]. A game is characterized by four dimensions: the players of the game, the information that is available to each player, the actions available at each decision point and the payoff structure for the resulting outcome(s) [3]. To apply game theory in the decision-making process, managers should know the possible actions, timing available to each competitor and the payoff from choosing each type of action [6].

GT is very useful in the decision-making process of analyzing strategic investments. Firstly, the dimensions and rules can reduce "a complex strategic problem into a simple analytical structure" [6]. Secondly, GT is a valuation instrument for strategic decisions because "it encompasses a solution concept that can help in understanding or predicting how competitors will behave, it provides an equilibrium strategy and values for the strategic decisions" [6, p. 172]. Thirdly, GT can be used in ways such as: explanation, prediction and prescription. GT can be used to explain insights and effects of a situation. GT can predict different moves of agents on various types of situation by analyzing their actions, preferences, options etc. and can provide a model for future decision-makings [2]. Although GT is a successful tool because of how rational players make decisions under interdependent circumstances, in the literature, criticisms have been made of some of its assumptions. The theory is based on a presumption of rationality, as there is need for more practical case studies to support the basis of rationality on which decision-makers select strategies and make complex decisions under uncertainty. Relevance of the study is due to the interest in GT as an instrument for decision-making in Romanian companies.

In the game theory literature, there are three categories of games: games of skill, games of chance and games of strategy. Games of skill are "one-player games whose defining property is the existence of a single player who has complete control over all the outcomes" [7]. The action of a single-player decision making could be resolved using linear programming and optimization or using Lagrange's method of partial derivatives. Games of chance are "one-player games against nature (second player) where the player does not control the outcomes completely; the outcomes depend partly on the player's choices and partly on the second player" [7]. This type of games involves risk and uncertainty. In this category, utility theory has an important role. Utility theory supposes that decisions are made "on the basis of what the outcomes are worth to the player, rather than their objective value, although, simple pay-off value sometimes equates to utility value" [7, p. 38]. Games of strategy are "games which involve two or more players, each of whom has partial control over the outcomes" [7]. This category includes: cooperative games of strategy where two or more players have the same interest; zero-sum games of strategy where the players' interests are conflicting; mixed-motive games of strategy where "the interests of players are neither fully conflicting nor fully coincident" [7, p. 6]. The strategy of solving such games implies in many cases finding a form of Nash equilibrium for the game. A Nash equilibrium is "a set of strategies such that no player can do better by unilaterally changing his position or strategy" [6, p.175].

A particularly interesting category of strategic games is represented by games without Nash equilibrium points where two players are involved. Such a two-player game without Nash equilibrium can be characterized by the fact that, if either side reveals its strategy, it will lose the game as the other side will be able to choose the winning strategy. Therefore, "each player should keep the other guessing and the best way to do this is for both players to randomize their strategic selections" [7]. This means that the solution to such a game implies random strategic decisions that are using mixed strategies. Adopting a mixed strategy means "assigning to each choice a predetermined probability of being chosen" [7].

3. Research Questions/Aims of the research

These days, the business environment is dynamic and volatile. It is very difficult to survive on the market and to gain competitive advantage. In this context, it is very important for a company to have knowledge, resources, dynamic capabilities, and a proactive thinking [4]. Regarding the literature review of the research, what is the influence of the use of GT as an effective business instrument to obtain performance? In addition, is GT an efficient instrument in the decision-making process?
Sub-research questions:

- What is game theory?
- How would games influence the decision-making process?
- Is game theory applicable in practice or it is a theoretical instrument?

This research aims to identify the efficiency of GT as a managerial tool and to stimulate companies from Romania to use GT in their decision-making process.

4. Research Methods

The study's methodology is based on real case studies and mathematical methods which demonstrate the efficiency of the GT in practice. The case studies analyze two manufacturers from Brasov, Romania, which applied GT in different situations. The studies were made in January and February 2018 at companies from the automotive industry. In this paper, the manufacturers are called α and β. Both are multinational companies with more than 1.000 employees. During the discussions with the managers from α and β manufacturers, some situations regarding the decision-making process were identified. To take the best decision according to some cases, GT's methods were applied. The cases are presented below.

Case Study 1. The α manufacturer, which activates in the automotive industry, allocates project budgets to the Production Department in funding units for materials of 30€ each and production time units of 70€ each (which covers all the costs with the employees). During the last production year, the company's project managers studied the link between the number of implemented projects and the unitary funding costs mentioned before. They discovered that the relationship can be described by the mathematical equation:

$$p = 6tm^{\frac{1}{3}},$$

where p denotes the number of implemented projects, m is the number of funding units allocated for materials and t is the number of allocated time units.

The Production Department is required to implement a number of 180 projects per week, while minimizing funding costs by finding a balance between material and time expenditures.

Solution. The problem in this case study can be solved by using the Lagrange's method of partial derivatives.

Denote by: m – the number of funding units for materials/project/week,

t – the number of time units (hours)/project/week,

p – the number of projects to be implemented/week,

c – the cost of an implemented project/week.

The costs are obviously expressed by

$$c = 30m + 70t,$$

where c is a function of two variables which needs to be minimized, while the variables satisfy the condition:

$$6tm^{\frac{1}{3}} = 180.$$

Two functions are involved in the optimization problem, of the same two variables each:

$c(m,t) = 30m + 70t$ – the function to be minimized, and

$p(m,t) = 6tm^{\frac{1}{3}}$ – the function which describes the minimizing condition.

The Lagrange's function which is used in the method is:

$$L(m,t,\lambda) = c(m,t) + \lambda[180 - p(m,t)],$$

such that the solution of the optimization problem is obtained by solving the system of differential equations:

$$\frac{\partial L}{\partial m} = \frac{\partial L}{\partial t} = \frac{\partial L}{\partial \lambda} = 0.$$

In other words, the system of Lagrange equations which gives the solution to the optimization problem is:

$$\begin{cases} \frac{\partial c}{\partial m} = \lambda \frac{\partial p}{\partial m} \\ \frac{\partial c}{\partial t} = \lambda \frac{\partial p}{\partial t} \\ 6tm^{\frac{1}{3}} = 180 \end{cases}$$

Since

$$\frac{\partial c}{\partial m} = 30, \qquad \frac{\partial c}{\partial t} = 70, \qquad \frac{\partial p}{\partial m} = 2tm^{-\frac{2}{3}}, \qquad \frac{\partial p}{\partial t} = 6m^{\frac{1}{3}},$$

the Lagrange system becomes:

$$\begin{cases} 2\lambda tm^{-\frac{2}{3}} = 30 \\ 6\lambda m^{\frac{1}{3}} = 70 \\ 6tm^{\frac{1}{3}} = 180 \end{cases}$$

The second equation gives $\lambda = \frac{70}{6} m^{-\frac{1}{3}}$, which replaced in the first equation yields $\frac{70}{3} tm^{-1} = 30$, hence $t = \frac{9m}{7}$. The last equation then becomes $\frac{54}{7} m^{\frac{4}{3}} = 180$, therefore $m = (23.3)^{\frac{3}{4}} \approx 10.6$ and $t = 13.65$.

The minimum cost for each project per week is:

$$c = 30 \cdot 10.6 + 70 \cdot 13.65 = 1273.5€.$$

To conclude, the Production Department needs material funding of 318€ per week and approximately 13 hours 40 minutes per week for each project.

Case Study 2. The α manufacturer from the first case study analyzes the possibility of developing a new training course for the employees from the Department of Research and Development. 40% of the department's personnel need constant training. Presently, there are two stages of the training, the first one is done by the Romanian branch of the company and the second one is done by other branches of the organization. Stage 1 trainings value 100€ per employee in the department's budget and Stage 2 trainings value 150€ per employee. The training course the Romanian branch intends to introduce is completed in one stage and it would be performed entirely by the local branch. It would value 270€ per employee in the department's budget.

Should the Romanian branch introduce the new training course (T_1) or keep the current two-stage trainings (T_2) if the manufacturer is:

a) risk-neutral;
b) averse to risk;
c) risk-taking?

Solution. The decision the manufacturer has to make is in this case based on the greater payoff value of each option. These values can be described by the expected utility value of an option,

$$U(O) = \sum_{i=1}^{n} p_i u(x_i),$$

where $u(x_i)$ is the so-called von Neumann-Morgenstern utility function, which represents the player's options among the expected values, $E(x_i)$.
The link between the expected utility value and expected payoff value can be described in three cases, depending on the manner in which an organization tolerates risk:

a) $u(x_i) \propto E(x_i)$ - the organization is risk-neutral;
In the present case study, this translates into:

$U(T_1) = \frac{40}{100} \cdot 270 = 108$
$U(T_2) = \frac{40}{100} \cdot 100 + \frac{40}{100} \cdot 150 = 100$

Therefore, the new training option T_1 is marginally preferred.

b) $u(x_i) \propto \sqrt{E(x_i)}$ – the organization is averse to risk;
The expected utility values for the two trainings options are:

$U(T_1) = \frac{40}{100} \cdot \sqrt{270} \approx 6.57$
$U(T_2) = \frac{40}{100} \cdot \sqrt{100} + \frac{40}{100} \cdot \sqrt{150} \approx 8.90$

In this case, the two trainings option T_2 is preferred.

c) $u(x_i) \propto E(x_i)^2$ – the organization is risk-taking;
The expected utility values for the two trainings options are:

$U(T_1) = \frac{40}{100} \cdot 270^2 = 29160$
$U(T_2) = \frac{40}{100} \cdot 100^2 + \frac{40}{100} \cdot 150^2 = 13000$

The new training option T_1 is clearly preferred.

Case Study 3. The α manufacturer from the automotive industry and one of its competitors, β manufacturer, are planning to make investments in order to gain competitive advantage and obtain performance. There are two investment strategies the manufacturers could adopt, one in new equipment and the other, in human resource.
The first strategy implies the acquisition of new technological equipment, of a greater degree of automation, while the other strategy means the increase of the number of employees and the number of working shifts.
If both manufacturers decide to invest in new equipment, then α would gain advantage (3, 1) in front of β, as it has a closer collaboration with an equipment supplier and could therefore obtain a better price offer.

If both manufacturers invest in human resource, then α manufacturer would gain a strong advantage (2, 0), as it is an older name on the market, with a stronger brand. Therefore, stronger advertising campaigns would have increased chances to find the additional number of candidates required by α. At the same time, β would suffer a loss, as the region has a limited human resource qualified for production jobs and the relocation of individuals from other regions would imply additional costs.

If α increases the number of employees, while β buys new equipment, the β manufacturer gains a small competitive advantage (2, 3). The company can train its employees in operating the new equipment in its own specialized training facility, therefore reducing additional costs with externalized trainings.

In the case when α decides to acquire new equipment and β decides to hire new personnel, then β would obtain competitive advantage (1, 2), as there is enough qualified human resource in the region for one company (in this case, β). Also, the β company has a stronger knowledge-based view, due to its training facility for the employees.

Solution. The case study can be interpreted as the following game (Table 1 - mixed strategy game):

Table 1. Mixed strategy game

		β manufacturer		
	Strategy	Invest in equipment	Invest in human resource	
α manufacturer	Invest in equipment	3,1	1,2	p_1
	Invest in human resource	2,3	2,0	$p_2=1-p_1$
		q_1	$q_2=1-q_1$	Assigned probabilities

Although the game has no Nash equilibrium in pure strategies, it can be solved in mixed strategies, in which case the game has a Nash equilibrium.

Notice that neither of the two competitors should reveal their investment strategies to the other, as this would mean losing the competitive advantage or, at most, leveling the results.

For a two-player game without Nash equilibrium, the pay-off of a mixed strategy can be computed as:

$$P_1 = \sum p_i q_j u_{ij}, \ \ P_2 = \sum p_i q_j v_{ij}, \qquad i,j = 1,2,$$

where u_{ij} is the pay-off of Player 1 if he chooses a strategy r_i and Player 2 chooses a strategy c_j and v_{ij} is the pay-off of Player 2 if he chooses a strategy c_j and Player 1 chooses a strategy r_i. According to Nash [9], "every game has a Nash equilibrium" in mixed strategies. The optimal mixed strategy pay-off is given by the solutions of the system of partial derivatives:

$$\begin{cases} \frac{\partial P_1}{\partial p_1} = 0 \\ \frac{\partial P_2}{\partial q_1} = 0 \end{cases}.$$

Let p_1, $p_2=1-p_1$, q_1 and $q_2=1-q_1$ be the assigned probabilities to each decision, as described in the table. Also, denote by P_α and P_β the expected pay-off functions for the two manufacturers α and β, respectively. These are computed as follows:

$$\begin{aligned} P_\alpha &= 3p_1q_1 + p_1q_2 + 2p_2q_1 + 2p_2q_2 \\ &= 3p_1q_1 + p_1(1-q_1) + 2(1-p_1)q_1 + 2(1-p_1)(1-q_1) \\ &= 2p_1q_1 - p_1 + 2 \end{aligned}$$

$$\begin{aligned} P_\beta &= p_1q_1 + 2p_1q_2 + 3p_2q_1 \\ &= p_1q_1 + 2p_1(1-q_1) + 3(1-p_1)q_1 \\ &= -4p_1q_1 + 2p_1 + 3q_1 \end{aligned}$$

Therefore,

$$\frac{\partial P_\alpha}{\partial p_1} = 2q_1 - 1, \quad \frac{\partial P_\beta}{\partial q_1} = -4p_1 + 3,$$

such that the solutions of the system:

$$\begin{cases} \frac{\partial P_\alpha}{\partial p_1} = 0 \\ \frac{\partial P_\beta}{\partial q_1} = 0 \end{cases}$$

give the following probabilities for the strategies:

$$p_1 = \frac{3}{4}, \qquad p_2 = \frac{1}{4}, \qquad q_1 = \frac{1}{2}, \qquad q_2 = \frac{1}{2}.$$

The corresponding pay-off values can be obtained by replacing these values in the expected pay-off functions, that is,

$$P_\alpha = 2, \qquad P_\beta = \frac{3}{2}.$$

To conclude, the α manufacturer should adopt the strategy to invest in equipment with a probability of $\frac{3}{4}$ and the strategy to invest in human resource with a probability of $\frac{1}{4}$. The β manufacturer should invest in

equipment with a probability of $\frac{1}{2}$ and in human resource with a probability of $\frac{1}{2}$.
Although randomizing the strategies seems a peculiar indication, it comes as a strategic subterfuge for not revealing one manufacturer's true intentions, as this would mean losing the competitive advantage.

5. Findings

Case study 1 is based on games of skills. The Production Department of α manufacturer from the automotive industry has to implement a required number of projects per week, while minimizing funding costs by finding a balance between material and time expenditures. A solution to this problem can be obtained using Lagrange's method of partial derivatives, which gives the extreme values (in this case, minimum) of a function when an additional condition is imposed.

If the Production Department is required to implement a number of 180 projects per week, then it needs funding for materials of 318€ per week and approximately 13 hours 40 minutes per week for each project. The minimum funding for one project should be of 1273.5€.

Case study 2 is based on games of change involving risk. The α manufacturer from the first case study analyzes the possibility of developing a new training course for the employees from the Department of Research and Development. The company must decide whether it should introduce the new training course or keep the current two-stage trainings, in three cases depending on the manner in which the manufacturer tolerates risk. The company can be risk-neutral, averse to risk or risk-taking, respectively. These cases are mathematically described by the link between a decision's expected utility value and the decision's expected pay-off value.

The study finds that, if the utility function is linearly linked to the expected utility function, that is, the organization is risk-neutral, then the new training option is marginally preferred. If the utility function is proportional to the square root of the expected values, that is, the organization is averse to risk, then the two trainings option is preferred. Finally, if the utility function is proportional to the square of the expected values, that is, the organization is risk-taking, then the new training option is clearly preferred.

Case study 3 is based on games of strategy. A particular category, two-player games without Nash equilibrium points, is the theoretical support of the case study. Manufacturers α and β should decide the direction for an investment with the purpose of gaining competitive advantage and maximizing their profit. If one of the competitors reveals its intention, the other can make the winning decision. The situation is described by a game without a Nash equilibrium. Such a game can be solved using mixed strategies, which means assigning a probability to each strategic choice a player can make, thus the solution of such a game assumes randomizing the decisions according to a probabilistic scheme. The α manufacturer should adopt the strategy to invest in equipment with a probability of $\frac{3}{4}$ and the strategy to invest in human resource with a probability of $\frac{1}{4}$, while the β manufacturer should invest in equipment and in human resource with the same probability of $\frac{1}{2}$.

6. Discussions

In the paper, GT and its applications in different situations by exploring various cases were discussed. There were described how GT models decisions and interactions of agents. Games such as: games of skills, games of chance and games of strategy were applied in case studies based on the needs of managers to make decisions for their companies.

To understand the importance of GT, the need is to use the theory for practical applications in different domains, rather than restrict it to applications for one filed, limited to specific and niche areas of research. Also, there is a need for the development of new applications based on real cases, where different taxonomies of games can be applied. Considering the importance of GT in various studies that are comprehensive, the successful applications in solving conflicts and problems in different fields, as well as the relatively limited studies of GT applications in industrial fields, it is important to explore the GT in practice to a greater extent.

The limits of this study consist in the small number of companies that accepted to apply GT in their decision-making process. There are few companies that consider game theory as a managerial instrument. The case studies presented in the paper describe situations only from the automotive industry. Further research will focus on enlarging the fields and presenting more examples that encourage companies to use GT as a useful tool.

7. Conclusions

This paper presents a framework of game theory and three case studies based on real situations. Firstly, the paper presented the literature review where the concept of game theory and its importance were explained. Secondly, the paper offered three case studies that applied GT in the decision-making process. The real case studies proved that GT has a positive influence in the final decision because it uses simple and precise mathematical methods.

This study will help researchers, managers and students in expanding their knowledge about game theory and some of its applications. In particular, it will help decision-makers to look at game-theoretic literature and at the three case studies analyzed from a complex perspective. According to the findings resulted after using GT, the α and β manufacturers selected the best decisions which helped them achieve the greatest profit. GT proved to be an efficient instrument in the decision-making process. In addition, GT is applicable in practice, it is not only a theoretical instrument. Games resolve practical difficulties when they appear, with increased effectiveness. Also, they offer an alternative perspective on problems, which may or may not yield solutions, but will conduce to an increased understanding of the cases for the decision-making process. In other words, GT helps decision makers to find new solutions to familiar problems that have not been satisfactorily resolved, by giving a deeper understanding of the nature of the conflict, of the decision-making process and of the cooperation of the involved players.

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