Organizational structure of construction entities based on the cooperative game theory

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Abstract

In the ever changing marketplace where construction entities are either competing or cooperating, the chance to achieve a higher gain boosts up once the players in the market understand the rules. Game theory as a recognized mathematical set of principles evaluates the competition and cooperation between intelligent, rational decision-makers. Competitive, AKA, noncooperative game theory as one of the main branches of game theory, studies the likelihood of the outcomes and behaviours of decision makers in a set of rules based on outsmarting other players by considering their objectives, behavioural characteristics, and possible countermoves. The players in this game set are those who give priority to their own personal objectives and achievements. On the other hand, cooperative game theory, as the foundation to most of the unicorns in the market place, deals with the interaction of players who has the public benefit as their objective. It provides valuable insight for the adoption of various strategies in order to utilize the resource-sharing and also lays a fair foundation so that players could benefit from the outcome. A survey had been conducted in this study to identify the importance of 4 major departments in a construction company. The principles of cooperative game theory, then, had been imposed on the data collected.

Keywords

Introduction

Game theory is being considered as a useful strategic framework to pinpoint various aspects of construction projects [1]. As opposed to competitive game theory where market players tend to outsmart each other, the cooperative game theory aims to form a coalition where the primary unit of decision making performs a collaborative behaviour. The cooperative game theory focuses on the resulting collective payoffs by considering the value that each department contributes to the organization. Cooperative game theory enables the investigation on joint resource management through alliancing in construction projects. On this foundation, an individual department can identify the possible coalition that can be formed in order to increase the mutual benefits and also decide on how to distribute the generated wealth fairly and efficiently amongst the members [2].

In the mathematical terms, if N represents the grand coalition that contains all of the role makers (individuals in departments), subset S (S ⊆ N) represents a possible permutation of alliances formed by individuals in departments. v is the characteristic function that assigns the value or worth v (S) to each possible coalition. In an n-player cooperative game, the allocation [x(1), x(2), x(3), … , x(i), … , x(n)] is a fair and efficient way of distributing the generated wealth resulted from the coalition amongst the players. In other words, x(i) is the player i's payoff. A cooperative strategic solution is based on the following axioms [Eqs. 1-3]:

(1) $\sum_{i \in N} x(i) = v(N)$

(2) $x(i) \geq v(i), \quad \forall i \in N$

(3) $\sum_{i \in N} x(i) \geq v(S), \quad \forall S \subseteq N$

Equation (1) basically indicates that a set of rational decision makers in an organization will form a coalition where to sum of individual payoffs adds up to the value of the grand coalition. Equation (2) requires that the payoff for any individual would be greater than what they have initially invested. And also equation (3) indicates that the sum of cooperative allocations to any coalition S to be greater than the total obtainable gains under any coalition that includes the same players. As a summary, the core of the game C(v) is as followed:

$$C(v): \{x \in R^n \mid \sum_{i \in N} x(i) = v(N), \text{and} \sum_{i \in N} x(i) \geq v(S), \forall S \subseteq N\}$$

The allocations that do not belong to the core are potentially not acceptable by players or coalitions. The above equation also states that if the core of a cooperative game is nonempty, there's a chance for cooperation. After the core had been formed, the challenge facing the strategic planners is the definition of fairness. Various notion of fairness had been proposed claiming the fairness in the allocation of wealth amongst the coalitions: *Nash-Harsanyi Bargaining Solution (Harsanyi 1959,1963), Nucleolus (Schmeidler 1969), Shapley Value (Shapley 1953)*. Amongst these three famous approaches, Shapley had attracted most of the attentions.

In this study, a brief introduction to the body of 4 major departments namely IT department, Human Resources department, Finance and Accounting department, and Marketing department had been provided followed by their set objectives. Survey results on the importance of each of the aforementioned departments is an indication on the characteristic function in the cooperative game theory. It is important to be noted that the combination of the department as a new formation of an alliance had not been evaluated for the sake of this study and it is encouraged to be done in the next step of this research. The participants in this survey are all high level educated construction practitioners with more than 8 years of experience in this industry.

Information Technology Department

It is widely accepted that IT had become a key element of any progressive business structure including entities within the construction industry. Relying on the size of the business, the number of features employed from the computer based functions varies. This normally reflects a higher complexity in the network structure in large businesses and relatively a simple network structure in small businesses [3]. Due to the high fragmentation of skills required to accomplish a construction project ranging from piping, concreting, formworking, earthworks, and so on, the productivity level in this particular sector of the economy is known to be amongst the lowest [4]. One of the recognized reasons for the low degree of productivity had been identified as the lack of effective communication; and the solution for that is suggested to be the implementation of IT services in the organizational structure of the entity. This not only increases the productivity level but also compromises the trending utilization of robotics in variety of construction practices including green building design[5, 6]. The use of IT services, in fact, improves the quality of collaboration and cooperation between the subcontractors, leading to a better communication practice. Another areas subject to improvement followed by the utilization of IT service in the construction firms are better financial control, less number of errors in documentation, a simpler and faster access to common data. Integrated Project Delivery (IPD) had laid the foundation for the use of internet based communication system which ultimately allows a greater information collaboration between the project participants [7].
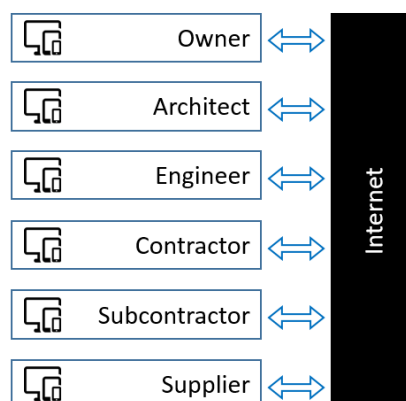
Figure 1 The interaction of construction project participants and internet based management system

Another important factor that affects the outcomes from the utilization of IT services in construction is the flow of information. In other words, it is crucial to identify the producer and user of the information. In the modern context of the construction, participants are either human or robot. There are 3 unique permutations exist from the combination of these two participants:

1. Communication between human and human on the internet infrastructure
2. Communication between human and robot on the internet infrastructure
3. Communication between robot and robot on the internet infrastructure (IoT)The

The above permutation becomes significant when the communication language comes into consideration.

The main objectives of IT department briefly are facilitating the fast communication between the employees and departments, developing and deployment of functional software's, and maintaining the quality of the services.

Human Resources Department

Despite all of the improvements and advancements in the computer and robotic related technologies, it is still humans that form the majority of managerial strategies. It is known that once the human resources management strategies have been established, those configurations guide employee behaviour and as a result a considerable level of the entity's performance. Higher organizational performance is resulted from a higher productivity, greater cost effectiveness and greater overall efficiency [8]. Precisely in the construction industry with its dynamic nature, the allocation of human resources plays a crucial role in the productivity level of the project [9]. Considering the livelihood of the modern construction industry in the current era where data is available instantly at the tip of the fingers on the mobile phones, the traditional concept of human resources management had undergone tremendous changes. It is required to re-evaluate the main duties of human resources department under the current changes in terms of recruitment, talent training, talent assessment, and remuneration [10].

The main objectives of the human resources department are usually set as high satisfaction rate (work-life balance), longer career in the industry, increased value in increased wages, and positive group interactions.

Finance and Accounting Department

Public-private partnership (PPP) as the most popular means of financing the construction in the recent years enables the project completion throughout collaboration between a government body and a private-sector. This model of financing the construction projects allows the completion of the task in a sooner period and also associate a lower level of risk. PPP is beneficial to both public and private parties in a sense that the private sector would

provide its technological and innovative services which helps the public sector through improving operational efficiency. The private sector also benefits in this type of partnership with the financial support given by the public sector which ultimately leads to a lower level of risk. On the other flip of the coin, the disadvantage of this model becomes bold in large infrastructure developments. If the project is not delivered on time and within the budget, or has technical defects, the private partner usually bears the burden[11-13].

Regardless of the size of the entity, financial management had been always a crucial part of construction. The main objective of the finance and accounting department is to provide sufficient access to funds by considering the project timetable. It is also responsible to ensure the savings and the profit margin throughout the time.

Marketing Department

One of the major challenges facing the modern construction industry is the high level of competitiveness and high associated risk specially in the large complex construction projects [14]. Rapid changes in project procurement and advances in technology all together highlights the importance of effective marketing strategy which would guarantee the success of a construction firm. Marketing is known as a tool that creates value in the market place [15]. In a managerial context, marketing is seen as central function crossing all internal and external boundaries [16]. Due to the large scale of the projects compared to other products and services delivered in other industries the construction industry is highly customized based on the client's demand. Thus, it is crucial to outline the areas in which the construction manager should put more emphasis on. One of the special characteristics in the construction industry is that it provides both tangible goods and intangible services[17]. Examples of tangible goods being provided are construction materials e.g. cement, steel, aggregate, superplasticizers, etc. Construction tools and machineries can also be categorized as tangible goods. On the other side, consultancies, builder's performance, design, tendering, etc. are amongst the examples of intangible services that are being provided in the construction industry. Based on this classification of businesses operating in the construction industry, the manager must be aware of the suitable different strategies to be deployed in order to maximize the firm's gain along with the customer's satisfaction.

Marketing mix, also referred to as 4Ps, had been introduced by McCarthy in 1979 [18] as a means of translating the marketing plans into practice. The so called 4Ps stand for price, product, promotion, and place. Rather than being a thorough scientific theory, marketing mix is a conceptual framework that configures the offer to match the consumer's need. Depending on the context of the marketplace and circumstances the manager may decide to vary the proportion of the mix in accordance [19]. In a competitive marketplace with a certain demand for a particular good or service (in our case construction industry), the first P, price, is an important factor in the customer's decision making process. It does not necessarily indicate that a cheaper price has advantage over the one with a higher price, but it relies closely on other factors such as brand positioning, brand loyalty, scarceness of the offer, etc. Product (or

service) refers to the promise made by the business entity throughout the medium of exchange. One of the key considerations in that regard which affects the ultimate marketing strategy is the nature of the product being delivered in terms of tangibility. It is known for a fact that even service based business models are better to deliver at least one form of a tangible good upon their offer in order to increase the possibility of sale. Promotion, as the third P emphasises on the significance of means of delivering the marketing message whether can be a television ad, brochure, phone call, etc. This depends a lot on the type of product that the construction firm delivers. Usually service based businesses are utilizing face-to-face conversation with the client to describe the benefits of the service. Place as the last P in the mix, notes the location where trade happens i.e. for a restaurant that's a saloon, for an online retailer that's via the internet, and for our case in construction, is the job site[19-22].

Overall, upon the development of the marketing strategic plan in regards to the 4Ps, the construction firm needs to consider the client's decision making process so that the mix proportion would be designed optimum. The process typically falls into 5 stages as followed:

1. Need recognition
2. Information search
3. Evaluation of alternatives
4. Purchase decision
5. Post purchase behaviour

Surveys and Game Theory

14 questionaries had been collected upon this study with the participants being highly educated construction practitioners. Consent had been given for the use and publication of the data received. The following list of questions were subject to this survey where the participants were asked to rate the importance from a range of 0-100 arbitrary units:

- How do you rate the importance of IT department in an organization?
- How do you rate the importance of Human Resources Department in an organization?
- How do you rate the importance of Finance and Accounting department in an organization?
- How do you rate the importance of Marketing department in an organization?

The average of the scores given is summarized in the following table 1:

Table 1 The average of the questionnaires responses in regards to the importance of organizational departments

	IT	Human Resources	Finance and Accounting	Marketing
Average response	87.38	76.84	82.46	73.77

Now the question is, what values do we get if departments form a coalition two by two? Three by three? And as a whole? By definition, interest rate is the expectation of market from the turnover on the initial amount invested. The correlation of risk and interest rate is in such a way that once the investor/borrower identifies a high risk associated with the tasks, the interest rate typically rises as a consequence. For the case of this study, it can be said that once the number of sub-coalitions increases the total risk will be divided across a greater number of players/departments. Thus, lower risk and lower interest rate is anticipated. The data collected from the surveys indicates the x(i) in equation 1 introduced in the introduction. In order to outline a logical output/payoff for the coalition of the 4 departments a fix interest rate had been applied to the sum of individual payoffs.

According to the reports obtained from the Reserve Bank of Australia the interest rate in the Australian market had been 1.5% constant since August 2016 until May 2019.
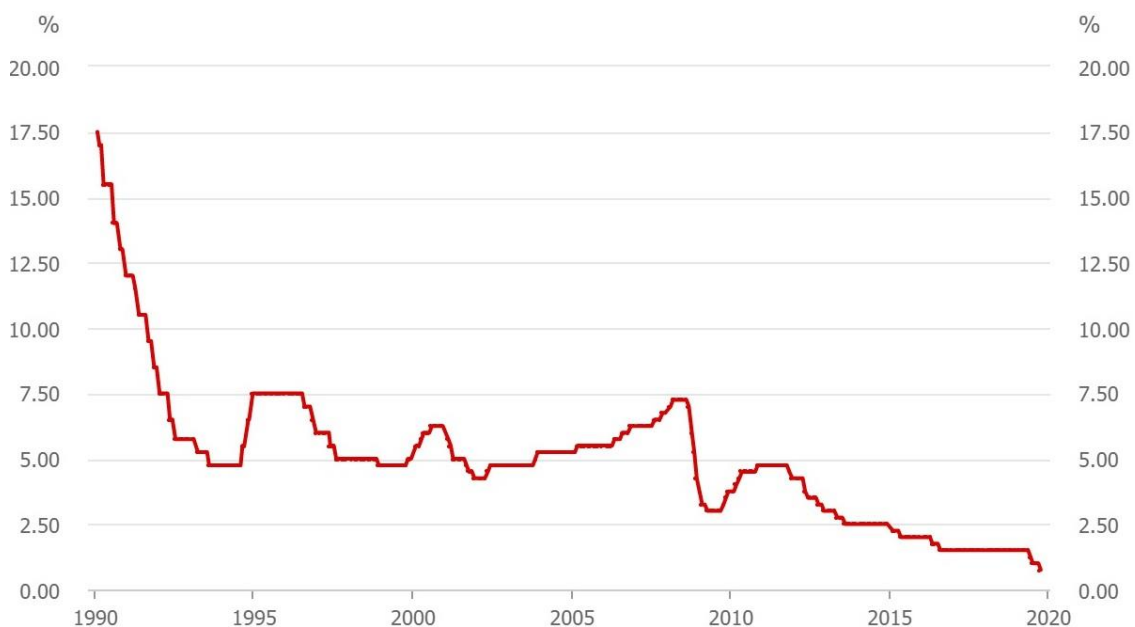
Figure 2 The Australian cash rate throughout the history as the indicator to understand the payoff values in the Shapley model

Assuming 1.5% applicable to the payoff values in the cooperative game theory of this case study the payoff values are produced using the following Shapley equation:

$$x(i) = \sum_{S \subseteq N\{i\}} \frac{s!\,(n - s - 1)!}{n!} M(i, S), \quad s = |S|$$

Let the payoffs be defined as followed:

IT payoff = {1} = 87.38

Human resources payoff = {2} = 76.84

Finance and Accounting payoff = {3} = 82.46

Marketing = {4} = 73.77

{1,2} = 166.68; {1,3} = 172.39 {1,4} = 163.57; {2,3} = 161.69; {2,4} = 152.87; {3,4} = 158.57

{1,2,3} = 250.38;   {1,2,4} = 241.56;   {1,3,4} = 247.26;   {2,3,4} = 236.57

{1,2,3,4} = 325.26

The Shapley values, or in other words the fair portion of distribution for the wealth generated as the result of the grand coalition are as presented in table 2:

Table 2 Produced Shapley values based on the cooperative game theory

	IT	Human Resources	Finance and Accounting	Marketing
Shapley value	88.33	78	83.5	75.16

Conclusion

The fair distribution of wealth as a result of a grand coalition of four major departments in a construction firm had been identified based on the data collected in the surveys. The results show that in a modern context of a construction firm the IT department plays the most important role followed by the Finance department in the second place. It is interesting since a highly labour intensive industry as construction had voted for the importance of Human Resources department in the third place. The influence of robotics in construction had been once again emphasised as the result of this study. It is recommended for the newly established large construction entities to invest and distribute the wealth in accordance with the data provided.

Acknowledgement

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