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José Ramón San Cristóbal
University of Cantabria

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The use of Game Theory to solve conflicts in the project management and construction industry

José Ramón San Cristóbal
Project Management Research Group-University of Cantabria
Germán Gamazo, s/n, Santander 39004
Spain
www.shortbio.net/jose.sancristobal@unican.es

Abstract:
A typical construction project involves a wide range of disparate professionals, in many cases geographically distributed, working together for a relatively short period of time on the design and construction of a facility. Since organizations are becoming flatter, culturally rich, geographically diverse and intensely competitive, the possibilities for conflict in such environments are greater. Negotiation is an important aspect of a project and plays an important role in resolving claims, preventing disputes, and keeping a harmonious relationship between project participants. Part of any project manager's role as a leader is to recognize conflict, understand the sources of conflict and manage it, and to do this a project manager must be able to understand the basics of negotiation theory and have sufficient competencies to lead in such situations. To address the complex technical and human issues in negotiation, different negotiation theories and models are available which mainly include game theory, economic theory, and behavior theory. Since Game Theory provides, by its very nature, the appropriate tools for the analysis and eventual solution of conflicts of any kind, this paper uses a model based on Game Theory in order to identify the activities that are responsible for the delays in a project and divide the costs among them.

Keywords:
project management; conflict; negotiation; Game Theory.

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1. Introduction

Nowadays, the construction industry suffers from several problems such as high fragmentation, complexity and dynamicity, resource discrepancies, cost and time overruns, conflicts and disputes, etc. Since projects are becoming large and complex, involving multiple participants located at different places, the resources and operations of a project are distributed by nature [1]. The wide range of stakeholders and multiple objectives in large-scale construction projects inevitably cause conflicts. Construction problems also involve complexity and dynamicity. The construction sector represents one of the most dynamic and complex industrial environments requiring the application of different technologies or technical approaches [2]. The components of these large, open, and complex projects are not known in advance, can change over time, and consist of highly heterogeneous agents implemented by different people, at different times and with different software tools and techniques [3]. Resource discrepancies are also a major cause of change. When the timing of the tasks is not well matched with the available resources, subcontractors may try to change the master schedule in order to accommodate their desires. This may cause conflicts because in tightly coupled project schedules any move affects the tasks of other subcontractors. In most cases, these conflicts cannot easily be resolved simply by delaying the succeeding tasks, since task delays could extend the project completion beyond the deadline [4]. In these cases, subcontractors hinder their own performance as well as that of other subcontractors and ultimately the entire project [5].

According to Lei et al. [6] the possible reasons for conflict in the construction industry are the following: (i) during the lifecycle of construction, especially in the planning phase, the participants are confronted with enormous issues and a multitude of implicit and explicit interests; (ii) there are obvious differences in mental behavior, culture, temperament, etc., among different negotiators. Thus, their abilities, knowledge and preferences for the same issue differ too; (iii) a huge amount of information is required for decision-making in the construction industry. Therefore, it is difficult for decision-makers to grasp all the information required, the information used by every participant is unilateral and deficient.

The construction industry has a long tradition of collaborative working between the members of a construction project. To ensure that interdependencies are properly managed, the global construction industry requires that project participants across the world are able to work more closely, to exchange project information in a more structured way, and to collaborate and co-ordinate with each other to perform construction activities in order to gain maximum competence [1], [3]. There is a need to develop a negotiation methodology for the project schedule optimization process that ensures overall optimality and resolves conflicts by negotiation among project participants [4]. The challenges are to find a new approach that enables project participants to identify schedule conflicts, consider alternatives, and resolve conflicts in a highly coupled network of related activities [5].

This paper uses a model based on Game Theory, defined as the study of mathematical models of conflict and cooperation between intelligent rational decision-makers [7], in order to identify the activities that are responsible for the delays in a project and divide the costs among them. The paper is organized as follows. In the next section, the conflict in the construction industry and the basics of negotiation theories are analyzed. In section 3, game theory and the Core of a game are presented and, in section 4, this concept is applied to a road construction project. Finally, there is a concluding section with the main findings of the paper and future research.

2. Conflicts in the construction industry

A project can be conceived as a single continuum or recurring negotiations with multiple participants with varying concerns [8]. A typical construction project involves a wide range of disparate professionals (clients, architects, structural engineers, contractors, etc.,), in many cases geographically distributed, and working together for a relatively short period of time on the design and construction of a facility [9]. Since organizations are becoming flatter, culturally richer, geographically diverse and intensely competitive, the possibilities for conflict in such environments are greater and project managers must have sufficient competencies to lead in such situations [10].

There are different views on conflict and the causes that originate it. Levinson [11] describes conflict as a dispute over resources, whereas other authors [12]-[14] believe that conflicts are either interpersonal (affective) or task/goal oriented (substantive). Interpersonal conflicts are clearly more intractable than task/goal conflicts and can lead to imbedded friction [10]. Rahim [12] contends that interpersonal conflict diminishes group loyalty, commitment, job satisfaction, and intention to stay in the organization. Jehn [15] and Rahim [12] suggest that while task/goal conflict may enhance performance under certain circumstances, the downsides are the same as for interpersonal conflicts. Conflict can arise from several causes such as cross-cultural differences. Many authors argue that cross-cultural training is a very strong mediator for avoiding and diminishing destructive conflict [16, 17]. Another method for reducing differences in cross-cultural conflict and to help to educate people in the richness of diversity is the use of metaphors and stories [18]-[20].

There is a limited coverage of conflict management and negotiation in the standards for project management. The Australian National Competency Standard for Project management, one of the most widely recognized and referenced project management standards based on the nine areas of the American Body of Knowledge [21], focuses on the mechanisms of communication within a project but the only reference to negotiation is that of contract negotiation. Conflict is covered in greater detail, with the establishment of procedures for conflict resolution, the management of inter and intra project conflict, the reduction of client conflict, management of the resolution of contract conflict and the escalating of conflict issues to senior personnel. According to Hudson et al. [10], conflict management competencies include: reducing conflicts within project teams, not hiding or avoiding conflict but facilitating resolution, identifying the social behavior reflected in conflict situations, supporting the creation of healthy argumentative cultures, and being able to find consensus with others, aiming for win-win situations, and reacting coolly to personal attacks and forgiving such attacks.

Part of any project manager's role as a leader is to recognize conflict, understand the sources of conflict and manage it, and to do this a project manager must be able to understand the basics of negotiation theory. Negotiation is an important aspect of a project and plays an important role in resolving claims, preventing disputes, and keeping a harmonious relationship between project participants [22]. In a multi-person decision- making process when there are a number of decision-makers involved in choosing a single alternative from a set of possible alternatives, multiple disciplines and teamwork, different concerns caused by different preferences, experiences and background, negotiation plays an important role for multi-person decision-makers to select unfinished projects that will be continued, postponed or terminated [23].

Negotiation is the process of joint decision-making [24]. It is communication, direct or tacit, formal or informal, between individuals who are motivated to converge on an agreement for mutual benefit [25]. According to Raiffa et al. [26], the basic structure of negotiations in different contexts is fundamentally the same and all negotiation situations share four common characteristics: (i) there are two or more parties; (ii) the parties can be creative and cooperate to arrive at a joint decision; (iii) the payoffs to any party depend either on the consequences of the joint decision or alternatives external to the negotiations; (iv) the parties can reciprocally and directly exchange information, honest or not.

It is widely admitted that a client and a contractor face significant difficulties in negotiating major projects. These major projects entail hundreds of issues and a multitude of implicit and explicit interests resulting in substantially complex negotiations between the client and contractor. However, project negotiations are not confined to the planning oriented phase culminating in contract signing. Serious bargaining often commences only after an initial settlement is reached and the most arduous negotiations are typically conducted during or after implementation [27].

Most project managers consider negotiation as the most time-and energy-consuming activity in claim management [28]. In addition, claim negotiation is commonly inefficient due to the diversity of intellectual background, many variables involved, complex interactions, and inadequate negotiation knowledge of project participants [28], [29].

To address the complex technical and human issues in negotiation, different negotiation theories and models are available which mainly include game theory, economic theory, and behavior theory [28]. Game theory is divided into two approaches, the axiomatic approach and the strategic approach. Under the latter, approach game theorists treat economic theory as a part of game theory. On the other hand, negotiation theorists usually distinguish game theory (mainly referring to the axiomatic approach) from economic theory [30]. Game theory seeks to get to the essence of decision-making and the associated strategies in situations where two or more parties are interdependent, and where the outcome of their conflict and competition must be the product of their joint requirements and the interaction of their separate choices [31]. All the players in games are assumed to be rational, try to maximize their own utilities, and have complete information on the payoff function and utility function [32]. In contrast to the classical game theory approach, in economic theory there is no concern for the discovery of once-and-for-all strategies, but rather an intention to examine how the bargainers should interact in terms of their expectations of each other [33]. Economic models analyze the processes through which the demands of the participants converge in the course of offers and counteroffers toward some specific point on the contract curve [31]. In behavior theory, much attention is given to the nature of changing expectations and negotiators' tactics, and to the significance of uncertainties of information, perception and evaluation, all matters that tend to be ignored by game theory and economic theory [34]. Behavior theory attempts to analyze the negotiation processes in which negotiators influence each other's expectations, perceptions, assessments, and decisions during the search of an outcome.

3. Game Theory

Since game theory may provide, by its very nature, the appropriate tools for the analysis and eventual solution of conflicts of any kind in the construction industry, this paper adopts the negotiation theorist's approach. Game theory, defined as the study of mathematical models of conflict and cooperation between intelligent rational decision-makers [7], has the potential to address some of the problems facing the construction industry within a collaborative framework. In construction projects, conflicts among builders and owners are very common, particularly in a bidding or claiming situation, and game theory is a natural tool that can be used to analyze the situation systematically. Game theory focus on strategic interaction and conflict providing a way to think about the conflicting structure of collective decision making processes.

In project management, game theory is still in the beginning of its practical applications. Branzei et al. [35] proposed two coalitional games related to delay cost sharing problems to determine fair shares for each of the agents who contribute to the delay of a project so that the total delay cost is clear. Bergantinos and Sanchez [36] introduced a non-transferable utility game associated to the Program and Evaluation review Technique (PERT) problem to divide the floats of time among the different activities. In a second paper, Bergantinos and Sanchez [37] presented two different approaches, one based on serial cost sharing problems and the other in game theory, to distribute the cost caused by the delay of a project among the firms which are responsible for it. Estevez-Fernandez et al. [38] analyzed both delayed and expedited problems where the penalty (reward) function is proportional with respect to the total delay (expedition) of the project. In a second paper, Estevez-Fernandez [39] analyzed project problems with arbitrary but non-decreasing penalty and rewards functions taking into account whether an activity could be started before its planned starting time. San Cristobal [40] applied the Shapley value to the fair allocation of gains obtained by cooperation among several firms carrying out a vessel drydocking who form a coalition to expedite the project.

In a broad sense, game theory can be classified into two categories: non-cooperative game approaches, where a decision-making unit treats the others as competitors, and cooperative approaches where a group of decision-makers decide to undertake a project together in order to achieve their joint business objectives. In game theory, individuals or groups become players when their respective decisions, coupled with the decisions made by other players, produce an outcome. The options available to players to bring about particular outcomes are called strategies. Strategies are linked to outcomes by a mathematical function that specifies the consequences of the various combinations of strategy choices by all of the players in a game. A coalition refers to the formation of sub-sets of players' options under coordinated strategies.

In game theory the core is the set of feasible allocations that cannot be improved upon by a coalition. An imputation $x = \{x_1, x_2, \ldots, x_n\}$ is in the core of an n-person game if and only if for each subset *S* of *N*:

$$\sum_{i=1}^{n} x_i \geq V(S) \qquad (1)$$

where *V*(*S*) is the characteristic function *V* of the subset *S* indicating the amount (reward) that the members of *S* can be sure of receiving if they act together and form a coalition (or the amount that members of *S* can get without any help from players who are not in *S*).

Eq. (1) states that an imputation *x* is in the core (that *x* is undominated) if and only if for every coalition *S*, the total of the received by the players in *S* (according to *x*) is at least as large as *V*(*S*). The core can also be defined by Eq. (2) as the set of stable imputations:

$$C : \left\{ x = (x_1, \ldots, x_n) : \sum_{i \in N} x_i = V(N) \text{and} \sum_{i \in S} x_i \geq V(S), \forall S \subset N \right\} \qquad (2)$$

If $V(S) > \sum_{i \in S} x_i$, we say that the imputation *x* is unstable through a coalition *S*, and we say *x* is stable otherwise.

The core can consist of many points. The size of the core can even be taken as a measure of stability or how likely it is that a negotiated agreement is prone to be upset. In order to determine the maximum penalty (cost) that a coalition in the network can be sure of receiving, the linear programming problem represented by Eq. (3) is used [41]:

$$\begin{array}{ll} \text{Maximize} & x_1 + x_2 + \ldots + x_n \\ \text{subject to} & \sum_{i \in C} x_i \leq V(C) \forall C \subset N \\ & (x_1, x_2, \ldots, x_n) \geq 0 \end{array} \qquad (3)$$

4. Case Study

A vital section specified in any contract is the performance period of time of project execution. However, the real duration of the activities in a project is usually extended and the time required to complete it is frequently greater than the time specified in the contract. These overruns on time extension give rise to delays.

Delays may be defined as an act or event that extends the time required to perform the tasks under a constraint [42]. They occur in every construction project and their magnitude varies considerably from project to project [43]. Strikes, rework, poor organization, material shortage, equipment failure, a change in orders, an “act of God”, are the main factors causing delays.

Delays are disruptive and expensive. There is a universal agreement that delay is acknowledged as the most common, costly, complex and risky problem, representing an area of leakage in the construction industry worldwide [44]-[45]. Peurifoy and Ledbetter [46] identify that the construction industry is one that deals with the conversion of plans and specifications into a finished product. It comprises a mixed variety of organizations that face different situations and to some degree similar pressures. Many of these problematic situations (cash-flow problems, equipment failures, material shortage, etc.) are beyond control and often lead to delay. In addition, delays are interconnected, making the situation even more complex and the problem can be more evident in traditional types of contract which is awarded to the lowest bidder [47].

Because of the overriding importance of time for both the owner (in terms of performance) and the contractor (in terms of money), delays are the source of frequent disputes and claims among owners, clients and consultants leading to lawsuits [43]. Such situations usually involve questioning the facts, causal factors, contract interpretations, quantum of the claims, mistrust, arbitration, cash-flow problems, loss of productivity and even total abandonment or termination of contract [48].

When a project is delayed, the questions that emerge are: Does a particular delay warrant an extension of project duration and/or an extra cost? If an activity, whose real duration is greater than the planned duration, makes use of the expedition created by other activities, is this activity responsible for the delay? What is the maximal amount that an activity can be held responsible for? How can costs be divided among the activities? Despite the high number of papers published, most of these papers only focus on identifying factors, causes and effects of delays based on surveys of owners, contractors, or clients. Several papers analyze factors of delays focusing on the factors of delays in projects in different countries [49-53], factors that contribute to the likelihood of project delay using statistical methods [54], factors influencing contractor performance [55], factors affecting the analysis of inclement weather delays [56], and factors that lead to project delays and tools used to mitigate their effects [57]. Other papers deal with causes of delays focusing on the causes of these delays in projects in different countries [43], [45], [57]-[66], causes of delays and their importance according to project participants [67], causes of delays from the viewpoint of owners, contractors and architectural/engineering firms [68], causes of delays by looking at the responsibility of major parties [69], contributions of clients, contractors and others to time overrun [70], causes of delays with traditional type contracts, causes of delays to establish adequate evaluation prior to the contract award [71], causes of non-excusable delays identifying the factors contributing to those causes [72], perceptions of civil construction practitioners on how significant causes of delays are [73]. Several papers deal with other aspects of project delays as dispute resolution [74], tools to aid in analysis of delay claims [75], computational methods [76], delay analysis methodologies and their advantages or disadvantages [77]-[78], effects of project size, construction type, number of bidders on project delays [79] and effects on time and cost [80].

The purpose of this section is to determine the maximum delay that an activity of a project can be held responsible for, and subsequently, to share the penalty associated with the total delay of the project among the activities that have caused this delay. To explain the proposed approach, the road construction project shown in Fig. 1 and Table 1 is presented. Let us consider that, when drafting the contract, the following terms are included: “A coalition is defined as the activity or set of activities of the network that represent a sub-path within a path. Each coalition is considered a player. The activities that form a coalition and are in the same path can take advantage of the expedition of the activities or coalitions within the same path. Any coalition cannot be held responsible for more than the total delay of the project but will be held responsible for, at least, ten percent of the delay caused by these coalitions individually. Each day that the project is delayed a penalty of 500 dollars will be applied to a coalition”.

As we can see, in the network there are three paths and four coalitions (*AB*; *CDE*; *GH*; and *F*). In order to calculate the delay and expedition of the activities, and real duration of the project, the following equations are used [39]:

$$d(i) = \max[r(i) - p(i), 0] \qquad (4)$$

$$e(i) = \max[p(i) - r(i), 0] \qquad (5)$$

where $p(i)$ and $r(i)$ represent the planned and real time, and $d(i)$ and $e(i)$ represent the delay and expedition functions of activity i respectively.

The planned, real duration and float of the paths are calculated as follows:

$$D(N_\alpha, p) = \sum_{i \in N_\alpha} p(i) \tag{6}$$

$$D(N_\alpha, r) = \sum_{i \in N_\alpha} r(i)_i \tag{7}$$

$$Float(N_\alpha, p) = D(l) - D(N_\alpha, p) \tag{8}$$

where $D(N_\alpha, p)$ and $D(N_\alpha, r)$ are the planned and real duration of a path N_α, $D(l)$ is the planned duration of the project (i.e., the maximum of $D(N_\alpha, p)$), and $Float(N_\alpha, p)$ is the maximum time that the path N_α can be delayed without altering the duration of the project. If a path has float zero, then we say that this path is critical.

Table 1. Tasks associated with the project

Task	Description	Predecessor
A	Demolitions	-
B	Walls	A
C	Transport of soil (dirt/gravel??)	-
D	Longitudinal and transversal drainage	C
E	Telecommunication infrastructures	D
F	Granular and asphalt capes	B,E
G	System of road signs	B
H	Markings on the road	G

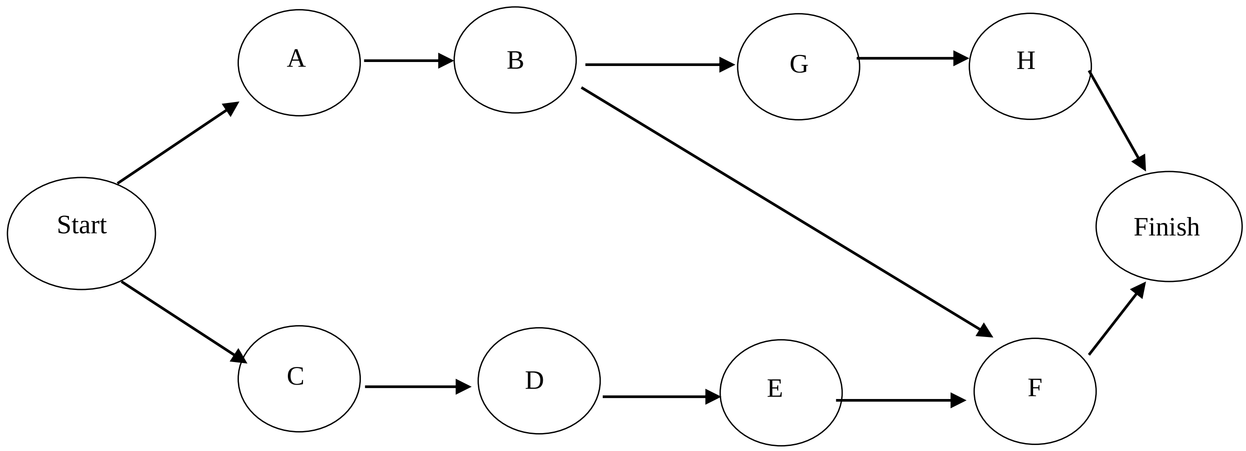

Fig.1. Network associated with the project

Table 2 shows the planned and real time (in days), and delay and expedition of the activities after the realization of the project, calculated using Eqs. (4) and (5), and the planned, real duration, and float of the paths calculated using Eqs. (6), (7) and (8) are shown in Table 3.

Table 2. Planned time, real time, delays and expeditions

Task	$p(i)$	r(i)	$d(i)$	$e(i)$
A	20	35	15	0
B	40	60	20	0
C	30	25	0	5
D	40	30	0	10
E	20	18	0	2
F	70	90	20	0
G	70	65	0	5
H	40	35	0	5

Table 3. Planned, real duration, and slack of the paths

Path	Coalitions	$D(N_\alpha, p)$	*Slack* (N_α, p)	$D(N_\alpha, r)$
N_1	*AB-GH*	170	170-170 = 0	195
N_2	*AB-F*	130	170-130 = 40	185
N_3	*CDE-F*	160	170-160 = 10	163

Table 4. Coalitions, delays (days) and costs associated to each coalition

Coalition	Delay	Cost	Coalition	Delay	Cost	Coalition	Delay	Cost
AB	35	17,500	*AB,CDE*	35	17,500	*AB,CDE,GH*	25	12,500
CDE	0		*AB,GH*	25	12,500	*AB,CDE,F*	35	17,500
GH	0		*AB,F*	35	17,500	*AB,GH,F*	25	12,500
F	10	5,000	*CDE,GH*	0		*CDE,GH,F*	15	7,500
			CDE,F	0		*N*	25	12,500
			GH,F	0				

The planned duration of the project, $D(l)$, is 170 days, the maximum duration of $D(N_\alpha, p)$ that corresponds to path N_1, but the real duration, $D(r)$, is 195 days, the maximum duration of $D(N_\alpha, r)$ that also corresponds to path N_1. Thus the total delay of the project is $D(r)$-$D(l)$ = 25 days. By adding the delays of activities *A* and *B*, we obtain that the delay of the coalition (*AB*) is 35 days. The delay of coalition (*F*) is 10 days (activity *F* is delayed 20 days minus a float of 10). However, these coalitions cannot be held responsible for more than 25 days, the total delay of the project, because other activities of the project have been expedited. Thus, coalition (*AB*) is responsible for 35 days on its own but when forming a coalition with (*GH*), they are only responsible for 25 days because they take advantage of the expedition of activities *G* and *H* (10 days). The delay of coalition (*AB*,*CDE*) is 35 days because, although coalition (*CDE*) is expedited 17 days, these two coalitions are in different paths of the network. The delay of the coalition (*AB*,*F*) is 45 days, 35 days corresponds to the delay of coalition (*AB*) plus 10 days that corresponds to the delay of coalition (*F*).

Once we have the coalitions that can be created in the project and the total delay that these coalitions can be held responsible for, the next step is to allocate the total penalty among the delayed coalitions and activities. Using model (3) and the assumptions considered at the beginning of this section, we have:

$$\text{Maximize} \quad \left(X_{AB} + X_{CDE} + X_{GH} + X_F\right) \tag{9}$$

$$\text{subject to} \quad 1{,}750 \le X_{AB} \le 17{,}500 \tag{10}$$

$$500 \le X_F \le 5{,}000 \tag{11}$$

$$X_{AB} + X_{CDE} \le 17{,}500 \tag{12}$$

$$X_{AB} + X_{GH} \le 12{,}500 \tag{13}$$

$$X_{AB} + X_F \le 22{,}500 \tag{14}$$

$$X_{AB} + X_{CDE} + X_{GH} \le 12{,}500 \tag{15}$$

$$X_{AB} + X_{CDE} + X_F \le 17{,}500 \tag{16}$$

$$X_{AB} + X_F + X_{GH} \le 12{,}500 \tag{17}$$

$$X_{CDE} + X_{GH} + X_F \le 1{,}500 \tag{18}$$

$$X_{AB} + X_{CDE} + X_{GH} + X_F = 12{,}500 \tag{19}$$

$$X_{CDE}, X_{GH} = 0 \tag{20}$$

$$X_{AB}, X_{CDE}, X_F, X_{GH} \ge 0 \tag{21}$$

where inequalities (10) and (11) are based on the assumption that any coalition that forms a sub-path and causes a delay in the project, will be held responsible for at least ten percent of the delay caused by these coalitions individually. Thus, coalition (*AB*) will be held responsible for at least 1,750 dollars and no more than 17,500 dollars (35 days) and coalition (*F*) will be held responsible for at least 500 dollars and no more than 5,000 dollars (10 days). Inequality (12) establishes that coalition (*AB*;*CDE*) cannot be held responsible for more than 17,500 dollars (35 days). Because coalition (*AB*) takes advantage of the expedition of coalition (*GH*), inequality (13) establishes that coalition (*AB*;*GH*) cannot be held responsible for more than 12,500 dollars (25 days). Inequality (14) establishes that coalition (*AB*;*F*) cannot be held responsible for more than 22,500 dollars (35 days plus 15 days). Inequalities (15)-(18) are calculated in a similar way, inequality (19) establishes that, since the total delay of the project is 25 days, the maximum penalty to allocate among the coalitions is 12,500 dollars, and inequality (20) establishes that coalitions (*CDE*) and (*GH*) cannot be punished because these coalitions have been expedited. Finally, inequality (21) establishes the non-negativity constraint.

The solution to the above linear programming problem is $X_{AB} = 11{,}000$, $X_{CDE} = 0$, $X_F = 1{,}500$, and $X_{GH} = 0$. This solution implies that, since any coalition cannot be held responsible for more that the total delay of the project, the maximum penalty that coalitions *AB* and *F* are responsible for is 12,500 dollars. Thus, coalition (*AB*) that has been delayed for 35 days, taking advantage of the expedition of coalition (*GH*), is only responsible for 11,000 dollars, and coalition *F*, that has been delayed for 10 days, taking advantage of the expedition of coalition (*CDE*), is only responsible for 1,500 dollars. Coalitions (*CDE*) and (*GH*) are not responsible for any delay.

The last step is to share the cost allocated to a coalition (player) among the activities that form this coalition. This is the case of activities *A* and *B*, responsible for a cost of 11,000 dollars. This amount will be shared proportionally according to the delay of these activities (15 and 20 days respectively) to the total delay of the coalition (35 days). Thus, the cost allocated to activity *A* is 4,714 dollars and to activity *B* is 6,285 dollars.

5. Conclusion

Part of any project manager's role as a leader is to recognize conflict, understand the sources of conflict and manage it, and to do this a project manager must be able to understand the basics of negotiation theory and have sufficient competencies to lead in such situations. Negotiation plays an important role in resolving claims, preventing disputes, and keeping a harmonious relationship among project participants. The construction sector represents one of the most dynamic and complex industrial environments where conflicts among builders and owners are very common particularly in a bidding or claiming situation where owners, builders and contractors pursue their own interests at the expense of the others, leading to conflict or cooperation. The time required to complete the project is usually greater than the time specified in the contract and, because of the overriding importance of time for both the owner and the contractor, delays are the source of frequent disputes and claims among owners, clients and consultants, leading to lawsuits. There is a general consent between theorists that Game theory provides, by its very nature, the appropriate tools for the analysis and eventual solution of conflicts of any kind. The course of a conflict as well as its resolution depends on the decisions made by the various actors involved. Each party, when considering its decisions, should take into account the decisions made by all the other parties. Game theory is a natural tool that can be used in such interactive situations where the results of the interaction depend on all the players' decisions.

Using the model presented in this paper, a wide variety of project situations can be modelled and placed as contractual obligations when drafting the contract. For example, the contract could contain terms which ensure the maximum or minimum penalty that an activity and/or coalition can be held responsible for. This can be performed considering different values in the first and last terms of the constraints. For example, inequality (11) establishes that coalition (*H*) will be held responsible for at least 500 dollars (minimum) and no more than 2,500 dollars (maximum). If these values are replaced, the activity and/or coalition will be held responsible for an amount between the new maximum and minimum values. Limiting the period of delays can also be considered in the model by giving different values to the term $V(N)$ in the model. In the application presented in this paper, the maximum amount that a coalition can be held responsible for is the maximum delay of the project, 25 days ($12,500). By replacing this value, the period of delays can be limited to the specified value.

Who takes advantage of the delays is also possible to be represented in the model. This can be easily introduced, for example, setting the value of an imputation, x, equal to zero. This states that an activity, that forms a coalition with other activities, will not be held responsible for any delays caused by the coalition. The model is also able to represent situations where an activity and/or a coalition can be penalized more than others or situations where players (i.e., contractors or subcontractors) are encouraged to form coalitions. These situations can be considered through the introduction of coefficients in the model equations, both in the objective function or in the constraints. In the objective function, if the coefficient of a variable (activity and/or coalition) is greater (less) than the unity, the corresponding activity and/or coalition will be less (more) penalized than the rest of the activities. Similarly, contractors and subcontractors can be encouraged to form coalitions using these coefficients in the constraints of the model. The greater (less) the coefficient, the more (less) encouraged the contractors are, since they will be less (more) penalized than the rest of the contractors. Many other types of situations can be modelled using the model presented in this paper. The number of variables, equations, and inequalities needed to model these real-life situations will depend on the complexity of the problem.

In order to increase the attractiveness of game theory for decision support in construction project management, the limitations of the model presented must also be mentioned. In game theory all players are assumed to be rational, try to maximize their own utilities, and have complete information on the payoff function and utility function. The assumption that players are perfectly rational may never match a real-life situation in a construction project. Recent developments in game theory pay more attention to the behavioural aspects of the players including bounded rationality, emotions, and intuitive decision-making. Behavioural theory focuses on the complex human factors of negotiation trying to analyse the negotiation processes in which negotiators influence each other's expectations, perceptions, assessments, and decisions during the search for an outcome. Initially, game theory assumes that the players possess complete information about the strategies and payoff functions of the other players. Unfortunately, in practice this is not the case. To overcome this limitation, games with incomplete, imperfect or asymmetric information are studied more and more.

Classical game theory assumes that each player decides in advance, before the game actually starts, what move he/she will make to maximize his/her own gain in any possible situation. However, the superlative rationality paradigm may not be the best one. Players tend to classify units as good enough or not good enough in terms of their positive attributes (benefit) and their negative attributes (cost) with regard to the evaluation goal. Satisfying game theory is an approach that evaluates alternatives on a bipolar basis introducing supporting and rejecting options in terms of two measures, selectability and rejectability.

The example used in this paper to demonstrate the validity of the model is rather simple. When dealing with real project networks which may contain hundreds of interrelated activities, two main approaches have been proposed in order to transform complex networks into simpler and more synthetic networks. The method of modular decomposition, based on the identification of modules that can be synthetized by equivalent macro-activities, and the method of network reduction based on three different types of reduction, series, parallel and node reduction. Aggregation of project networks using these types of methods, can help to transform complex networks into simpler and more synthetic networks.

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Biographical notes

José Ramón San Cristóbal

Dr San Cristóbal has been a teacher at the University of Cantabria, Spain, since 1998. He obtained his PhD in 2004 and leads the Project Management Research Group at the University of Cantabria. His area of work management science/operations research in general, applied to several fields. His research has focused on fields such as project management, input/output and natural resources; investment criteria and cogeneration plants; linear programming models and environment; multi-criteria analysis in renewable energies. He has authored many papers and two books.

www.shortbio.net/jose.sancristobal@unican.es