Dynamic Contracting in Infrastructures (Doctoral Consortium)

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ABSTRACT

In the joint initiative 'Dynamic Contracting in Infrastructures' the aim is to develop a contracting procedure that is able to cope with the additional complexities of recently popular performance based contracts. Commonly in maintenance of (public) infrastructures, such as a national highway network, an asset manager is responsible for high network quality and throughput, while limiting expenses to a minimum. The maintenance activities however are often performed by commercial, third-party contractors, mainly driven by profit. There is a misalignment between the objectives of both parties, complicated by the contingency inherent to the domain, that has to be resolved on a network level in order to achieve high quality joint maintenance plans.

The focus of this PhD is on the design of a dynamic payment mechanism that, in combination with stochastic planning, can be applied to the development and execution of joint maintenance plans. Through monetary incentives we stimulate selfish contractors to consider global objectives, such as asset quality and network throughput, and coordinate their activities on a network scale.

Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Multiagent systems

General Terms

Algorithms, Experimentation

Keywords

Multiagent systems, Planning and Scheduling, Coordination

1. INTRODUCTION

The planning and scheduling of maintenance activities on infrastructural networks, such as the national highway network, is a challenging real-world problem. While improving the quality of the infrastructure, maintenance causes temporary capacity reductions throughout the network. Given the huge impact of time lost in traffic on the economic output of a society, planning maintenance activities in a way that minimises the disruption of traffic flows poses an important challenge.

A powerful real-world example of the benefits that careful maintenance planning can provide is the Summer 2012 closure of the A40 highway in Essen, Germany. Instead of restricting traffic to fewer lanes for 2 years (the usual approach), authorities fully closed a road segment for 3 months, diverting traffic to parallel highways. Traffic conditions on the other highways hardly worsened, while €3.5M in social costs due to traffic jams were avoided (besides lowering construction costs) [3].

Such convincing examples have motivated research into more innovative contracting procedures for infrastructural maintenance. In previous work [5], we presented a two-phase, dynamic contracting procedure to the platform of construction management as a solution for these problems. In the first phase, known as the procurement phase, maintenance activities are identified, priced and distributed amongst contractors through tendering. Subsequently, in the execution phase all these maintenance activities must be planned and performed efficiently on a network level. Here efficient denotes socially optimal for all participating parties, i.e. we cannot improve the plan for any agent without harming at least one other.

In this PhD we mainly focus on the execution phase of the dynamic contracting procedure, striving to develop an incentive mechanism that implicitly stimulates selfish contractors to develop efficient solutions autonomously. As a first step towards a new procedure, we have applied a combination of dynamic mechanism design and stochastic multi-agent planning on real-world applications [4], briefly discussed in Section 2. Moreover, as this research is inspired by issues encountered in practice, we are also studying the application of our method on realistic scenarios using a serious game (submitted as demo) that incorporates our incentive mechanism, explained in 3. Finally, in Section 4, we outline current open challenges that we address in the remainder of the PhD.

2. COORDINATING MAINTENANCE PLANNING

The main purpose of our contracting mechanism is to develop and execute efficient joint plans without resorting to coordination through legislation. Allowing contractors a high degree of freedom indeed often leads to many benefits, e.g. increased flexibility, more innovation, better performance and subsequently lower costs [1]. Nevertheless these benefits are accompanied by a higher level of uncertainty and introduce additional possibilities for opportunistic be-

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haviour. Moreover, although such performance based contracting methods allow for a greater degree of freedom in project implementation, consequences thereof are commonly neglected.

In [4], accepted for presentation at the ICAPS 2013 conference, we discuss a real-world application of a novel dynamic mechanism and planning method for coordination under uncertainty that combats these additional challenges. Using a monetary incentive scheme we stimulate contractors to develop plans that also consider global goals such as asset quality and network throughput. Basically, contractors are rewarded or fined for their contribution towards global goals, but have to balance this with their own maintenance revenues and costs.

A complicating factor however is that maintenance activities are inherently contingent. For example, a contractor might not know the exact state of an asset or the work might take longer than initially accounted for. In order to take this uncertainty into account (in our work we consider only temporal uncertainties) contractors develop stochastic plans. Instead of a single plan, contractors develop policies that dictate the best action to perform given the current state the contractor is in. The mechanism payments are modified accordingly: rather than using one fixed payment for a plan, we use dynamic payments such that contractors in expectation make the most profit when they consider global goals.

The mechanism we propose in [4] uses a dynamic variant of the Vickrey-Clarke-Groves (VCG) (see [2]) mechanism to determine the payments each contractor pays or receives for his participation. Informally the VCG-mechanism charges each contractor the harm they cause to other agents (including the asset manager and asset user) by their presence, i.e. their maintenance on the network. With this mechanism we show that we are able to implicitly coordinate contractors on a network level, even when maintenance activities can have uncertain durations. Nonetheless, finding optimal joint policies, required for the mechanism, is computationally hard and current research is hence directed to smarter planning methods and approximation mechanisms (see Section 4).

3. SERIOUS GAME

Concurrent to the theoretical work on mechanism design and planning, we also concentrate on the practical aspects and impact of our dynamic contracting procedure. First of all, the maintenance planning problem, subject of study in [4], has been obtained through interviews and discussions with domain experts. Moreover, in order to validate our theoretical work, we are developing a serious game that tests the concept of dynamic contracting (submitted as demo). The major goals of this game are:

- Studying whether our novel contracting method can be used in practical scenarios, and whether practitioners are likely to accept and adopt our method.

- Creating awareness and support amongst practitioners regarding the impact of (coordinating) maintenance activities on a network level. Using this tool we want practitioners to get a feel for our novel and progressive concept, increasing the likelihood of acceptance.

- Validation of the payment mechanism. Human players will most likely not be perfectly rational, therefore we study the strategies played by human planners and the resulting outcomes.

- Closing the gap between theoretical concept and realistic contracting. This will increase the likelihood of practical implications.

In this game, players take on the roles of contractors and have to maximise their profit over a given portfolio of maintenance activities, while taking the mechanism payments into account. They are supported by an automated planner that provides insight into costs and payments, and is able to provide plan suggestions, based upon the work in [4].

4. OPEN CHALLENGES

Our current research activities are currently divided over two tracks: 1) finding (more) tractable methods to solve the maintenance planning problem and 2) the development and improvement of our serious game through experimental sessions. For the first track, we are now considering using state-of-the-art RDDL planners as the core solver for the problem, but also we try alleviate the complexity through exploitation of the problem structure.

In future work we want to study approximation methods for the maintenance planning problem. The main difficulty is that while approximation makes finding maintenance plans easier, the payment mechanism does not have to be incentive compatible anymore (i.e. truthful). The payment mechanism has to be adapted to remain its desiderata, but this depends largely on the used approximation technique.

Another extension we are addressing in future work is that of multi-objective planning. Maintenance planning is inherently multi-objective: for example, one cannot simply compare one euro of maintenance cost to a quality improvement of 2%. Currently we operationalise all objectives other than cost into monetary values using rewards and fines. Using pure multi-objective approaches would be more realistic, but makes both the planning problem and mechanism design problem much more complex.

5. REFERENCES

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