DESIGNING A DYNAMIC NETWORK BASED APPROACH FOR ASSET MANAGEMENT ACTIVITIES

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Transportation networks are important public infrastructures because they enable economic and social activity. Trends in contracting the maintenance of such assets have caused a shift in governance from a public body to market-like arrangements and changed the roles and responsibilities among asset owner, asset manager and service providers. Basic assumption of this research is that collaboration between contractors in road infrastructure is needed and can be stimulated through facilitating joint coordination on a network level, based on a social costs incentive. Based on a literature review design components and possible techniques are identified. Then the concept design and testing methods for a dynamic network-based tool to facilitate strategic infrastructure asset management is proposed.

Keywords: asset management, collaboration, procurement, scheduling, serious gaming.

INTRODUCTION

Infrastructures represent long enduring and shared resources that are used by different actors. Compared to other kinds of assets, infrastructure has specific characteristics, such as a very long lifespan of assets with no resale value and little administration over the current status, consisting of a widely distributed evolutionary networked system with passive elements that requires dynamic and flexible design. Consequently managing infrastructure assets often faces complex uncertainties that are often more compound that those found in other forms of asset management (Altamirano 2010).

Ever since the increase in maintenance of current infrastructure and the growing lack of financial means of governmental bodies, the interest in strategic asset management in the field of infrastructure is increasing (Moon *et al.* 2009, Schraven, Hartmann and Dewulf 2011). The Institute of Asset Management (2011) defines asset management (AM) as ‘systematic and coordinated activities and practices through which an organization optimally and sustainably manages its assets and asset systems, their

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associated performance, risks and expenditures over their life cycles for the purpose of achieving its organizational strategic plan'. The most important actors in AM are the asset owner (e.g. the national government), the asset manager (e.g. the National Highway Agency), and the service provider; a contractor or professional service firm that provides the maintenance and other kinds of construction work.

The main issues in current contracts can be related to their more static nature; contracts are commonly fixed at the beginning of a project and are not sufficiently capable of adapting to changes. Especially in long-term projects, where a lot of (unforeseen) changes occur, current contracts are hardly adequate to ensure a successful result. Moreover, the network aspect of infrastructural maintenance is commonly neglected in current contracting procedures, thereby failing to work towards system optimal asset management.

Due to the fact that individual infrastructure assets such as road segments, are connected in a network structure, a disruption in one part influences the load in another part. Consequently maintenance often leads to a lower overall network performance. Furthermore, the size of the network requires the involvement of a number of service providers. Until now these service providers hardly collaborate since the asset manager centrally coordinates their activities on the network.

This research explores the possibilities of self-regulating this process in order to increase the network performance in a dynamic contracting approach. It is argued that the execution of long-term performance-based road maintenance contracts may benefit greatly from addressing this issue of self-regulation on a network level already in the procurement phase, with a view to the implementation phase. Basic assumption is that collaboration between contractors and awareness about social costs of maintenance in infrastructure is needed and can be stimulated through incentives.

This paper lays out the components of such dynamic contracting and planning concept for asset management activities. We present the design approach for a strategic procurement and planning tool that will facilitate this complicated, uncertain and dynamic process. Based on a literature review the current gaps in theory and practice are identified, a concept for a network-based tool for dynamic planning in asset management is proposed and possible model and simulation techniques for our work are outlined.

One way of characterizing governance strategies sprouts from organization and management studies: contractual governance strategies and relational governance strategies (Poppo, Zheng Zhou and Zenger 2008). Contractual governance can be defined as an established formal, legal, and economic governance strategy; relational governance refers to the developing strength of the social norms present in the exchange and has often been referred to as relationalism (Vandaele *et al.* 2007). Relational governance usually employs a positive link with contractual governance.

This is also confirmed by Eriksson and Westerberg (2011), who claim that construction collaboration is enhanced by the mediating role of joint specification, selected tendering, soft parameters in bid evaluation, joint subcontractor selection, incentive based payment, collaborative tools and contractors self-control in the procurement phase. The moderating role of cooperative procurement procedures is fed by the fact that: existing partnering agreements facilitate joint specification in concurrent engineering; long-term collaboration with a few competent contractors decreases the risk of unsuccessful partner selection; trust based collaboration facilitates the design and use of an effective incentive scheme; and contractor self-control is based on concern for the client and therefore facilitated by long-term collaborative relationships.

In the development of our dynamic contracting concept five major factors are therefore identified that play an important role: performance based contracting, social costs, incentives, trust, and past performance. These are discussed in the next sections.

Performance based contracting

In the past two or three decades we have witnessed a considerable change in the procurement and realisation of infrastructural maintenance projects. The introduction of Public-Private Partnerships (PPP) in the late 70s and early 80s has resulted in more innovative, risk-sharing contract forms, adopted by governments and public institutions world-wide (Altamirano 2010). Indeed such contracts are expected to offer various benefits over the more 'classical' regulatory contract - contract approaches that are based on controlling contractors by regulation - such as increased flexibility, more innovation, better performance, and subsequently lower costs.

These benefits, however, are accompanied by a higher level of uncertainty and introduce additional possibilities for opportunistic behaviour. Particularly in the long-term, performance based contracts these undesired effects are likely to arise, resulting in unsatisfactory results or even total failures (O'hare, Leone and Zegans 1990). Moreover, performance based contracts allow for a greater degree of freedom in project implementation. This freedom could result in innovations but could also lead to a misalignment in the objectives of both parties: public institutions seek to optimise social welfare whereas contractors are focussed only on profit. These different interests frequently give rise to conflict, a problem identified already in earlier work on buyer-supplier relationships (Pigou 1912, Jensen and Meckling 1976).

Social costs

Although it is widely acknowledged that the network user has a key part in asset management, its role is commonly neglected or minimised in current contracting procedures (Brown and Humphrey 2005). The overall costs to users can be considered as a kind of social costs (Coase 1960). By incorporating social costs into the contract, contractors can be made aware of the consequences of maintenance on users. From an economic perspective one could argue that actions that hurt society most should cost a contractor more money, allowing the contractor to make their own planning trade-offs. Secondly, sharing of social cost can be introduced to stimulate contractor co-operation in planning correlated activities. This is an opportunity that has not been present in contracting procedures before, and is of important value in our research approach.

Incentive mechanisms

Bower *et al.* (2002) distinguish three main types of incentives in construction: share of cost saving incentives between client and contractor, schedule incentives with a premium for early completion, and technical performance bonuses for meeting other performance targets. The work of Bresnen and Marshall (2000) is based on motivation theories from management and organizational theory, and demonstrates that attitudes towards gain share-pain share arrangements were found to be quite positive and useful in reinforcing collaboration. Yet, other intrinsic and extrinsic sources such as autonomy and the prospect of further work, and the relationship between client and contractor were much more important to the companies and staff members.

The general principles upon which incentive systems should be based include the need to ensure that risks and rewards are commensurably and fairly distributed among the parties concerned and that they are tailored to specific project objectives (Bresnen and Marshall 2000). Rose and Manley (2011) emphasize the need for a procurement strategy that encourages trust, unity, and fairness in project team interactions in addition to financial incentives. They developed and tested four motivation indicators for project success in four large construction cases: goal commitment, distributive justice, process fairness, and interactional justice. It was, amongst others, concluded that financial incentive mechanism design should incorporate flexibility to modify goals and measurement procedures over time, and that financial incentive mechanism benefits are maximized through equitable contract risk allocation, early contractor involvement in design, value-driven tender selection, relationship workshops, and future work opportunities.

Despite the overall believe that incentive mechanisms improve value for money during procurement and project performance during execution, empirical research is scarce (Rose and Manley 2011). For the dynamic contracting concept it will thus be a challenge to combine the best of both worlds and design a concept that meets the needs of the service providers and the asset managers.

Trust

The need for trust between organizations arises from the dependence risk in combination with a lack of control (Laan 2009). This is affected by performance which leads to a dynamic relationship between risk, control, trust, and performance. Trust research has identified three levels of trust: personal, organizational, and institutional trust.

There are three ways to influence trust and opportunistic behaviour (Nooteboom 2006): opportunity control (restriction by limiting the opportunities for action by a contract or hierarchical supervision); incentive control (discouragement by limiting the exploitation of opportunities through reliance on relationships, 'hostage' or reputation effects), and benevolence or goodwill (intrinsic motivation by limiting tendencies toward opportunism based on social norms or personal relations).

The results of a longitudinal study of Badenfelt (2010) indicate that the use of control mechanisms is part of a complex and dynamic socially constructed process that requires on-going discussion and evaluation, and to which informal control mechanisms are central. Even in trust-based collaborative settings, such as partnering arrangements, the contracting parties must pay attention to micro level informal and subtle trust-nurturing actions and control mechanisms. In a network context Klijn, Edelenbos and Steijn (2010) have found that a higher level of trust will lead to outcomes that actors in these networks perceive to be of higher quality. The level of trust will be higher when more network management strategies will be used.

Past performance

Because the selection process of parties takes place early in the project life cycle, it is perhaps one of the most critical undertakings with respect to performance by clients and in direct relation to the success of the project. In this context project success is often measured by the aspects of cost, time, quality, environmental impact, work environment and innovation (Doloi, Iyer and Sawhney 2011, Eriksson and Westerberg 2011). Despite the large interest in the effects of partner selection on project success, research results are still indistinct about the actual factors of influence.

On the one hand scholars aim at identifying a universal set of criteria or the development of decision support systems for contractor selection. For example, the Discrete Choice Experiment of Watt, Kayis and Willey (2010) revealed that past project performance and technical experience (and to lesser extent tendered price and project management expertise to a considerably) are considered to be the most important criteria for actual decision making in procurement situations. Factors that were found to be of considerable perceived importance in previous research, such as workload/capacity, client supplier relations, company standing and experience, seemed to make surprisingly little difference in the choice of a contractor.

On the other hand Doloi, Iyer and Sawhney (2011) have found that the overall project success mainly relies on the technical ability of the contractors in planning and controlling the project. According to their findings a contractor needs to be able to analyse the underlying challenges in execution – a competence which is strongly influenced by the soundness of business and workforce. In this sense performance would improve if contractors are free to plan their own activities.

CONCEPTUAL DESIGN OF DYNAMIC CONTRACTING

The aim of this research is to facilitate scheduling decisions of both the asset manager and the service providers to improve the overall network performance. By connecting a set of asset management activities to a group of service providers, the dynamics and flexibility of asset management is expected to increase while the quality of assets is expected to stabilize or increase on the stated level.

As described in the previous section five design elements have been identified that play an important role in collaboration and project success: performance based contracting, social costs, incentives, trust, and past performance. Initially the concept is developed for a road network and includes mainly schedule incentives based on traffic loss hours, and long term performance based contracts for a designated part of the network. This increases the autonomy and social awareness of the contractors. The level of trust is stimulated through the network based incentive structure. The concept will include a new kind of software which shows the planned activities of all contractors on the network, and supports the service providers in their strategic consideration by calculating all scheduling options available and the consequences for the overall revenues.

In overcoming the gap between strategic and operational issues of asset management, we propose an integrated contracting procedure, linking procurement to construction activities. In the procurement phase the boundaries of the network are defined. Based on the goals and demands specified by the asset manager, the network is divided in segments which are put up for tender. In addition a pricing scheme is announced that captures the social costs of maintenance. The market – i.e. service providers – can submit offers for segments of the road network, basing their prices on the expected cost of maintenance (both their private and social costs in traffic loss hours) given the asset demands. As a result of this phase a group of service providers will be identified, each responsible for a part of the infrastructure, and a set of asset demands and a pricing mechanism that corresponds to the offered prices incorporating the social cost charges. Note that in this phase no actual maintenance plans are developed.

The resulting contract from the procurement phase is used to define the boundaries of the subsequent execution phase in which the actual scheduling of the construction activities is performed. It is now up to the service providers to identify the maintenance activities that should be performed on their own part of the network and develop a joint, socially (near) optimal schedule for these activities. As we are dealing with long-term contracting in a contingent environment, we propose a periodical scheduling approach. Using one plan for the entire contract duration is unrealistic; infrastructural maintenance is vulnerable to unexpected delays, possibly affecting the entire schedule (Altamirano 2010).

In the dynamic contracting concept for road maintenance the asset user is represented by including the social cost of maintenance in traffic loss hours, which depend on the scheduled maintenance activities over the entire network. Service providers are charged payments relative to their share of the social cost. So causing more congestion on the network means a larger social cost payment. An additional major challenge of this kind of payment is that it implicitly creates dependence between service providers, as the social costs are computed over the joint maintenance plan. The assumption is that by using our social cost as an incentive, the most profitable outcome for the individual agents with the socially optimal outcome are aligned.

MODELLING DYNAMIC CONTRACTING

Because the dynamic contracting model involves social aspects and technical characteristics, we will make use of the insights from organisation science (see previous section) and combine this with more traditional theories and methods such as game theory (Camerer 2003) and mechanism design (Nisan 2007). This enables modelling the system from both the perspectives of the asset manager and service providers, and take the life cycle perspective of assets into account while designing the desired incentives. As mentioned before the concept consists of two parts: procurement of the responsibilities and scheduling of the construction activities. In this section the technical details of the contracting and scheduling model are introduced.

Procuring network based activities

In the procurement phase of the contracting procedure the entire network is procured, allowing service providers to bid on combinations of network segments. Of course, the value for such a combination depends greatly on the segments it consists of. Service providers are most likely more interested in a set of ‘related’ network parts than a random set, for instance because this offers logistical advantages. To capture this ‘added-value’ for related parts, a Combinatorial Auction (CA) is employed to procure (Cramton, Shoham and Steinberg 2006). More specifically, to also consider the multi-dimensional aspect of offers – price, quality, duration, etc. –a Multi-attribute Combinatorial Auction (MCA) is implemented (Suyama and Yokoo 2005, Yokoo, Matsutani and Iwasaki 2006).

In the approach of Müller, Perea and Wolf (2007), bids are scores produced using a publicly known scoring rule and contracting is done based upon that single score. The problem with this however, as also pointed out by Rieck (2011), is that when the scoring function is publicly known, bidders are no longer incentivised to produce multiple quality/price bids. As they contract on a score, they will settle on one (for them) optimal combination of the two. Transferring this to our dynamic contracting approach, the quality/price trade-off is done by the contractors themselves and not by the asset manager. For procurement of public infrastructure this is unacceptable: the asset manager should be able to make its own assessment of price and quality instead of contracting on a score. Therefore an Ausubel-Milgrom ascending price proxy auction will be used, where bids are composed of price/quality pairs instead of single scores (Rieck 2011). In this mechanism, bidders specify the minimum price for which they want to obtain the contract and a proxy-agent will iteratively bid decreasing (possible multiple) price/quality pairs that offer the potentially highest profit for that contracting in each round of the auction. If the potential profit becomes negative for a bidder (i.e. bid price minus minimum price) he refrains from further bids. The bidding is continued until no better offers, according to the asset manager's scoring rule, are made and for each bundle the bid with the best score is contracted.

Performing maintenance activities

For the next phase of the dynamic contracting model, support is provided for service providers to plan their maintenance activities, preferably in a cost-optimal way. However, a cost-optimal planning for a service provider most likely differs from a socially optimal planning. In the model these two objectives are aligned. Using a mechanism design approach an incentive structure is developed that creates a 'social awareness' at the service provider by showing them the congestion costs. One of the assumptions in the first stage of the concept development is that all service providers are rational agents. These assumptions will be testing and adjusted if needed in a later stage of the development.

Furthermore, the planning problem considers an infrastructural network as opposed to the more commonly encountered single-project asset management contracts. The social cost is computed over the entire network, taking into account all maintenance activity by all service providers. Each service provider is then charged a part of the social cost equivalent to their share of the additional cost they incur (e.g. extra traffic congestion). Therefore service provider revenues depend not only on their individual planning but also on the choices made by other contractors active within the same network. This dependency introduces an additional complexity in the planning of maintenance, as service providers have to co-operate in order to develop optimal joint plans.

To counter these drawbacks, we study a decentralised approach such as the one presented in Jonsson and Rovatsos (2011). Their Best-Response Planning (BRP) iteratively works towards an optimal outcome. In this procedure, service providers initially develop their plans individually, only considering their private cost. Then these plans are combined into a joint plan, which is subsequently improved in rounds. In each round of the BRP, service providers can improve the joint plan by rescheduling their own activities in a turn-based fashion. In contrast to the centralised approach, only the resulting plans have to be presented to the asset manager. Also, the computational complexity of the planning problem is reduced as we only consider a few options at each contractor's local problem. As a price for reduced computational complexity, this method is unlikely to achieve (near) optimal schedules.

TESTING THE CONCEPT

Validation of our dynamic contracting concept will be done in multiple modes of simulation: serious gaming and computer simulation. In both modes, the entire contract procedure will be simulated, although focussing on different aspects. Moreover, the computer simulation functions also as a prototype for the tool that facilitates the procedure.

In the computer simulation the dynamic contracting concept is played by computer agents. This allows us to run a very large number of experiments within a relatively short time, giving us the opportunity to verify different incentive mechanisms exhaustively. Nonetheless, the quality of the results depends largely on the quality of the input, i.e. traffic data, agent behaviour models. A substantial share of the effort of designing the simulator will therefore be put into acquisition of such data from practitioners and further literature.

In order to study the behaviour of contract partners we will use serious gaming as our research tool (Duke 1980, Axelrod 2003). Gaming has been used in a large number of studies, among others in asset management (Altamirano 2010), as it captures complex system behaviour by involving humans in the actual decision making process (Bekebrede 2010). Traditionally, economic theory (classic as well as new institutional economy) and mathematics would aim at representing human behaviour by means of rules or equations. By including games in our research we mean to get closer to capturing the actual behaviour of humans, even though there are shortcomings attached to gaming as well (Bekebrede 2010). For each of the phases of the concept (procurement and scheduling), a separate serious game will be developed.

The scheduling phase of maintenance activities for the complete road infrastructure network will be tested first. The procurement issues will follow in a later stage. In the first game, which is currently being developed, each player (service provider) is responsible for performing a portfolio of activities in a segment of the network within a period of three years. The individual profit of the service providers relies on the joint amount of congestion caused by these activities. Hence, the players need to collaborate to improve network performance and thus increase their profits. This will affect the level of collaboration and trust between the service providers.

The service providers are supported in this process by the scheduling tool as described in the previous section. The tool shows how the service providers can schedule their tasks and calculates the potential congestion on a network level. By designing different plays, the role of the asset manager on the self regulating mechanism, the role of the tool, and the level of trust between the players will be tested to see which conditions are beneficial for the success of the dynamic contracting concept. The results will be used to further develop and implement the tool in asset management practice.

CONCLUSION

The need for asset management maintenance will only increase in the next decade. This is a particular challenge in times of intensive use of infrastructure assets as a critical link in logistical supply chains, decreasing funds and increasing expected service levels from the users. The literature review shows that both financial and social incentives structures are needed to turn a dynamic contracting and scheduling concept into a success. This research contributes to the need for dynamic and network based maintenance activities by including social costs on a network level, connecting service providers in a new collaborative way.

It will be a challenge to combine the rational assumptions from game theory and auctioning methods perspective to the socially oriented empirical findings of construction research. Applying serious gaming methods opens up the possibilities to find the best of both worlds in testing a concept and a software tool in a protected environment. Explorative conversations with asset managers and service providers imply that a cultural change in construction is required to have a network based maintenance concept implemented. At the same time the potential of the concept for is well acknowledged. It could, for example, also be applied within the supply chain or facilitate multidisciplinary scheduling on the construction site. Since a lot of serious gaming also focuses on organizational learning and concepts can be adjusted to specific situation relatively easily, this research could contribute to these kinds of applications as well.

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REFERENCES

Altamirano, M A (2010) Innovative contracting practices in the road sector - cross-national lessons in dealing with opportunistic behaviour, Next Generation Infrastructures, Delft University of Technology.

Axelrod, R (2003) Advancing the art of simulation in the social sciences. Japanese Journal for Management Information System, Special Issue on Agent-Based Modeling, **12**, (3) 1-19.

Badenfelt, U (2010) I trust you, i trust you not: A longitudinal study of control mechanisms in incentive contracts. Construction Management and Economics, **28**(3), 301-10.

Bekebrede, G (2010) Experiencing complexity - a gaming approach for understanding infrastructure systems, Technology, Policy and Management, Delft University of Technology.

Bower, D, Ashby, G, Gerald, K and Smyk, W (2002) Incentive mechanisms for project success. Journal of Management in Engineering, **18**(1), 37–43.

Bresnen, M and Marshall, N (2000) Motivation, commitment and the use of incentives in partnerships and alliances. Construction Management and Economics, **18**(5), 587-98.

Brown, R E and Humphrey, B G (2005) Asset management for transmission and distribution. Power and Energy Magazine, IEEE, **3**(3), 39-45.

Camerer, C (2003) Behavioral game theory: Experiments in strategic interaction. Princeton University Press.

Coase, R H (1960) The problem of social cost. Wiley Online Library.

Cramton, P, Shoham, Y and Steinberg, R (2006) Introduction to combinatorial auctions. Cambridge: MIT Press.

Doloi, H, Iyer, K C and Sawhney, A (2011) Structural equation model for assessing impacts of contractor's performance on project success. International Journal of Project Management, **29**, 687-95.

Duke, R D (1980) An paradigm for game design. Simulation & games, 11(3), 364-77.

Eriksson, P E and Westerberg, M (2011) Effects of cooperative procurement procedures on construction project performance: A conceptual framework. International Journal of Project Management, **29**, 197-208.

Jensen, M C and Meckling, W H (1976) Theory of the firm: Managerial behavior, agency costs and ownership structure. Journal of Financial Economics, **3**(4), 305-60.

Jonsson, R and Rovatsos, M (2011) Scaling up multiagent planning: A best-response approach. In, Twenty-First International Conference on Automated Planning and Scheduling, Freiburg. The AAAI Press, 114-21.

Klijn, E-H, Edelenbos, J and Steijn, B (2010) Trust in governance networks. Administration & Society, **42**(2), 193-221.

Laan, A (2009) Building trust, Construction Management & Engineering University of Twente.

Moon, F L, Aktan, A E, Furuta, H and Dogaki, M (2009) Governing issues and alternate resolutions for a highway transportation agency's transition to asset management. Structure and Infrastructure Engineering, **5**(1), 25-39.

Müller, P W, Perea, A and Wolf, S (2007) Combinatorial scoring auctions. Research Memoranda.

Nisan, N (2007) Introduction to mechanism design (for computer scientists). Algorithmic game theory, 209-242.

O'Hare, M, Leone, R and Zegans, M (1990) The privatization of imprisonment: A managerial perspective. Private prisons and the public interest.

Pigou, A C (1912) Wealth and welfare. London: Macmillan and Co.

Poppo, L, Zheng Zhou, K and Zenger, T R (2008) Examining the conditional limits of relational governance: Specialized assets, performance ambiguity, and long-standing ties. Journal of Management Studies, **45**(7), 1195-216.

Rieck, T (2011) Essays on information disclosure in auctions and contests, Universitäts- und Landesbibliothek Bonn, University of Bonn.

Rose, T and Manley, K (2011) Motivation toward financial incentive goals on construction projects. Journal of Business Research, **64**(7), 765-73.

Schraven, D, Hartmann, A and Dewulf, G (2011) Effectiveness of infrastructure asset management: Challenges for public agencies. Built Environment Project and Asset Management, **1**(1), 61-74.

Suyama, T and Yokoo, M (2005) Strategy/false-name proof protocols for combinatorial multi-attribute procurement auction. Autonomous Agents and Multi-Agent Systems, **11**(1), 7-21.

The Institute of Asset Management (cited 2011) What is asset management? [Available online from http://theiam.org/]

Vandaele, D, Rangarajan, D, Gemmel, P and Lievens, A (2007) How to govern business services exchanges: Contractual and relational issues. International Journal of Management Reviews, **9**(3), 237-58.

Watt, D J, Kayis, B and Willey, K (2010) The relative importance of tender evaluation and contractor selection criteria. International Journal of Project Management, **28**(1), 51-60.

Yokoo, M, Matsutani, T and Iwasaki, A (2006) False-name-proof combinatorial auction protocol: Groves mechanism with submodular approximation. In, AAMAS'06, May 8–12, Hakodate, Hokkaido, Japan. ACM, 1135-42.