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Research Article

Teamwork Management in Additive Manufacturing Using Game Theory

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Abstract: The game theory lays out frameworks for studying decision-making in different environments. The principles of this theory predict human behaviour, leading with decision-making and describing how established outcomes may appear that are not optimal for all groups. This article presents a procedure for teamwork management in additive manufacturing projects. The new challenges in this industry must cope from a perspective that yields a response to changing actuality. The symmetric of 2 × 2 games is used to decompose the payoff matrix into two, a cooperative and a zero-sum part. The variations in the relations between the parts are the key to managing team works. The topology properties of these games are used to study the representation of the game space, which will enable us to take decisions in an additive manufacturing project. Furthermore, the analysis of game regions will allow us to obtain further information for arranging the teams. The study shows that game theory provides a proper framework to manage the collaboration between teamwork in additive manufacturing projects and can derive suitable models for strategic interactions that often occur in applications in these settings.

Keywords: teamwork, additive manufacturing, game theory, project

1. Introduction

One of the most relevant aspects of Industry 4.0 is three-dimensional (3D) printing. Additive manufacturing (AM) allows us to produce personalized goods at lower development costs, reduce energy consumption during production, reduction material waste and shorter lead times. According to Prashar et al. [1], AM market is predicted to manufacture US$ 2 trillion value of components and end products by the year 2030. It can be claimed that AM is promoting Industry 4.0, playing an essential role in the resolutions of some of the 4th industrial revolutions' main needs. AM has progressed from an archetype to production technology and is employed to fabricate end-use parts for aerospace, automotive, medical as well as other industrial applications. The rate of production can cover from small series up to 100,000 commercial products. Design for AM has the optimization of the product design as aims to address the complexity of the production procedure. Studies have reported that the foul of knowledge of design for AM tools and techniques is considered one of the obstacles to the added implementation of AM. Vaneker et al. [2] have presented a framework for design for AM procedures and tools. It was split into three phases of product development such as AM process selection, product redesign for functionality improvement and product optimization for the AM process selected.

In AM plenty of technologies have been developed in a fast-increasing market. These technologies put important

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advantages forwards; however, many limitations exist to utilizing their entire potential. Durakovic [3] has investigated the trends, problems and challenges in design for AM. The study covered associated costs, design options and quality considerations. He has reported that most AM studies are based on conceptual approaches, i.e., this field is still in its early stage. The author pointed out that the design for AM is not defined well as a consequence; there is no proper understanding of the proceeding method, strategies and when to set out the design for AM. Existing standards are employed on AM, but it will be required to develop AM-specific standards. Abdulhameed et al. [4] have studied the evolution of AM and its various phases. They identified problems associated with different AM methods. Due to the imperfections in AM, its hybridization has been tackled with other methods such as subtractive manufacturing.

Game theory can aid in managing different manners of interacting with people, particularly in professional settings. Bočková et al. [5] tackled how game theory can be one of the methods of managing communication risks at educational projects of diverse types and sizes concerning the economic and management particulars of the post-crisis Czech Republic. They claimed that game theory can be used as a project management framework. The game theory application covers teamwork. To recap, game theory has its setting in project management and is rather used. This theory can be advantageous in settings such as team management, task assignments, resource negotiations with stakeholders and managers of these as well as contract negotiations with traders. Piraveenan [6] has done a literature review and study of using game theory to model project management settings. According to the industry-based categorization, it can be ranked in terms of the construction industry, information and communications technology industry or unspecified industry. Regarding the types of players, he established the classification in terms of government-contractor games and contractor-contractor games, among others. He claimed that game theory is a suitable tool for modelling project management scenarios. Ahmed et al. [7] have used the game theoretic approach to study the effect of demand uncertainty. The work will aid to work out an industrially available decision support tool for the adoption of AM in a production setting.

The assignment of tasks to employees is one of the most fundamental features of a project manager's job. Lagesse [8] has used game theory to yield an algorithm for task assignment with set-up-in feedback mechanisms. Karabiyik et al. [9] have studied the Scrum methodology and game theory. They have proved that the game theory can be applied to understanding the Scrum Master and other team member interactions.

Sonar et al. [10] have identified AM implementation factors from speciality literature in light of industrial and academic perspectives. Bracken et al. [11] have examined if an AM workshop associated with an idea generation session was able to motivate engineering professionals to employ AM solutions to work out technical issues that they must address. They collected ideas for twenty-four projects focused on design for AM. It provided instructions about the design of two metal-based AM processes. Four particular metrics were used to assess the participants' ideas: cost, time, completeness of solution and quality. To summarise, the duration of the workshop was sufficient for engineers to put forward ideas that they employed in AM. The quality of the ideas was improved between the non-AM ideas and the AM ideas.

Romero-Torres et al. [12] have reported numerous large mechanical and aircraft engineering companies have assumed AM technologies in their forthcoming product strategy. The overall idea of 3D printers based on e-manufacturing principles is pointed at the integration of computer models of objects and processes. This needs a huge transformation of the company's business model. For example, AM could also modify project management practices. They pointed out how AM could change the project management function for the aerospace industry. The outcomes have shown that projects could enhance their performance by integrating AM. The project managers could adjust their approach to a new archetype for lifecycle management and leaner supply chain management in aerospace companies. Khatib et al. [13] have shown that project managers have encouraged organizations to adopt AM technology. This can ease manufacturers' production costs and improve their adaptability. Project managers must lead the investigation to help their companies to adjust to the different changes that are occurring in the industry. This will allow them to learn about the options at their disposal. The review of the impact of AM on project management proves that a suitable application of the technology can increase the effectiveness of project managers and enhance organizational performance.

Some companies are seeking choices for temporary project structures that distribute a single product or service. It is due to the markets changing from a project delivery model to a continuous delivery model. Alternatively, they are looking for delivery models that hold a solid customer focus, and it is aligned with the ongoing service of faithful customers. These elements have led to a growing interest in and change to product management life cycles. Thus, product management has a longer life cycle view, including support, sustainment and continuous development with the same team. The changing focus on product management generates some project-oriented companies to adjust their delivery models. Product life cycles can seem weird with conventional project delivery models as the temporary character of projects. When it is created long-running stable teams and program management constructs, among others. The companies in these settings can find alignment and further resources [14].

According to PMBOK Guide (7th edition) [14], companies that are changing to long-running, product-based settings may use different strategies to organise product management. Three strategies can be considered, but are not limited to establishing stable teams, using incremental guidance and funding, and utilising program management structures. Considering the first item must be pointed out that instead of dissolving the team when initial development is over, the team must be used to hold and make progress on the product with the designated product owner or the technician who shows the customer viewpoint. Long-standing teams provide better market knowledge, customer empathy and insights than short-term teams. In addition, quality, maintainability, and extensibility are frequently enhanced with long-serving teams rather than teams that work out and then hand over products. Concerning the second strategy, in place of predefined project durations or annual financial plans, take into consideration often reviews, for example, quarterly and funding for the next one. With more recurrent evaluations and funding, the company is in closer control of total progress, direction, and decision-making. The third strategy deals with practitioners who work with stable teams that sustain customer-centric products. They may apply program management sets up for managing long-running enterprises. To recap, companies that adopt an integrated view of project and product management may profit from evaluating program management frameworks as a platform. Product life cycles can seem to get in conflict with classic project delivery forms such as the temporary nature of projects.

To release a new product to the market, two points are essential to guarantee productivity sustainability over time: quality and reproducibility. It is reached by qualifying and certifying a process. This is carried out by employing the accreditation that the production method may derive the expected quality and reproducibility, together with workers, machines, operations, etc. González et al. [15] have reported that organizations lack references to accredit the capacity of a manufacturing process by using AM technologies. This depends basically on proper efforts and combined work with helpers and customers, which provides traceability and credibility for all stakeholders.

Narbaev et al. [16] have carried out a literature review on game theory models in project management. The revision showed the need for studying knowledge-sharing mechanisms to improve project governance and cooperation, among others. The findings contributed to pointing out directions in the management of engineering research. Jing et al. [17] have researched the problems that enterprises are impacted by multiple stakeholders in the process of lean management. The work studied the interaction mechanism between internal and external stakeholders that affects the implementation of enterprise lean management by using dynamic game theory. Hiller [18] applied cooperative game theory to model the design of the structure of teams. The author introduced production games. These games enable the modelling of teams. The work analysed two situations of team theory, based on the coalition structure approach of cooperative game theory. According to Kleer et al. [19] the game theory provides a mathematical approach to assess and predict stakeholders' interactions. The construction industry is plenty of encounters among its stakeholders, construction engineering and management. However, this field lacks a thorough investigation of game theory applications. The authors presented an overview of the game-theoretic models in construction engineering and management research. The aim was to improve the understanding of the applications of game theory in analysing strategic interactions in this field; in multiple application domains and project delivery systems. Al-Gharaibeh et al. [20] have pointed out that organizations require to implement knowledge management procedures and organizational mechanisms to transform collective knowledge into a learning organizational capability. Knowledge sharing is a fundamental knowledge management process. The dynamics of knowledge management behaviour require further examination. They studied this scenario using game theory. Stevens et al. [21] reported that self-organising software teams may be modelled using game theory, which may provide a tool for agile developers to act when behaving strategically. They presented a model for self-assignment of development duties using game theory. Gavidia-Calderon et al. [22] have reported that game theory studies conflict, as well as cooperation and its use will expedite the development of efficient processes. A study of game theory in software engineering has found models that were unusually based on process data. They have displayed how to make use of game abstractions, achieved in artificial intelligence, to derive game-theoretic models of software practices.

These considerations motivate that game theory can be considered in project management according to

Narbaev et al. [16]. Hiller's work [18] enables us to apply game theory to model the designing of the structure of teams. Thanks to Kleer et al. [19], it is known that game theory derives a mathematical approach to test and predict stakeholders' interactions in a project environment. As organizations need to run knowledge management procedures and organizational procedures to change collective knowledge in a learning organizational capacity [20], this motivates that game theory to be used as a tool for the management of teamwork in this work. According to Stevens et al. [21], self-organising software teams can be modelled by using game theory, providing a tool to perform when behaving strategically. Furthermore, game theory studies conflict and cooperation, which expedites the development of efficient processes, as reported Gavidia-Calderon et al. [22]. This gives rise to an approach based on game theory which will allow us to expand these works beyond software teams' management. The 2 × 2 games are used due to their features, for example, remarkable diversity. Its strategic scenario involves two players, each with only two choices. There are only four outcomes, and each one is given a single payoff for each player [23].

The main contributions of this work can be summarized as follows: (a) to present a procedure to tackle the symmetric 2 × 2 games in an AM environment, wherein the payoff matrix is decomposed into two a cooperative part and a zero-sum part; (b) to use the topology properties of these games to study the representation of the game space in an AM setting; (c) to analyse the game regions to derive further information for arranging the teams.

2. Materials and methods

Game theory is a method for the study of decision-making in settings of dispute. It tackles issues in which the individual decision-maker does not control the factors impacting the result [24]. A game is characterised in terms of individual decision-makers called the players, the rules of the game, the payoffs, the ratings that the players allocate to different payoffs, the variables that each player controls, and the pieces of information that there exist during the game. A player is an autonomous decision-making unit. A player is not mandatorily one person; it can be a group of individuals who act in an organisation, a company, etc. A player has an aim in the game and acts to earn it. Each player has the management of some set of resources, together with the rules of the game, all of them describing how can be used. This allows us to determine every choice that is available to a player. The result of a game will be conditional on the strategies used by every player. Assume the player chooses a strategy from all available for him. The result of the game to him will be determined by what he did and what his opponents performed. His payoff is a function of the strategies used by all the players. Overall, a player has a rating outline by which he can assess the worth of any set of likelihoods with which he is faced. For example, a manufacturer whose products must compete with those of another implicates struggles that can be classified as game situations. In game theory, the individual has to determine how to get as much as possible, considering that there exist others whose aims are distinct and whose actions have an impact on all. A player in this scenario addresses a cross-purpose maximization problem. He must lay out an optimal return, considering the actions of his opponents [24].

A game in strategic form is a function with one input for each player, which may be called strategy and one output for each player, which may be called payoff. The ordinal 2 × 2 games are in strategic form, with only two players. The strategies are the actions available to the players [23]. Böörs et al. [25] have reported that any game can be broken down into a mutual interest game and a zero-sum game, according to Kalai et al. [26]. A two-player game with payoff bimatrix P can always be decomposed into the sum of a zero-sum game with payoff bimatrix Z and a game of mutual interest with payoff bimatrix $C : P = C + Z$. Two-player game bimatrix may be decomposed into one mutual interest game and a zero-sum game. The elements of the matrix are called A, B, C and D. The decomposition of the payoff matrix is given by:

$$\begin{bmatrix} (A, A) & (B, C) \\ (C, B) & (D, D) \end{bmatrix} = \begin{bmatrix} (A, A) & (\frac{B+C}{2}, \frac{B+C}{2}) \\ (\frac{B+C}{2}, \frac{B+C}{2}) & (D, D) \end{bmatrix} + \begin{bmatrix} (0, 0) & (\frac{B-C}{2}, -\frac{B-C}{2}) \\ (-\frac{B-C}{2}, \frac{B-C}{2}) & (0, 0) \end{bmatrix}. \quad (1)$$

The decomposition disconnects the mutual interest part from the zero-sum or conflictive part of the game. The variables C_1, C_2 and Z_1 can be defined for the division in the mutual interest and the zero-sum (see Figure 1).

$$C_1 = \frac{B+C}{2} - A \tag{2}$$

$$C_2 = D - \frac{B+C}{2} \tag{3}$$

$$Z_1 = -\frac{B-C}{2} \tag{4}$$

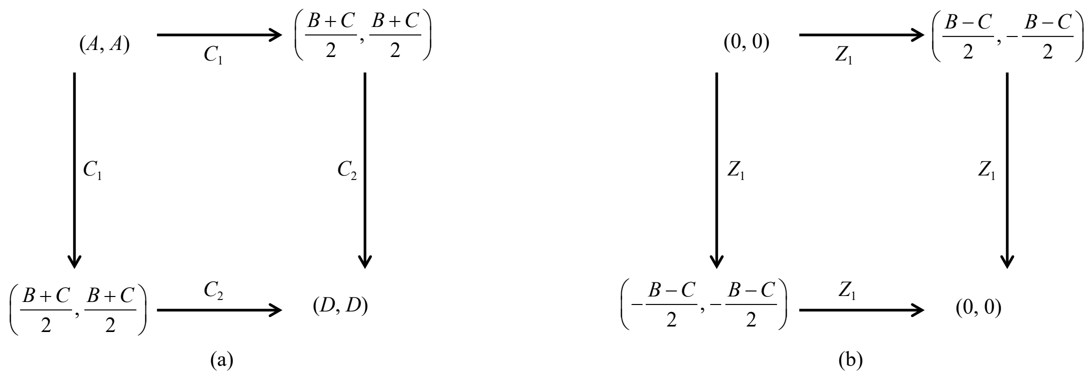

Figure 1. The variables that represent the preferences of both players are displayed as arrows: (a) the payoffs of the mutual interest part of the payoff matrix; (b) the payoffs of the conflict part of the payoff matrix [25]

In symmetric 2 × 2 games, it is only required C_1, C_2 and Z_1 lay out the incentives in the mutual interest and the zero-sum parts. The variables C_1, C_2 and Z_1 enable us to contrast the strength of the incentives in the mutual interest part with the conflict and to evaluate whether the incentives are aligned or not. For instance, if $C_1 > 0$, then player 1 chooses result (C, B) in the mutual interest matrix over the result (A, A). The sign of the variables establishes what result the players prefer. Figure 1 shows these preferences as arrows, the directions displayed are positive, and the opposite directions are negative. The vertical arrows illustrate the preferences of player 1, and the horizontal arrows are the preferences of player 2. The absolute value of the variables C_1, C_2 and Z_1 indicate the strengths of the players' preferences. The conflict part counteracts the mutual interest part of the decomposition, i.e., the conflict variable Z_1 and at least one of the mutual interest variables C_1 or C_2 present opposite signs, and the value of Z_1 is greater than this variable [25].

Topology is the field of mathematics that study of objects' properties which are conserved throughout twisting, deformations and stretching, these do not cover breaks or cuts. A topological space can be generated from points. In this work, the set of points will be given by the 2 × 2 game. Modern topology does not consider the individual nature of the elements, but their mutual relationships. Developing an adequate concept of neighbour is the key to working out a topological treatment of these games. The games are featured by the payoff function. So, analogous games must present analogous payoff functions. To establish significant neighbourhoods, it is required to characterise the smallest meaningful change in the payoff function [23, 27].

3. Results

This section presents the main results of the work. Different subsections will allow us to study the decomposition of symmetric 2 × 2 games in AM environment. The topology of 2 × 2 games in an AM scenario and the analysis of the several game regions.

3.1 *Applying the decomposition of symmetric 2 × 2 games to an AM setting*

As mentioned previously, project managers have to face the investigation to aid their organizations to fit the different changes that are taking place in the industry. The effect of AM on project management shows that an appropriate application of the technology may raise the effectiveness of project managers and improve organisational production [13]. Furthermore, companies are changing to long-running, product-based settings. In this way, they can employ different strategies to organise product management. The industries that assume an integrated view of project and product management can earn from estimating program management frameworks as a platform. Product life cycles can seem that confront classic project delivery forms as the temporary nature of projects [14].

To release a novel product to the marketplace, two items are fundamental to assure productivity sustainability over time, these are quality and reproducibility. They are got by qualifying and certifying a process. This is done by using the accreditation that the production method can provide the predicted quality and reproducibility, together with AM machines, operations, workers, etc. The organisations must address the lack of references in AM to approve the capacity of a manufacturing process by using these technologies. This is conditional on the efforts and combined work with collaborators and clients, which gives traceability and credibility to all interested parties [15]. To tackle the symmetric 2 × 2 games in the AM environment:

a) two teamwork have to be chosen;

b) the teams' functions must be established through their corresponding work periods (WP) and labour units (LU);

c) the bimatrix of the teamwork payoff matrix has to be determined;

d) to derive the bimatrix decomposition.

A functional block diagram of the decomposition of symmetric 2 × 2 games to an AM setting is displayed in Figure 2.

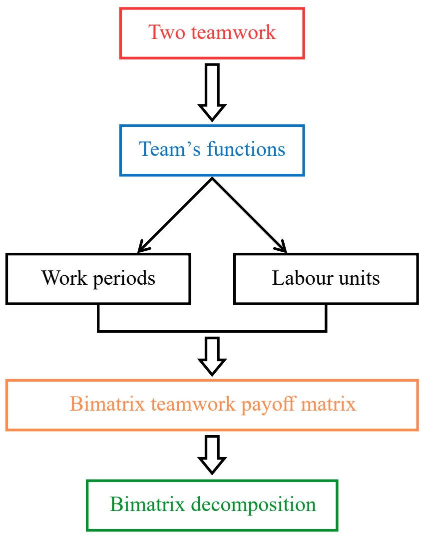

Figure 2. Functional block diagram of the decomposition of symmetric 2 × 2 games to an AM setting

According to González et al. [15], in AM the values chain step description can be set out, see Figure 3.

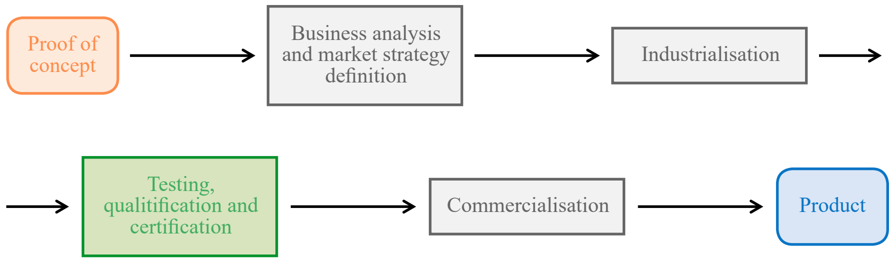

Figure 3. AM impact on value chain step: testing, qualification and certification [15]

Considering Figure 3, two teamwork are considered the industrialisation and the commercialisation team, respectively. As can be seen, both are related to testing, qualification and certification. An aerospatial organisation hired an AM company to design a product that must be subjected to accurate testing and certification trials. The project manager has to consider the teams' effort and the duration to accomplish management to overcome the lack of certification experience in new product development.

According to PMBOK Guide (7th edition) [14] duration is the total number of WP needed to conclude an activity or work breakdown structure part, expressed in hours, days, or weeks. The effort is the number of LU needed to conclude a scheduled activity or work breakdown structure part, frequently expressed in hours, days, or weeks. The industrialisation team functions are given in Table 1. There are four functions for this team. The first one is monitoring the temperature in every 3D printer, the second is checking the O_2 level, and the third is controlling laser power, all enabling building up the pieces with high quality. Once the pieces are built, these have to be check-up with high accuracy. The computed tomography will allow us to carry out this task successfully. These are 2 LU for the monitoring temperature, 2 LU for the O_2 level, 2 LU for the laser power and 4 LU for the computed tomography. On the other hand, the durations associated with the previous efforts are the monitoring temperature 1 WP, O_2 level 1 WP, laser power 1 WP and computed tomography 2 WP.

Table 1. Industrialisation team functions

	Monitoring temperature	**O_2 level**	**Laser power**	**Computed tomography**
Effort unit (LU)	2	2	2	4
Duration unit (WP)	1	1	1	2

The commercialisation team functions are given in Table 2. There are four functions for this team. The first one is marketing, the second is distribution, the third is sales and four is customer support. The efforts are 2 LU for marketing, 2 LU for distribution, 2 LU for sales and 4 LU for customer support. The duration associated with these efforts is marketing 1 WP, distribution 1 WP, sales 1 WP and customer support 2 WP.

Table 2. Commercialisation team functions

	Marketing	**Distribution**	**Sales**	**Customer Support**
Effort unit (LU)	2	2	2	4
Duration unit (WP)	1	1	1	2

The elemental duration for the industrialisation team is 2 WP, and the advanced duration is 4 WP. The commercialisation team has the same levels of duration as with analogous WP. To manage the duration levels and team functions and face new challenges, project managers need to use a framework that enables them to address the certification experience between new teams that have never worked in cooperation. The following case is considered, the teams have to select between cooperation and rejection. If the teams cooperate, both have to do: one advanced duration (4 WP) plus three additional functions, which means, 3 WP. In total: 7 WP. If both teams reject the cooperation, they have to do: an elemental duration (2 WP) plus two additional functions, which means, 2 WP. In total: 4 WP. This is a standard duration, see Figure 4.

On the other hand, if one team decides to do full cooperation, they have to do: one advanced duration (4 WP) plus four additional functions, which means, 5 WP. In total: 9 WP. In this case, if the other team rejects the total cooperation, they will not do anything. This can be represented in the form of a bimatrix, see Figure 4. The inclination of the rejection choice is stronger than the motivation to cooperate and as an outcome (1 1) both teams renounce and decide to do a standard duration, even though both teams could obtain a suitable certification experience (payoff) from cooperating.

		Commercialisation team 0	Commercialisation team 1
Industrialisation team	0	(7, 7)	(0, 9)
	1	(9, 0)	(4, 4)

Figure 4. Bimatrix of the teamwork payoff matrix

Equation 5 shows the bimatrix decomposition for this case.

$$\begin{bmatrix} (7,7) & (0,9) \\ (9,0) & (4,4) \end{bmatrix} = \begin{bmatrix} (7,7) & (\frac{9}{2},\frac{9}{2}) \\ (\frac{9}{2},\frac{9}{2}) & (4,4) \end{bmatrix} + \begin{bmatrix} (0,0) & (\frac{-9}{2},\frac{-9}{2}) \\ (\frac{9}{2},\frac{-9}{2}) & (0,0) \end{bmatrix} \quad (5)$$

As Figure 5 shown by the arrows, the conflict part (zero-sum) of the decomposition draws the teams toward the rejection outcome and it is intense enough to counteract both of the mutual interest variables that draw the teams toward the cooperation outcome. In the mutual interest game, both teams prefer an outcome (0 0), i.e., cooperation. As can be seen, the arrows point in this direction. In the conflict (zero-sum) game the industrialisation team prefers the (1 0) outcome and the commercialisation team prefers the (0 1) outcome. As a consequence, their combined motivations draw them toward the (1 1) outcome, as the arrows indicate. Due to the payoff differences in the conflict (zero-sum) game being larger than those in the mutual interest game, the motivations in the conflict game counteract the motivations in the mutual interest game. The conflict and mutual interest variables can be figured out, $Z_1 = 4.5$, $C_1 = -2.5$ and $C_2 = -0.5$. Because the Z_1 variable and the C_1 and C_2 variables have different signs the conflict counteracts the mutual interest and since $|Z_1| > \max(|C_1|, |C_2|)$, the zero-sum is intense enough to overpower the mutual interest.

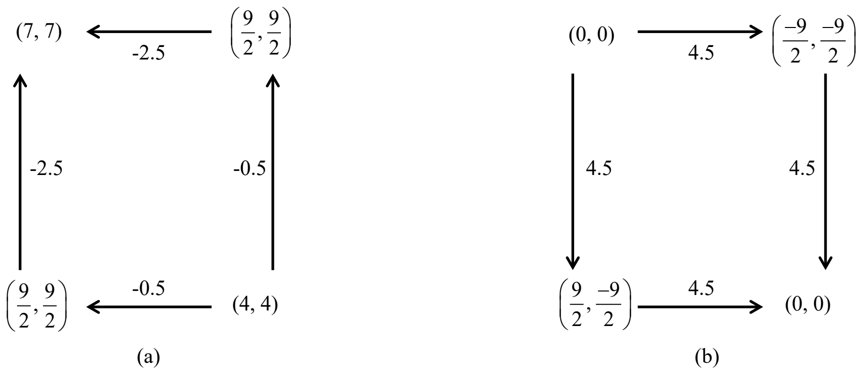

Figure 5. The preferences of the players are shown as arrows: (a) the payoffs of the mutual interest part for industrialisation and commercialisation teams; (b) the payoffs of the conflict part for industrialisation and commercialisation teams

3.2 *Topology of 2 × 2 games in an AM setting*

To apply the topology of 2 × 2 games in an AM setting, it is considered that if the teams cooperate, both have to do: one advanced duration (4 WP) plus two additional functions, which means, 2 WP. In total: 6 WP. If both teams reject the cooperation, they have to do: an elemental duration (2 WP) plus one additional function, which means, 1 WP. In total: 3 WP, see Figure 6(a). On the other hand, if one team decides to do full cooperation, they have to do: one advanced duration (4 WP) plus two additional functions, which means, 4 WP. In total: 8 WP. In this case, if the other team rejects the total cooperation, they will not do anything; see Figure 6(a).

Evaluating the neighbours of a game can lay out evidence of the robustness of solutions in the face of perturbations in the payoff framework. In Figure 6(b), changes in the rows of the least-liked outcomes drive a change in the player behaviour, from 0 WP to 2 WP and from 3 WP to 1 WP, see Figure 6(b). This transforms the game with its inefficient equilibrium, into a game with a Pareto-efficient equilibrium, see Figure 7.

		Commercialisation team 0	1
Industrialisation team	0	(6, 6)	(0, 8)
	1	(8, 0)	(3, 3)

(a)

		Commercialisation team 0	1
Industrialisation team	0	(6, 6)	(2, 8)
	1	(8, 0)	(1, 3)

(b)

Figure 6. Change of the ordinal values for two outcomes

Preferences involve a structure of overlapping neighbourhoods and lead to a topology in the games. These can be characterised as close and distant neighbours, see Figure 7(a). This depends on how many swaps are required to turn one into the other, see Figure 7(b) [25, 28].

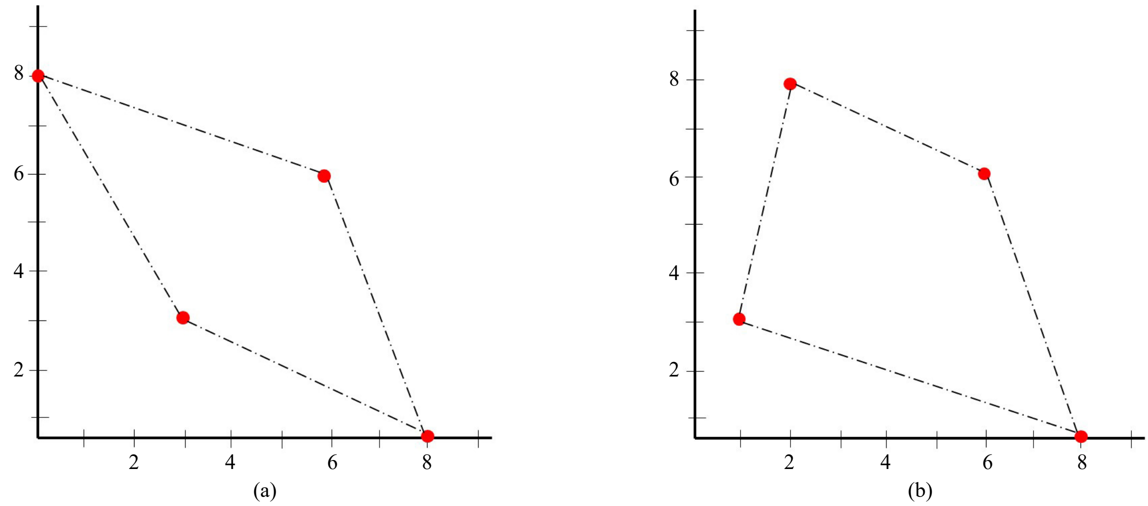

Figure 7. Graphical representation of the change of the ordinal values for two outcomes

3.3 *Analysis of game regions*

In this subsection, it is analysed the regions associated with 2 × 2 games. These regions provide information for approaching the issue from several starting viewpoints. The payoff parameters are called A, B, C and D, see Table 3.

Table 3. Symmetric 2 × 2 game

	0	**1**
0	(A, A)	(B, C)
1	(C, B)	(D, D)

The variations in the game can get interesting in iterated play, wherein a player can sacrifice short-term payoff to raise the possibilities of the opponent cooperating. In play region 1, see Figure 8, the expression $B + C < 2D \leftrightarrow B - D < D - C$ is held. Thereby, the cost of pointing out the cooperation ($B - D$) is less than the gain of activating the opposing player to start cooperation first ($D - C$).

	0 (Cooperation)	1 (Rejection)
0 (Cooperation)	(7, 7)	(0, 9)
1 (Rejection)	(9, 0)	(4, 4)

Figure 8. Play region 1

In play region 2 and play region 3, see Figure 9, the expression $2D < B + C < 2A$ is also held. In this case, is split into two distinct games, depending on whether $C_1 > C_2$ (play region 2) or $C_1 < C_2$ (play region 3).

	0 (Cooperation)	1 (Rejection)
0 (Cooperation)	(3, 3)	(-1, 6)
1 (Rejection)	(6, -1)	(0, 0)

(a)

	0 (Cooperation)	1 (Rejection)
0 (Cooperation)	(5, 5)	(-1, 6)
1 (Rejection)	(6, -1)	(1, 1)

(b)

Figure 9. Regions: (a) play region 2; (b) play region 3

It could seem that there is no distinction between play region 2 and play region 3, however, this involves the cost of collaborating and the cost of admitting it yielded that the game is replayed and in Nash equilibrium [29]. In the play region 2 instances in Figure 9(a), the cost of the event that causes rejection is lower, while the cost of accepting the action is high. Player 1 pays a cost of $|D - B| = |0 + 1| = 1$ to indicate to player 2 that would wish to collaborate, paying the cost $|A - C| = |3 - 6| = 3$ for admitting to collaborate.

In play region 3, Figure 9(b), the situation is reversed, the event that causes the rejection is higher compared to taking the action to collaborate. The cost for acting, by changing from 1 to 0, which means "mentioning the other player that you desire to collaborate with" is $|B - D| = |- 1 - 1| = 2$. Nevertheless, the cost of attending to the action is $|A - C| = |5 - 6| = 1$.

In play region 4, Figure 10, the players can begin to rotate between the game outline (0 1) and (1 0) because it provides both players with a higher payoff than cooperating as the game is replayed. In this case, the difference between cooperation and defection is uncertain due to the players may collaborate by turns.

	0 (Cooperation)	1 (Rejection)
0 (Cooperation)	(2, 2)	(0, 6)
1 (Rejection)	(6, 0)	(1, 1)

Figure 10. Play region 4

4. Discussion

Game theory is the science of strategy and decision-making, where the fundamental is the interdependence of strategies used and the connection of these to the games' outcomes. A theory for the rating of games is relevant for several motives; one of them is the process of studying games, which allows us to establish the difference between games. In addition, it lays out an outline of potential strategic conflicts, which can lead to situations in real scenarios, such as AM projects. In the game, the variations get interesting in iterated setting, wherein a player can lay down a short-term payoff to raise the possibilities of the other player collaborating. Shubik [24] reported the uses of game theory in management science and the two-person zero-sum game. In all of the standard games, the zero-sum games counteract the interests in the non-conflict games. This yields a separation of the symmetric 2×2 games established for the benefit of the players. This procedure has been applied in an AM project to manage two teamwork, such, as the industrialisation and the commercialisation team. These teams are beneath the perspective of testing, qualification and certification in an AM value chain. The project manager may employ this process to accomplish management to overcome the lack of certification experience in new product development in a particular setting, for example, the aerospatial industry. In any project, effort and duration are basic items. Their corresponding ratios have been provided in Tables 1 and 2 for each team.

For example, the two teams have to select between cooperation and rejection. If the teams cooperate, both have to do: one advanced duration (4 WP) plus three additional functions, which means, (3 WP). In total: 7 WP. If both teams reject the cooperation, they have to do: an elementary duration (2 WP) plus two additional functions, which means, (2 WP). In total: 4 WP. This is a standard duration. It has been obtained that the balance between common interest and self-interest is low. Thereby, it is straightforward for the players to arrange the most favourable result. On the other hand, the topology of 2 × 2 games in an AM setting has allowed us to assess as the neighbours of a game may present robustness of solutions in the payoff framework. Thus, swaps in the rows of the least-liked outcomes address a change in the player's behaviour, see Figures 6(a) and 6(b), which change the game into an inefficient equilibrium to become into a Pareto-efficient equilibrium. This behaviour can be seen graphically in Figures 7(a) and 7(b). The study of game regions derives information for approaching the problem from different viewpoints. The analysis of game regions derives information for approaching the problem from different starting points of view. The variations in the game may become interesting as a player may trade off short-term payoff to raise the options of the other player collaborating. As can be seen, this procedure is restricted to 2 × 2 games and has not been implemented in any software package, which is a limitation of the work.

5. Conclusions

Nowadays, AM covers a variety of industrial applications such as aerospace and health care, among others. The AM on project management has shown that an adequate application of the technology can increase the effectiveness of project managers and improve organisational behaviour. The project managers must encourage AM technology in the organisations to enhance product features. Thereby, companies must acquire an integrated view of project and product management.

The markets are shifting toward a continuous delivery model and are seeking to keep a stable customer focus. This enables them to be aligned with the in-service of faithful customers. Product management presents a longer life cycle view that involves support, sustainment and continuous development with the same team. The game theory establishes a means of abstracting the fundamental structure of interaction and the corresponding representation of a strategic game. This article has presented:

- an approach based on game theory to deal with the symmetric 2 × 2 games in an AM environment, where the payoff matrix is decomposed into two parts a cooperative and another zero-sum. It has been shown that zero-sum games counteract the interests in non-conflict games.
- the topology properties of these games have been used to study the representation of the game space in an AM project to manage two teamwork, such as the industrialisation and the commercialisation team, where the teams are beneath the perspective of testing, qualification and certification in a value chain.
- the standard game regions have been analysed. It has been observed that the balance between the common interest and self-interest is reduced, and it is not difficult for the players to agree on the most approving result.

This methodology can be implemented as a tool in AM environment to provide suitable information in an AM project to manage two teamwork. This is a decision instrument for the project manager and companies that work in AM technologies. This manuscript opens the door to future research on the application and implementation of the topology, the decomposition of symmetric 2 × 2 games and the analysis of game regions in AM environments. The design of experiments to deal with real teamwork management cases by using this manuscript's results will be considered for future works.

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Conflict of interest

There is no conflict of interest for this study.

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