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Concept and prototype of a web tool for public–private project contracting based on a system dynamics model

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Abstract Contracting has a significant impact on the efficiency of acquisition processes, especially in the context of so-called public–private partnership (PPP) projects. Improperly drafted contracts may cause significant time and cost overruns in project execution due to opportunistic behaviour of private-sector suppliers. The main objective of our paper is to give a better understanding of opportunistic behaviour in PPP projects. The focus is on analysing the effects of delay penalties on the duration of such projects. We developed a system dynamics model, which depicts the complex relationship between the different aspects of a PPP project. In combination with this model, we present a web tool for conducting web-based experiments, which offers the possibility to track the decisions made by the private-sector suppliers during the progress of a simulated project. Using this web tool our experimental pilot study shows that carefully designed contracts help to keep the projects on schedule and bring benefits to both governmental entities and the private-sector suppliers.

Keywords System dynamics modelling · Public–private partnership (PPP) · Web tool · Project contracting

1 Introduction

Delays in a public–private partnership project (PPP) cause a two-fold disadvantage for the contracting authority. Firstly, the planned services (e.g. software, infrastructure)

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are not available during the period of delay. Secondly, in many cases, due to the delay features of services are partly already out of date when they are put into use. Improvement of project contracting may have a significant contribution to reduce cost and time overruns and to enhance the outcome of a PPP project.

The purpose of our web-based simulation tool for public–private project contracting based on a system dynamics model is to give a better understanding of the opportunistic behaviour of the private-sector supplier. Furthermore, it enables the participants to test the different outcomes of the consequences of various contract types.

In addition, we want to show how project contracts that include incentives and carefully designed time penalties can help keep a project on track and within the planned timeline. Our web tool shall be used for exercising project contracting in the future. Generally speaking, with this tool project contractors should be able to achieve better understanding of the relation and the potential problems between the contracting authority on the one side and the private-sector project supplier on the other side.

This paper starts with a literature review examining three related research issues: public–private partnership as well as opportunistic behaviour and contracting. Following that, we describe our concept development using system dynamics modelling, our web-based simulation and experiment tool. Furthermore, with in an experimental pilot study we want to check the effects of the penalties on the time delay and the effects of the additional costs of a PPP project.

2 Literature review

2.1 Public–private partnership

In literature, a variety of explanations of public–private partnership (PPP) can be found. Iossa et al. (2007) describe public–private partnership from the infrastructure point of view as a long-term contractual arrangement between the public sector and the private sector, in which the private sector is responsible for significant project aspects of the building and operation of an infrastructure for the delivery of public services.

As a certain basis for this purpose, we go ahead with the definition given by “The National Council for Public–Private Partnerships”. Hereby the term PPP is explained as means of utilising private-sector resources in a way that is a blend of outsourcing and privatisation.

PPP may involve a design, construction, financing, operation and maintenance of public infrastructure, facilities, or the operation of services to meet public needs. In the ideal way, PPP can be described particularly as a contractual arrangement between public and private entities where the resources, risks and rewards are shared to provide greater efficiency, better access to capital and improved compliance with a range of government regulations regarding the environment and workplace. The public interests are fully assured through the project contracts that provide with on-going monitoring and oversight of the operation of a service or development of a facility. In this way, the government entity, the private company and the public share the present benefit.

A long list of cases of failures of PPP can to be mentioned. For example, since the 1980’s the mayor of Farum, Denmark has followed an active strategy relying on contracting out and, later, PPP's for delivery of various public services. In 2002, the issue about the PPP contract for construction of the soccer stadium and the sports arena, and inadequate money spending led to a serious governmental scandal and consequently the mayor's leave. The main reason for the failure of PPP in this case was the fact that the structure of the contractual governance scheme in Farum was too complex for the mayor to keep to the planned city budget (Greve and Ejersbo 2002).

In the recent past, several large-scale infrastructure projects in Europe and especially in Germany have shown the importance of project contracting, due to extreme additional costs and delays. Such case studies, e.g. the new Berlin airport and also the new Stuttgart central station seem to be ideal to learn a lesson and analyse the critical issues of project contracting, which can be used for future studies. As a consequence of all these cases of failure, we discuss in the following paragraphs some aspects of opportunistic behaviour and project contracting within PPP.

2.2 Opportunistic behaviour and project contracting

Regarding the regulatory and institutional framework, the quality of contract enforceability and governance are a critical factor of success, which is affecting PPP agreements (Iossa et al. 2007). Aspects of the contract design, such as the risk allocation or the payment mechanism, significantly affect the PPP outcomes. Closely connected, the issue of opportunistic behaviour can be seen as an additional critical issue of PPP. Due to the sheer complexity of PPP contracts opportunistic behaviour is a key issue for the success of a PPP project. A crucial point is the opportunism, which plays an important role for interparty collaboration in every project. On the one hand, opportunism increases transaction costs in repeated exchange, mainly due to the crucial fact that covert behaviour seeking unilateral gains are difficult to observe and to verify. On the other hand opportunism can be seen as a significant obstacle to fostering confidence in partner cooperation, and consequently the risk of opportunism may escalates interparty conflicts (Luo 2007).

Opportunistic behaviour can be also described as taking the opportunity to manage earnings, in order to maximise their own utilities at the expense of the contracting parties and stakeholders. In details, opportunistic behaviour can be explained as the usage of information asymmetry between outsiders and insiders to maximise their utility in dealing with compensation contracts, debt contracts and regulations. Furthermore, investors are thereby misled by the unreliable information reported (Sun and Rath 2008).

Consequently, opportunistic parties manage on their own behalf and emphasise their own interests, hence weakening the foundation for collaboration (Luo 2007). Especially a lack of quality control during the project and additional institutional settings allow opportunistic behaviour, increase the likelihood of dealing with inadequate service suppliers, and represent a performance risk for the client. Therefore, one successful way to reduce this opportunistic behaviour is personal experience that evolves from interaction between clients and consultants, which becomes most important in reducing uncertainty and controlling for opportunistic behaviour (Glückler and Armbrüster 2003).

Another option to prevent opportunistic behaviour is the collaborative way of consulting with the help of modelling the project structure by building a system dynamics model together. Bernheim and Whinston developed a formal model and showed that making the contract more explicit, may further encourage opportunistic behaviour surrounding actions that cannot be specified within contracts (Bernheim and Whinston 1998). Nevertheless, the capacity for contracts to adequately safeguard relationship-specific investments against opportunistic behaviour by a contractual partner is limited (Mayer and Argyres 2004).

Especially large, long-term projects are now among the most important, while being the least organised activities in the modern society. Projects of all types typically experience additional costs, delays, and quality problems. Over several years, Cooper and Mullen (1993) analysed major projects in different industries. They reported that commercial software projects are on average more expensive by about 140 % than planned and lasted longer by about 190 % than originally scheduled. The complexity involved in a project in which multiple intertwined dynamic processes occur requires often a computer-aided modelling method, such as system dynamics, which is capable to handle such dynamic processes.

3 Concept development

3.1 A system dynamics model of project contracting

Projects, especially PPP projects, are "fundamentally complex dynamic systems, most project management concepts and tools either (1) view a project statically or (2) take a partial, narrow view in order to allow managers to cope mentally with the complexity" (Lyneis and Ford 2007). In this context, we aim at contributing to a better understanding of the complex dynamic relationship between different aspects of public–private-partnership projects, such as, between project contracting and execution.

One of the strengths of system dynamics is the representation of the interdependencies within a project and the subsequent tracking of changes in the model. It can be said that system dynamics consists of one of the most developed plans for action, the optimal representation, analysis and detailed explanation of dynamics in complex technical systems as well as in entrepreneurial systems (Sterman 1992). Additional costs and delays can be detected earlier. System dynamics should be regarded as an additional method for decision support in project management to the existing, traditional project management methods. Especially when handling complex project dynamics, based on causal relationships, feedback loops, time delays and non-linearity system dynamics can be regarded as a potential decision support method (Sterman 1992).

Generally speaking, modelling and simulation with system dynamics provides a transparent way to understand and to improve project contracting process efficiency in many perspectives. We developed a system dynamics model for project contracting and execution based on the model by Lyneis et al. (2001). In particular, the new version of the System Dynamics model includes the opportunistic behaviour, shown in Fig. 4. Such a model has not only a theoretic but also a practise-oriented background. From

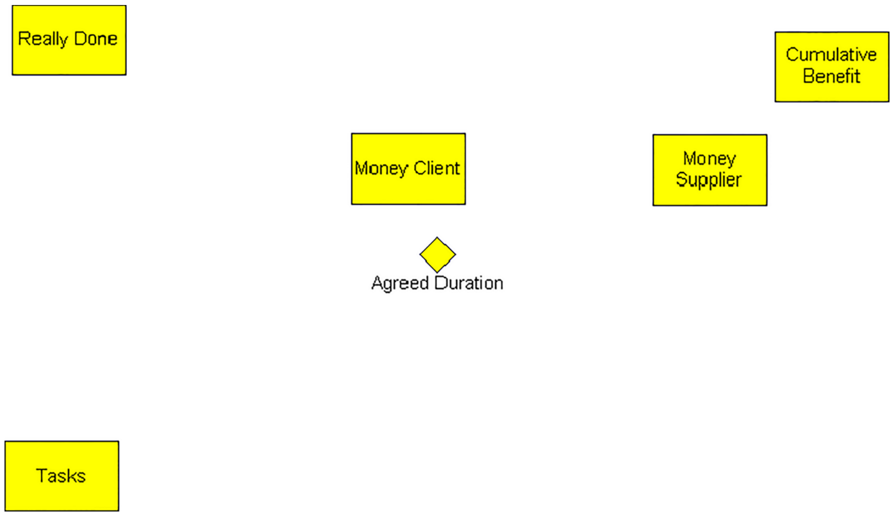

Fig. 1 Key indicators of a project

the authors' point of view, developing and deploying effective concepts and tools to support planning and contracting activities is an essential and long-term task.

Our model is capable to display the key indicators, which are essential for the public contracting authority as well as for the private-sector supplier. The basic parameter set describing a project includes the `Tasks` (unit of measurement: person · month) to be executed within certain `Agreed Duration` (month) and those ones which are `Really Done` (person · month), as well as the `Money` earned by the `Supplier` (person · month), the `Money` (person · month) spent by the contracting authority or the `Client` and the `Cumulative Benefit` (person · month^2) of the project over the time (Fig. 1).

During project `Progress`, planned `Tasks` are going to be completed. Therefore, planned `Tasks` will change into the status `Done`. However, not every executed task produces the intended results but type I or type II errors (Atkinson 1999). In these cases, the tasks have not been fulfilled sufficiently. Hence, these tasks `Need Rework` and change again into the status planned `Tasks`. The fraction of tasks that needs rework depends on `Team Quality`. However, tasks that are completed successfully pass into `Really Done`. From the point of view of a public project client, the more tasks are finished, the more `Features` can be put into use. Notice that for certain IT and other high-tech projects, the `Half Life` during which the time specific benefit is reduced to the half the original planned value can be as short as 24 months (Fig. 2).

The next step of the modelling is to reflect the financial flows (`Payment, Penalty, Interest` and `Costs`) and other dependencies (Fig. 3). This includes the core interest of the experimental study, the parameters for the `Payment: Pay per Delivery, Fixed Sum`, and `Penalty`. The contract's term of payment is set by `Frac`, which is the fraction of payment on a pay-per-delivery basis. At the same time, the `Frac` influences the `Penalty`. A number bigger than one means a penalty applies for each delayed person month according the `Plan`.

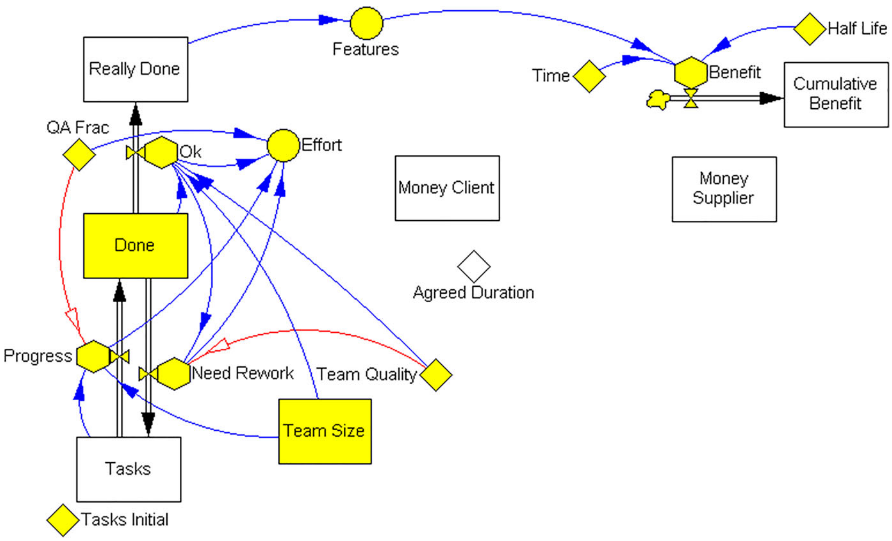

Fig. 2 Project execution

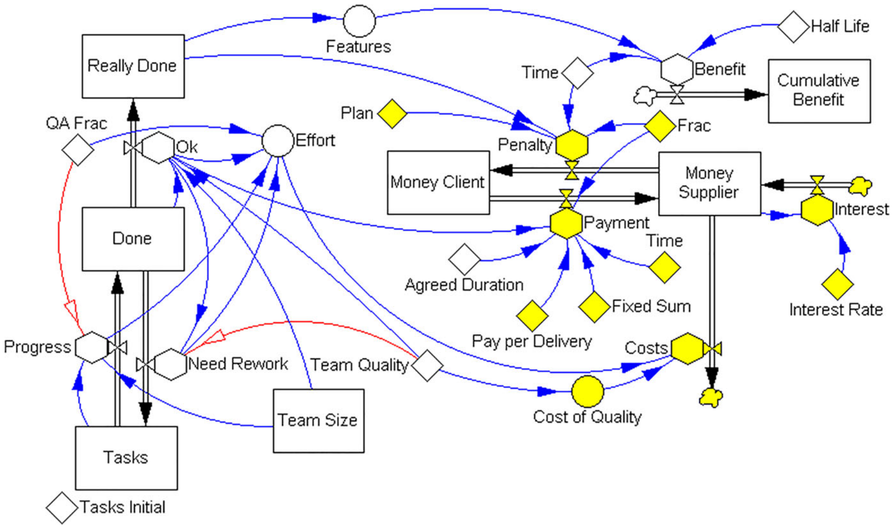

Fig. 3 Benefits of the project client and the financial aspects

Similar models can be found for example in Lyneis and Ford (2007), Garcia (2009), Sterman (2000).

As shown in Fig. 4, each participant acts as a possibly opportunistic private project supplier. Depending on the value of `Frac`, it may be beneficial to reduce `Team Size` at the cost of a significant project delay. Therefore, the Change of `Team Size` is influenced by the following parameters: `Team Size Initial`, `Opportunism`, `Profile`, `Time`, `Time Step`, `Period`, and `End of the Period`.

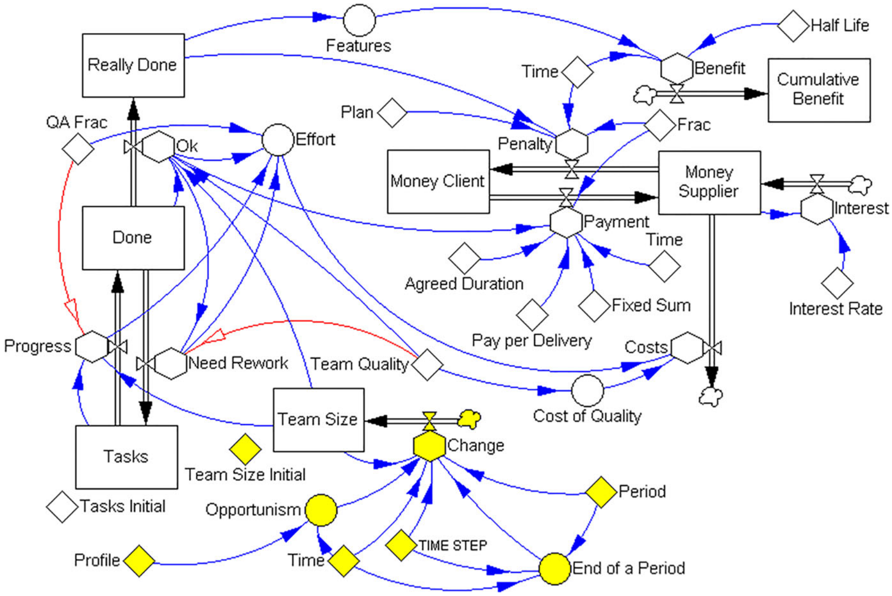

Fig. 4 Possible opportunistic behaviour regarding the team size

With our system dynamics model we set the basis for an overview on all relevant parameters within a PPP project. This SD model, which is fully integrated in our web tool, described in the following chapter, can be easily used for experimental studies.

3.2 A web tool for project contracting experiments

As shown by several studies, accuracy of the mental model of the participants for a complex managerial task (Gary and Wood 2005) as well as the presentation of the data materials (Hu et al. 2013) may influence the performance of an experimental decision process. Based on Hu and Leopold (2011) we have developed a web tool for PPP contracting experiments supported by the system dynamics model. The system architecture of the whole platform, which the web tool is embedded in, is shown in Fig. 5.

Within the platform, an experiment designer can setup and conduct an experiment based on a system dynamics model with all the relevant details. He/ she uses the modelling and simulation environment to edit the model and to provide necessary documentation of the model. A participant, assigned to play the role as the private sector supplier or the public contracting authority, obtains also his/ her access to the web-based collaborative modelling and experiment platform. To be able to integrate the newest research results, the platform is designed in such a way that this model can be easily adapted. A web-based tool not only facilitates deployment. Furthermore, such a tool helps to present data in a more understandable fashion and supports information management. We assume that the user will have the possibility to achieve improved decisions due to the more understandable data and information management by our web tool for experimental studies.

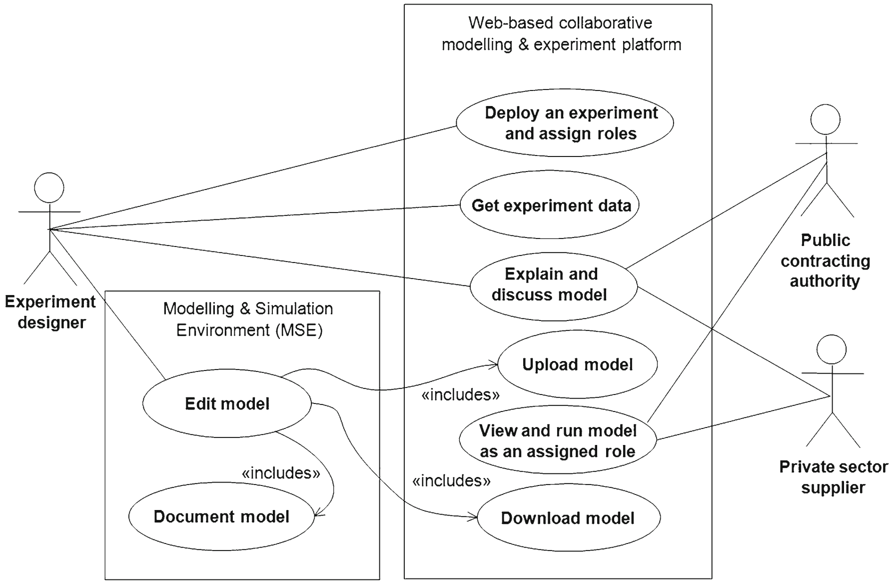

Fig. 5 Use case diagram for a web tool for collective experiments

This tool along with the system dynamics model intends to give users an improved decision support (Roth 2010). The web tool is embedded in an existing web content management system respectively collaborative authoring system which was first introduced in 2004 and has been being developed since then continuously (Hu and Lauck 2004; Hu 2006; Hu and Gollin 2010) to take the advantage of different existing content management functions. To implement the web tool, we extended our specific system dynamics model by an accessible user interface. With the help of this web tool, the participants are able to use contracting online and to share their results and experiences. This web tool contains the user Interface and the specific system dynamics model elaborated for this particular tool.

The user interface consists of two aspects, the project contracting terms for the public contracting authority (Fig. 6) and the user interface for the private sector supplier (Fig. 7). For defining the project contracting terms, five different options are available:

- 60 month fixed
- 30 % per delivery, 70 % fixed
- 70 % per delivery, 30 % fixed
- Pay per delivery only
- Pay per delivery + 30 % penalty for delay

One of these five can be selected for the PPP project study, to come to the project user interface, which is presented in Fig. 6. The focus within this project user interface lies on necessary project resources, i.e. team size, for project implementation. During a simulated project, the user interface informs the participants interactively about the main key indicators related to the project contract, which are the following parameters:

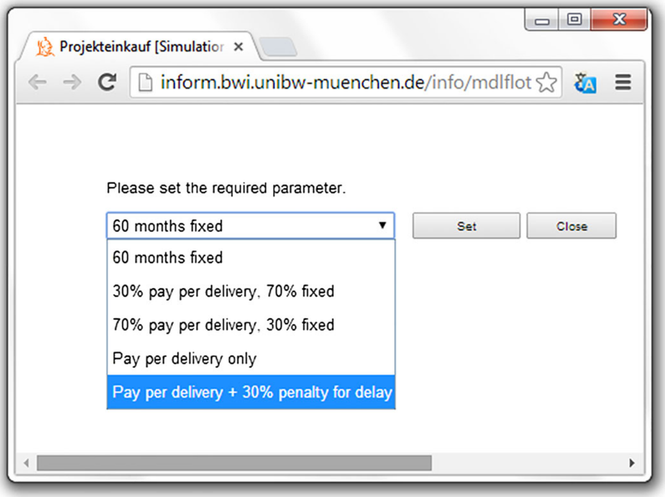

Fig. 6 User interface for contracting

- `Money` (earned by) `Supplier`—measured in person · month
- Number of tasks to be executed according the project `Plan`—measured in person · month
- `Penalty`—measured in person · month
- Number of tasks which are `Really Done`—measured in person · month
- `Team Size`—measured in person

Figure 7 shows these parameters and their value on three scales. The X-scale represents the project duration (0–120 month). The Y1-scale is relevant for team size (0–100 Team members). The Y2-scale represents the parameters `money supplier` (0–1,000 money units), `plan` (0–1,000 project tasks), `penalty` (0–1,000 money units) and `really done` (0–1,000 project tasks). The main task for the private sector supplier is to modify the `team size` by choosing one of the five options (+2, +1, 0, −1, −2), while starting with a team size of 30.

Generally speaking, our web tool for project contracting and interactive decision support offers the possibility to track private-sector suppliers' opportunistic behaviour in decision making during the progress of a simulated PPP project in a competitive environment. This includes as well as other key indicators for PPP projects. During a simulation run, all relevant data is stored for analysis in a pre-processing step. This allows identifying participants' behavior and adaption processes as well as the identification of well working policies. In our upcoming experimental pilot study, our main interest will focus on the power of penalty.

3.3 An experimental pilot study

14 participants carried out a first pilot study using the web tool in spring 2014 at the Universität der Bundeswehr München, Germany.

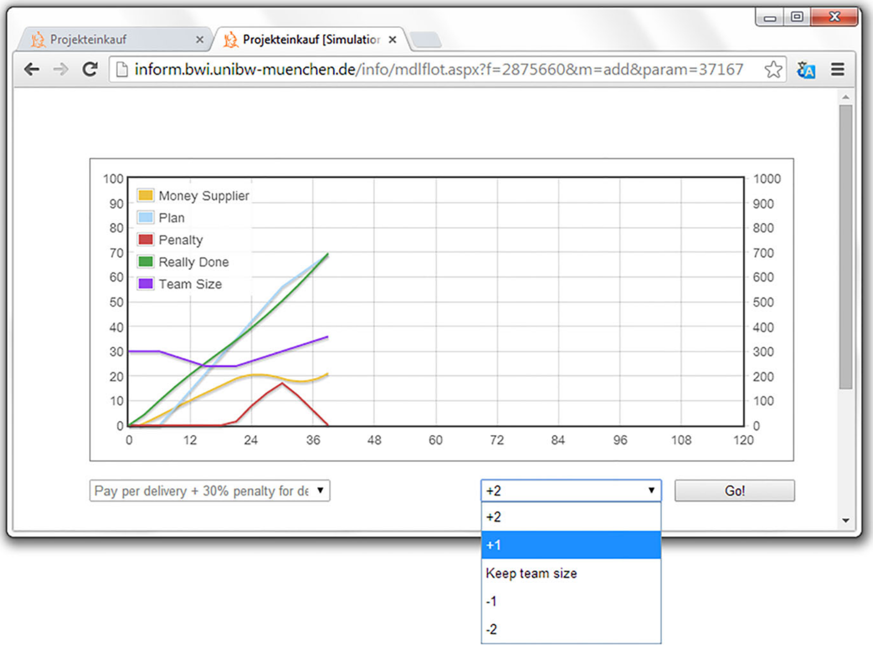

Fig. 7 User interface for project execution by the private sector supplier

The role of public contracting authority seeking to have their projects delivered in time were taken over by the authors. While each of the participants acted as a single, profit-maximising private-sector supplier (see Fig. 5). The project contracting experiment was carried out using only the web tool.

The following two different contract terms are executed alternately namely:

- pay per delivery only,
- pay per delivery + 30 % penalty for delay.

One-half of the participants started with the first contracting version: “pay per delivery only”, while the other half of them with the second one: “pay per delivery + 30 % penalty for delay”.

Each of the participants acted as a single, profit-maximising-private-sector supplier using the tool at hand.

After reading the introduction given on the web page, which explains the outline of this pilot study and in particular, this web tool for project contracting, each participant had to finish four projects in total. All participants were informed about the financial rewards for those ones with the five best average profit values (15, 10, 7, 5, and 3€ respectively). The money was paid immediately after the experiment had been finished.

Our user interface refers to the following details: At the beginning, the project `Team Size` consists of 30 members so that the project, which contains 1,000 planned project `Tasks`, can be carried out on time, exactly in 60 months. In this experimental pilot study, the participants can change only the parameter `Team Size` during the experiment.

Table 1 Project duration and learning effect (N = 14)

Run	Pay per delivery only		Paired t test	Pay per delivery + 30 % penalty for delay	
	Mean	SD		Mean	SD
1–2	58.5 Months	10.5 Months	0.735	56.6 Months	3.5 Months
Paired t test	1.835			1.333	
3–4	61.1 Months	11.7 Months	1.130	58.3 Months	4.5 Months
1–4	59.8 Months	11.0 Months	1.333	57.4 Months	4.1 Months

The only objective for the participants within this first pilot study, as a single private-sector supplier, was to maximise the total accumulated profit including interest as of the 120th month, for each of the projects.

After every third month, the private-sector supplier receives detailed Information via the web tool about the actual situation of the project. This information includes the actual profit, the actual team size, the actual penalty (if any) and the total amount of planned and finished tasks. The central aspect is that the project contractor has the possibility to adjust the team size. Both, a too high or too low team size may lead to profit loss.

The focus was to test the following hypotheses:

H1 In cases with 30 % penalty for delay the project is going to be finished earlier than in cases without penalty.

Table 1 shows the data for four runs for all participants. We can see that the participants finish the project earlier when having to pay a 30 % penalty for delay. The means and the standard deviations of the project duration are shown for two contracting Versions, namely without and with penalty.

There is a significant difference ($t = 1.835$) between the first and the second run when the version "pay per delivery only" is applied. This effect is weaker ($t = 1.333$) if there is a danger of delay penalty. H1 can be corroborated.

As described above, projects of two different contracting versions had to be executed alternately. One-half of the participants started with the version "pay per delivery only", while the other participants with the version "pay per delivery + 30 % penalty for delay". Tables 2 and 3 show the statistics differentiated between the versions with which the participants started.

Obviously, the order of the contracting versions does matter. The seven participants starting with the version "pay per delivery only" showed a significant effect towards more project delay for maximising their own profit (Table 2). If there is danger of delay penalty during a participant's first project, it will have seemly a sustainable effect upon his or her behaviour regarding project delays, as demonstrated by the other seven participants starting with the version "pay per delivery + 30 % penalty for delay" (Table 3).

The experiment shows the possibility to track the private-sector supplier's opportunistic behaviour while their putting the progress of the PPP project at risk.

Table 2 Started with the version "pay per delivery only" (N = 7)

Run	Pay per delivery only		Paired *t* test	Pay per delivery + 30 % penalty for delay	
	Mean	SD		Mean	SD
1–2	60.9 Months	13.5 Months	1.114	55.7 Months	4.5 Months
Paired *t* test	1.890			2.500	
3–4	64.7 Months	15.7 Months	1.130	60.0 Months	4.2 Months
1–4	62.8 Months	14.2 Months	1.525	57.9 Months	4.8 Months

Table 3 Started with the version "pay per delivery + 30 % penalty for delay" (N = 7)

Run	Pay per delivery + 30 % penalty for delay		Paired *t* test	Pay per delivery only	
	Mean	SD		Mean	SD
1–2	57.4 Months	2.1 Months	0.570	56.1 Months	6.6 Months
Paired *t* test	0.603			0.660	
3–4	56.6 Months	4.4 Months	0.795	57.4 Months	4.7 Months
1–4	57.0 Months	3.3 Months	0.173	56.8 Months	5.6 Months

4 Conclusions

We developed a system dynamics model capable for displaying the key indicators, which are essential for the public contracting authority as well as for the private-sector supplier. In combination with this model, a web tool, which we developed as well, was used to conduct a pilot experimental study to obtain a better understanding of the opportunistic behaviour of the private-sector suppliers. We concentrate is on analysing the effects of delay penalties on the duration of PPP projects. The decisions made by the participants in the role of private-sector suppliers during the progress of a simulated project were recorded in full details. Our pilot study shows that carefully designed contracts help to keep the projects on schedule and bring benefits to both governmental entities, and the private-sector suppliers. In particular, contracts with delay penalties during the project execution seem to be an effective approach to keep PPP projects on schedule.

The tool presented in this paper can be applied to further different system dynamics models. From our point of view, this web tool in combination with system dynamics models offers a high degree of flexibility and attractiveness for the conduction of experiments in management research.

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