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IMPACT OF MULTITASKING AND MERGE BIAS ON PROCUREMENT OF COMPLEX EQUIPMENT

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ABSTRACT

This paper describes how multitasking and merge bias may impact the procurement time of complex equipment, such as power distribution equipment used in capital projects. The time required to procure this type of product is often based on past experience and ad hoc assumptions, without explicit consideration for the contributing factors. Capital projects are becoming increasingly complex, requiring more experts to contribute knowledge. By relying on 'received traditions,' procurement times are often underestimated thereby creating numerous problems for the project participants downstream in the supply chain. The presented model builds on Sigma, an event scheduling simulation engine, and uses various input scenarios to show how sensitive the procurement time is to the effects of multitasking and merge bias. Insights gained from the simulation may help practitioners to more accurately determine the time required to procure complex equipment and to locate and size time buffers in the procurement process.

1 INTRODUCTION

Capital project are becoming increasingly complex, requiring input from and the coordination of work done by numerous stakeholders and specialists, including not only architects, engineers, regulatory agencies, and contractors, but also procurement personnel, product manufacturers and suppliers. In addition, many of these people are involved in the delivery of not only one but several capital projects at the same time, that is: they multitask. Increased complexity and multitasking pose major challenges for project managers, charged with delivering projects on time and within budget.

In order to schedule a project completion date, managers need to describe all activities to deliver the project and estimate their durations. In the schedules they generate at first—master-level or milestone schedules—such activities are shown with precedence relationships (finish-to-start, finish-to-finish, etc.). More often than not, activities also have other linkages, defined by shared resources for example, but these may or may not be shown. By abstracting these linkages away, managers may fail to appreciate the impact resource sharing can have on the duration needed to complete activities, so that their schedules will be overly optimistic.

2 PROCUREMENT PRACTICES

Consider procurement, an activity scheduled to start when an appropriate degree of design has been completed and resulting in the delivery of materials needed for construction on site (Figure 1). Procurement starts with defining the requirements of what is to be procured, issuing of a request for quotation (RFQ), receiving feedback from one or several suppliers, analyzing that feedback, selecting one supplier, and issuing a purchase order (PO). It is followed by other activities, including receiving.

Figure 1: Sequential relationships between design, procurement, and construction

Estimating the duration needed for procurement is not easy. Even so, the time needed from start to completion includes actual work time but also extensive delays or wait times because specialists need to get input from various sources. Because the activity is not performed uninterruptedly (as is commonly assumed in master-level or milestone schedules), it is better to use the term 'procurement lead time' rather than activity duration.

To study industry practices and identify opportunities for lead time reduction, the authors conducted three indepth case studies on the delivery of power distribution equipment used in capital projects (Elfving 2003, Elfving et al. 2003a, Elfving et al. 2003b). Because of this equipment's complexity, the definition of requirements and the analysis of the suppliers' feedback cannot be done by procurement personnel in isolation. Instead, they require review by electrical engineers, mechanical engineers, project architects, and others. This not withstanding, the lead time required for procurement of this type of product is often estimated based on past experience and ad hoc assumptions, without explicit consideration for the contributing factors. By relying on 'received traditions' (Schmenner 1993 p. 379), procurement lead times are often underestimated—as was the situation in each of the case studies—thereby creating numerous problems for the project participants downstream in the supply chain.

Thus, it would be valuable to better understand which factors impact the procurement lead time and how. We next present a simulation model to illustrate some of the culprits for underestimating procurement lead times.

3 MODELING THE PROCUREMENT PROCESS IN SIGMA

The authors developed a simulation model (e.g., Law and Kelton 2000) based on Sigma (Schruben and Schruben 1999), an event scheduling simulation engine, to illustrate the role multitasking and merge bias may play in a procurement process. Reference data was collected from the case studies and used as input in the model.

3.1 Definition of model variables and tasks

The procurement simulation model includes the following tasks: (1) preparing a RFQ, (2) providing input for the RFQ, (3) quoting, (4) evaluating the quote, (5) providing input for contract negotiation, and (6) negotiating the contract. Table 1 describes these tasks in more detail. All the processing times are beta distributed with shape parameters Beta {2:3} and a range specified by task. This distribution is skewed to the right towards the lower values of the range, because extremely large durations are less likely than shorter durations.

The corresponding event graph model (Figure 2) has 19 events that describe the execution of these 6 tasks, using 20 state variables of which 5 variables are investigated in this paper. Table 2 describes these variables in more detail.

The investigated 5 variables and their respective default values were PMMT=1, MMT=1, ENG=5, ENG/h=1-8h (Beta {2:3}), and ENG/c=10%. Resources that get generated and 'flow' in the model are RFQs and QUOTEs. Because of multitasking, numerous RFQs and QUOTEs appear in the model at different times, but metrics are collected only on the so-called 'focus job'.

Table 1: Definition of simulation tasks

Task	Definition
Prepare RFQ	The Project Manager collects data and prepares the RFQ documents, which may include specifications, drawings, and schedules.
Provide input for RFQ	Engineers, owners, users, and others provide detailed data for the RFQ, e.g., energy and reliability requirements.
Quote	The Manufacturer reviews the RFQ and prepares a quote, which specifies the equipment, price, and delivery information.
Evaluate the quote	The Project Manager evaluates the quote, compares it to the requirements, and conducts a price check.
Provide input for contract negotiation	Engineers, owners, users, and others review the quote and recommend needed changes to the requirements prior to approval.
Negotiate	The Project Manager and Manufacturer negotiate details of the contract, e.g., price, scope of contract, and delivery schedule.

Table 2: Definition of variables

Variable	Definition
PMMT	Number of RFQs the Project Manager multitasks with
MMT	Number of QUOTEs the Manufacturer multitasks with
ENG	Number of experts that need to provide input
ENG/h	Duration for generating expert input [hours]
ENG/c	Expert's commitment level to the focus job [% of their workweek]

The focus job is the job that is being tracked from start through completion in the simulation. For example, job B in Table 3 could be a focus job being studied. It requires the joint input from three project participants: the Project Manager, the Manufacturer, and the Domain Expert (ENG=1). Note that each of these participants may be working on other jobs at the same time. For example the Project Manager is assigned to jobs A and D in addition to B. However, the three participants do not work on the same jobs all the time.

Table 3: Jobs assigned to various project participants

Project Manager	A	B		D	
Manufacturer	A	B	C		E
Domain Expert		B	C	D	

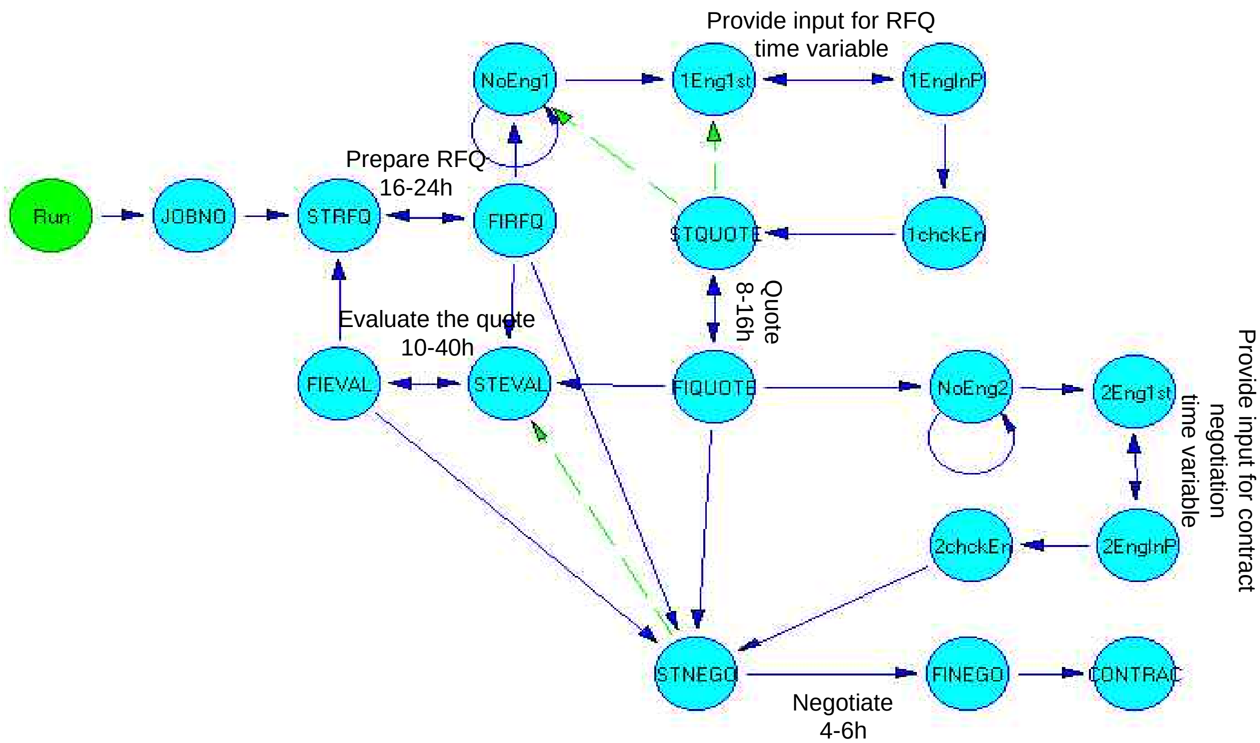

Figure 2: Event graph model for procurement simulation

3.2 Description of procurement model

The simulation time is the time it takes from the launch (RUN) of the simulation to the issuing of the procurement contract (CONTRAC) between the Project Manager and the Manufacturer. As the simulation is launched (RUN) the event JOBNO generates a JOB for the Project Manager, who will then start (STRFQ) to process it. The processing time has a range of 16-24 hours. At the end of the processing time (FIRFQ), a RFQ has been generated. However, if the Project Manager has other RFQs waiting before the JOB was launched, he has to process all of them prior to sending the focus RFQ that was generated by the JOBNO, to the experts (ENG) for input. Then, the event NoENG1 sends the RFQ to a specified number of experts for input. The default number of experts was 5.

The experts start (1Eng1st) simultaneously to evaluate the RFQ. The processing time has a default range of 1-8 hours. At the end of the processing time (1EngInP), an input for the RFQ is been generated. Because the experts are working on multiple jobs at same time, they are committed to spend only a certain percentage of their time to the focus RFQ. We used a default value of ENG/c=10% which equals 4 hours per week. Therefore, based on the commitment percentage the output from 1EngInP is either true or false. If it is false, a new processing of the RFQ is required. If it is true, it will be added to the event 1chckEn, where all true inputs from the various experts are collected.

After a specified number of expert inputs has been generated the Manufacturer can start to quote (STQUOTE) the RFQ. The processing time has a range of 8-16 hours. At the end of the processing time (FIQUOTE), a QUOTE has been generated. However, if the Manufacturer has other RFQs waiting before the focus RFQ arrives he has to process all of them in prior to sending the focus QUOTE for evaluation to the experts (ENG) and Project Manager.

The expert evaluation of the focus QUOTE follows the same logic as the expert evaluation of the RFQ. The Project Manager starts to evaluate (STEVAL) the QUOTE as soon as he is available. He is available when he is not preparing another RFQ for another job. The probability of STRFQ and STEVAL are set equal. The processing time has a range of 10-40 hours. At the end of the processing time (FIEVAL), the Project Manager has an equal probability to start contract negations (STNEGO) for the focus QUOTE, or STRFQ or STEVAL for another job, providing their conditions are satisfied. The conditions for the STNEGO are that the Project Manager and all required experts (ENG) have evaluated the focus QUOTE and both the Project Manager and Manufacturer are available. The Manufacturer can with equal probability STNEGO for the focus QUOTE or quote another RFQ. The processing time for the negotiation has a range of 4-6 hours and by the end of the processing time the events FINEGO and CONTRACT occurs simultaneously.

3.3 Modeling of multitasking

With multitasking we mean that a person is occupied with two or more jobs during a time period before either one results in an output or handoff, hence the resource is shared among the jobs. For example, in Table 3, the letters in a row represent the tasks being 'multitasked' by the person listed on that row.

The impact of multitasking on the procurement lead time is modeled by changing 2 of the variables, namely, PMMT and MMT. The rest of the variables are kept at their default values. Three scenarios were generated, (1) only the Project Manager multitasked, (2) only the Manufacturer multitasked, and (3) both the Project Manager and Manufacturer multitasked. E.g., if PMMT was 5, the Project Manager had to prepare five RFQs within the same time period. Therefore, before the focus RFQ was prepared we had to wait for the 4 other RFQs to be prepared as well, because they share the same server (Project Manager).

3.4 Modeling of merge bias

With merge bias we mean that two or more inputs from different sources have to be available before an event can start. For example, in Table 3, the letter in the columns refers to the corresponding people from whom input is needed (the level of merge bias) for that job.

Three factors contribute to the merge bias, (1) the number of resources or inputs that need to merge prior to an event taking place, (2) the processing times of the merging tasks, including their variability, and (3) the availability of the server who needs to process merging task. The impact of merge bias on the procurement lead time is modeled by changing 3 variables, namely, ENG, ENG/h and ENG/c. All other variables are kept at their default values.

3.5 Assumptions

We simplified the model in order to highlight the objectives of this paper. The most relevant modeling assumptions are the following:

1. No deadlines were enforced and no deliberate withholding of information took place. The authors wanted to filter out issues of gaming and focus only on multitasking and merge bias.
2. Every RFQ led to a contract with the manufacturer. The process did not get canceled.
3. Information distribution between the servers (participants) was always complete and the servers were capable of performing their task, e.g., no server needed to send a Request-For-Information (RFI).
4. The Project Manager and Manufacturer are treating every RFQ and quote, respectively, with equal priority and value. We are investigating the average practice thus high and low priority practices were discarded.

4 SIMULATION RESULTS

To investigate the impact of multitasking and merge bias we first simulated a hypothetical scenario. The simulation was run with settings where no multitasking or merge bias occurred (PMMT=1, MMT=1, ENG=0). The average procurement time of ten runs was 61 hours and the standard deviation 4 hours.

4.1 Multitasking and procurement lead time

The first actual simulation scenario investigated the impact of multitasking on the procurement lead time. The variables PMMT and MMT had values 1, 5, 10, and 20. The duration for preparing the RFQ was double (16-24h) that of the duration for quoting (8-16h). This relation is based on data from the case studies. The three other variables ENG, ENG/h, and ENG/c, respectively, kept their default values 5, 1, and 10%. For each set-up 10 runs were executed, then the mean, standard deviation, and lower and upper boundaries (with 95% confidence interval) of the procurement lead time were calculated (Tables 4 to 6).

Table 4 presents simulation results when only PMMT changed and MMT remained at its default value, 1. Table 5 presents the results when only MMT changed and PMMT remained at its default value, 1. Table 6 presents the results with PMMT and MMT taking on the values 1, 5, 10, and 20 at the same time. Figure 3 compares the impact of the various scenarios of multitasking on procurement time.

Table 4: Impact of project manager's multitasking on procurement lead time

PMMT	Procurement Time	Standard deviation	Lower bound	Upper bound
1	151	15	147	156
5	248	55	231	264
10	341	33	331	351
20	513	36	502	524

The results show that increasing the number of tasks to be worked on concurrently increased the lead time, and because the project manager's average task duration was longer than the manufacturer's, the number of tasks the project manager multitasks with had a greater impact on the procurement lead time than the manufacturer's number of multitasks. If both multitasked with only 5 jobs—which is very common in practice—the procurement lead time doubled (306 hours), and if they were very busy jumping between 10 jobs the required procurement time almost tripled (438 hours) compared to the default values. The impact of multitasking on project duration is intuitive, though it is common that contractors reserve fixed procurement lead times from project to project regardless of the prevailing procurement environment.

Table 5: Impact of manufacturer's multitasking on procurement lead time

MMT	Procurement time	Standard deviation	Lower bound	Upper bound
1	151	15	147	156
5	208	33	198	218
10	257	25	250	265
20	362	30	353	371

Table 6: Impact of project manager's and manufacturer's multitasking on procurement lead time

PMMT &MMT	Procurement time	Standard deviation	Lower bound	Upper bound
1	151	15	147	156
5	294	37	283	306
10	427	39	415	438
20	719	17	714	724

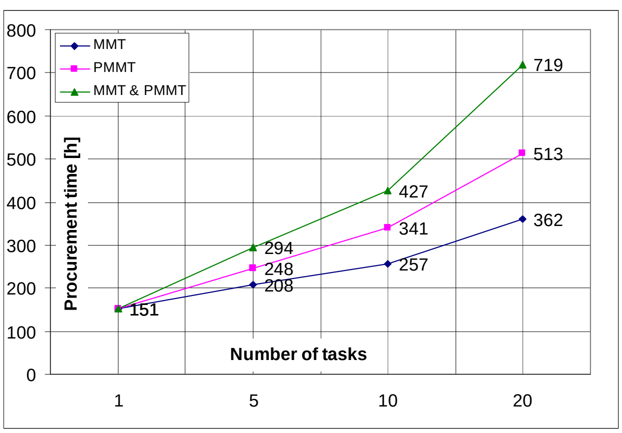

Figure 3: Comparison of various multitasking set-ups on procurement time, ENG=5, ENG/h=1-8h, ENG/c=10%

4.2 Merge bias and procurement lead time

We investigated three scenarios of merge bias. For each we changed only one variable at a time and the other four variables were kept at their default values. Again each set-up was run 10 times, then the mean, standard deviation and the lower and upper boundaries (with 95% confidence interval) of the procurement lead time were calculated.

The number of experts that had to contribute information has a lesser impact on the procurement lead time even in the extreme cases, where only 1 (135 hours) or up to 10 (198 hours) experts were needed. The reason was that the average duration for generating the input was set as low, only 1-8 hours (Figure 4).

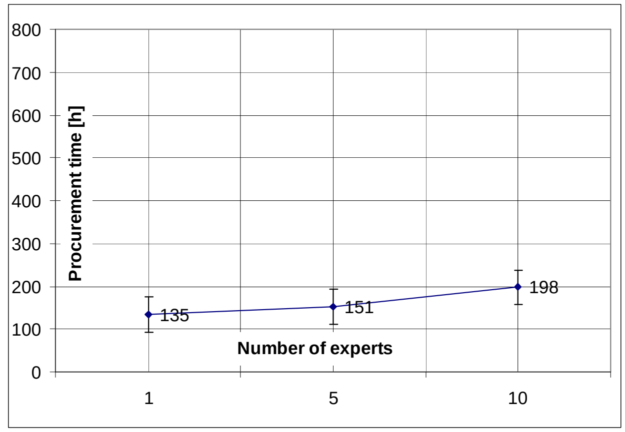

Figure 4: Impact of the number of contributing experts on procurement time, PMMT=1, MMT=1, ENG/h=1-8h, ENG/c=10%

In the next set-up, we changed the expert's task duration (Figure 5). The horizontal axis describes a beta distribution. The value 1 represented the range between 1-8 hours, the value 8 represent the range between 8-16 hours, and the value 40 represent a range between 40-48 hours. The expert's task duration had a major impact on the procurement lead time, if one day (8 hours) instead of 1 hour was needed to generate the input, the required procurement lead time increased nearly three times. If a task required serious calculation and design work up to 40 hours, the required procurement lead time was nine-fold compared to the default case. The standard deviation was high in this set-up, for the mean 151 hours it was 15 hours, for the mean 397 hours it was 154 hours, and for the mean 1361 hours it was 523 hours, respectively. The reason was that after the completion of the expert tasks (1EngInP and 2EngInP) the simulation randomly decided, based on the default commitment percentage of 10%, if the expert should work on the focus task or on some other task. Thus the longer the expert task duration, the more the procurement lead time extended.

Next, the expert's commitment percentage was changed. This percentage describes the fraction of time the person is actually ready to commit to this particular procurement item. We assumed four scenarios, 50% of the workweek (20 hours), 10% of the workweek (4 hours), 5% of the workweek (2 hours), and 1% of the workweek (15-20 min). The 50% and 10% commitment could reflect a project manager or engineers who are primary involved in the project. The 5% and 1% commitment could reflect an owner, user, or an authority whose primary business is not the project.

The results are very interesting. If the commitment percentage increased from 10% to 50% it only reduced the procurement lead time with 30%. However, if the percentage was reduced to 5% and 1% the impact on procurement lead time became significant. The procurement lead time increased to an average of 294 hours and 1,132 hours, respectively. The standard deviation was also relative high in this set-up, 20 hours (ENG/c=50%), 15 hours (ENG/c=10%), 66 hours (ENG/c=5%), and 379 hours (ENG/c=1%).

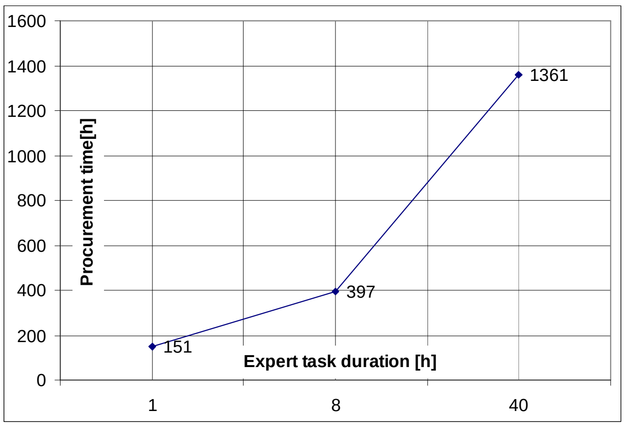

Figure 5: Impact of expert task duration on procurement time, PMMT=1, MMT=1, ENG=5, ENG/c=10%.

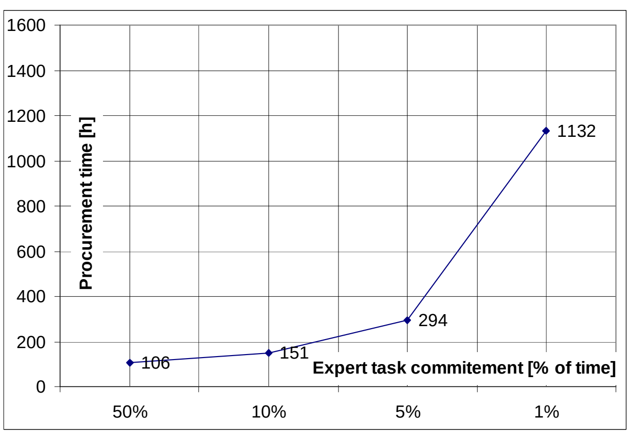

Figure 6: Impact of expert commitment on procurement time, PMMT=1, MMT=1, ENG=5, ENG/h = 1-8h.

5 DISCUSSION AND CONCLUSIONS

The idea of simulating workload and commitment in projects is not new (e.g., Jin and Levitt 1996, Tommelein et al. 1999, Arbulu et al. 2001), however the framework and approach used in this paper provide specific insights into the impacts on procurement of multitasking and merge bias.

The authors were especially surprised to find the significant role played by merge bias, particularly when experts have a low commitment percentage and their task duration is long. The simulation results lead us to speculate that there are at least two factors at play that lead to optimistic duration estimates for procurement in practice: (1) estimators assume that project participants will have a small degree of multitasking and high levels of work commitment so that their duration estimates correspond to values on the left-hand side of the x-axis in Figure 3, 4, 5, and 6; (2), when there is a low level of commitment there also is a greater amount of variability so that any deterministic estimate is more likely to be wrong. Moreover, people that multitask may not appreciate the value or importance of their contribution to the project, and thus erroneously judge how to prioritize their work.

The findings regarding the commitment percentage are also supported by Hopp and Spearman's "law of utilization" (2000 p. 303): as utilization approaches 1, the cycle time approaches infinity. Similarly, when the commitment level approaches 0, the procurement lead time approaches infinity.

The understanding derived from this paper may help to size buffers by more accurately including constraints. In case of multitasking (e.g., if a project manager has more tasks than usual) this has to be considered in the procurement schedule. In case of merge bias (e.g., if input is needed from non-procurement personnel, owner, user, or others, who normally have lower commitment levels for specific procurement items), significant input delays are to be expected. Hence, adequate time buffers in the procurement schedule are needed.

In conclusion, this paper may help particularly non-procurement personnel to understand the impact they could have on the procurement process and thereby on the whole project. In order to not impede the project, they may wish to dedicate personnel to critical tasks. For example, it is well known that in fast-track projects some owner organizations actually assign personnel to be 100% committed to the project (e.g., Rosta 1994). As a result, they notably reduce the time others have to wait for critical input.

Finally, building the simulation model required a detailed description of the current practice, which led to an interesting additional finding. In one of the cases we measured all the labor hours spent on competitive bidding and then we multiplied these hours with an estimated average cost of one employee per hour (40 euros/h). It turned out that this bidding practice cost 10% of the value of all the power distribution equipment that were required in the building, whereas the low bids were within 3-4% from each other. Thus the bidding process consumed more money than was gained (Elfving et al. 2003c).

In future work the authors intend to further validate the basic model with case data, and expand it to include aspects of gaming, such as the deliberate withholding of information and imperfect information exchange, which could include Requests-For-Information (RFI) and rework.

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