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A parallel multi-objective scatter search for optimising incentive contract design in projects

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ABSTRACT

We present a novel optimisation approach for incentive contract design within a project setting. the structure of the remuneration is one of the key challenges faced by the project owner when (s)he decides to hire a contractor. The proposed technique builds on the recently proposed contract design methodology by Kerkhove and Vanhoucke (Omega, 2015). Specifically, a novel multi-objective scatter search heuristic is proposed and implemented using parallelisation. Both single- and multi-population implementations of this heuristic are compared to the original full-factorial approach as well as commercial optimisation software. The results of the computational experiments indicate that the single-population parallel scatter search procedure significantly outperforms the other solution strategies in terms of both speed and solution quality.

1. Introduction

We present a novel technique to optimise the structure of the incentivised contractual agreement between the project owner and the contractor who executes the project. The goal of this technique is to optimise the contract from the perspective of the contractor, maximising the expected value of the owner and the alignment of the motivation of both actors, preventing conflicts of interest that can potentially result in suboptimal results for the project owner (Müller & Turner, 2005; Turner, 2004).

Because the delegation of a complete project to a contractor is a highly complex undertaking, an explicit contract which contains all the deliverables, as well as the remuneration for the contractor in sufficient detail is impractical (Van Weele & van der Puil, 2013). The best alternative for such a high-complexity environment is an alliance between the two economic actors, effectively forming a single actor for the duration of the project (Rose & Manley, 2011; Walker, Hampson, & Peters, 2002). However, the fugitive nature which is inherent to a project often causes the substantial investment required by both parties to create such a partnership to be disproportionate to the expected returns of the project. Because of this, contracts that use incentive clauses are often used as a viable middle ground between an explicit contract and a partnership of the two actors (Bower, Ashby, Gerald, & Smyk, 2002).

Investigating, and by extension optimising, such contract structures requires a systematic view on the relationship between the *owner* of the project, and the *contractor* who is responsible for executing the project. To do this, the framework proposed by Kerkhove and Vanhoucke (2017) is used in this research. This framework consists of three components, the first of which is the *contract model*, which describes the nature of the incentive clauses and targets which are set in a specific agreement. These incentive clauses are linked to the three outcome dimensions which are traditionally used in project management literature: cost, duration and scope (Marques, Gourc, & Lauras, 2011). The second component of this framework is the *trade-off model*, which is used to represent the nature of the project itself as a set of discrete trade-off points. Specifically, these trade-offs strike a balance between the three traditional outcome dimensions, as well as the effort investment made by the contractor who executes the project. The third and final component of the framework is the *evaluation model*, which is used to calculate the value of a specific outcome of the project, given the use of a specific contract. The dynamic of the complete framework considers the owner of the project to be in full control of the contract model, effectively deciding which contract structure will be used to govern the project. Similarly, the contractor controls the choice of a trade-off point, representing her/his control over the manner in which the project is executed. The precise dynamic of this model will be discussed in further detail in Section 3.

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Where Kerkhove and Vanhoucke (2017) used a brute-force enumeration approach to search for the optimal contract structure, the main objective of this research is the design of a meta-heuristic optimisation procedure that can be used by the owner of a project in order to maximise her/his profits as well as the degree to which the motivations of both parties are aligned. As such, this research departs from existing literature (see Section 2) because of its proactive and prescriptive nature, whereas the majority of existing research has focussed on the types of contracts used in practice, as well as their perceived effectiveness.

To achieve this goal, a multi-objective scatter search is designed and tested on a set of problem instances. This type of heuristic is highly suitable to deal with the complex solution space created by the wide range of possible contract structures. The reason for this being the inherent mechanisms of the scatter search procedure which conserve diversity in the solution population. The experiments show that the performance of this heuristic significantly exceeds that of a brute force approach which attempts to scan a broad area of solution space (see Section 7).

The key difference between the work presented in this paper and the earlier work by Kerkhove and Vanhoucke (2017) is that this research aims to provide answers for project-specific scenarios rather than generalisable managerial guidelines. Effectively, rather than specifying that specific types of incentive clauses and their combinations are to be preferred over others, the techniques presented in this research provide an answer to the question which specific combination of incentive clauses is most effective for a specific project. Moreover, this is not limited to the type of incentive clause, but also includes the specific parameters that are to be used for these incentive clauses.

The main contribution of this research is that it provides a tool to optimise both contract structure and contract parameters for case-specific contracts. It does so by introducing a scatter search algorithm that is tailored to the specifics of the contract design problem, namely the joint selection of the contract structure and the parameters used within the aforementioned structure. This departs from the majority of existing literature on contracts which is mainly limited to a descriptive rather than prescriptive analysis of incentive contracts in projects.

The remainder of the paper is structured as follows: Section 2 gives an overview of the existing literature on incentive contracting, as well as multi-objective optimisation techniques. Next, the modelling approach which is used to describe the problem is discussed in greater detail in Section 3. The dynamic of this model is further illustrated using a small-scale example in Section 4. Next, the parallel multi-objective scatter search (*MOSS*) is described in Sections 5 and 6. Finally, the computational experiments are discussed in Section 7 prior to formulating a general conclusion of the research in Section 8.

2. Literature

2.1. Project trade-offs

One of the key facets of managing projects is determining the right trade-off between different outcome dimensions. The representation of these relationships has evolved from a simple linear relationship between the cost and duration of a project (Kelley & Walker, 1959) to more complex convex relationships between multiple dimensions (Ghodsi, Skandari, Allahverdiloo, & Iranmanesh, 2009). Since the nature of these trade-offs is of course important to the incentive clauses that hope to influence the balance chosen in this dynamic, a large number of authors has spent time investigating the trade-offs in this contex (Arditi & Yasamis, 1998; Broome & Perry, 2002; Chan, Chan, Lam, & Wong, 2011a; Choi & Kwak, 2012; Choi, Kwak, & Yu, 2010; Jaafari, 1996; Lee & Thomas, 2007; Mackley, 2012; Shr, Ran, & Sung, 2004; Shr & Chen, 2003; Sillars, 2007; Stenbeck, 2008).

Analogously to the model proposed by Kerkhove and Vanhoucke (2017), this research uses a set of discrete multidimensional points to represent the trade-off decision. This accurately reflects realistic situations where more often than not the options are discrete rather than continuous (e.g. selecting a specific type of machine to use). Moreover, this has the advantage that no inherent assumptions have to be made as to the underlying dynamic of these trade-offs. Hence, the methodology can be used regardless of the assumptions that are made. Four different dimensions are distinguished for each of the discrete trade-off points: the cost (C), duration (D), scope (S) and the contractor effort (E). The cost dimension represents the cost to the project owner (not the contractor), meaning it only includes things such as material costs which are directly billed to the project owner. The duration of the project represents the time at which all the deliverables required by the owner have been delivered. Scope is defined in the broadest possible sense as the amount of valuable work performed by the contractor, including things such as the performance of the finalised product, as well as safety requirements, satisfying environmental restrictions and all other aspects which have a direct relevance to the owner of the project. This definition also implies that if performing more work destroys value for the project owner, this is regarded as a decrease rather than an increase in scope. The former three dimensions constitute the traditional *'iron triangle'* (Marques et al., 2011). In the context of this research it is assumed that these three dimensions reflect the outcome of the project as it is perceived by the owner of the project, including all potentially relevant aspects and no aspects which are irrelevant to the owner's utility derived from the complete project. A fourth dimension is used to reflect the effort exerted by the contractor (E), which represents the actions taken by the contractor that improve the performance of the project - as expressed by the former three dimensions – but which are not directly relevant to the owner of the project. Although nomenclature differs across authors many examples of contractor effort can be found in literature (Abu-Hijleh & Ibbs, 1989; Arditi & Yasamis, 1998; Bayiz & Corbett, 2005; Chapman & Ward, 1994; Choi & Kwak, 2012; El-Rayes, 2001; El-Rayes & Kandil, 2005; Kandil & El-Rayes, 2006; Lee & Thomas, 2007; Lippman, McCardle, & Tang, 2013; Sillars, 2007). The most straightforward example of contractor effort is the amount of managerial attention allocated to the project, a greater amount of management will increase the performance of the project, but naturally comes at a certain cost to the contractor who is incapable of allocating this scarce resource to other projects in her/his portfolio. Another example can be the allocation of additional employees to the project in a situation where the wages of the contractor's employees are not directly billed to the owner of the project. Note that if the wages of the contractor's employees are directly billed to the owner of the project increasing the number of employees assigned to the project would inflate the cost (C) of the contractor and would therefore not be seen as an effort investment by the contractor. The effects of a higher effort level can be observed in one or more of the three traditional outcome dimensions as a reduced cost (C) and/or a decreased duration (D) and/or an increased scope (S).

2.2. Incentives for projects

A contract between a project owner and a contractor can have a very large number of commercial and legal clauses to which the parties commit. The scope of this research is limited to the clauses which specify the remuneration of the contractor depending on the outcome of the project. These clauses can be categorised