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Impact of Project Complexity Factors on Project Cycle Time: A System Dynamics Modelling Approach

Reda M LEBCIR [1] and Jyoti CHOUDRIE [1]

[1] The Business School, University of Hertfordshire, Hatfield, AL10 9AB, UK

Abstract. The aim of this paper if to investigate the factors driving project complexity in construction projects and how they impact on project cycle time. This issue has been addressed by building a framework for project complexity for construction projects and evaluating is impact on project cycle time through a System Dynamics (SD) simulation model integrating project complexity, project operations, and its time performance

The results indicate that project complexity is driven by four factors: Project Uncertainty, Infrastructure Newness, Infrastructure Interconnectivity, and Infrastructure Size and that Project Uncertainty is the most influential factor on project cycle time comparatively to the other factors

Keywords: Project Management, Project Complexity, Project Uncertainty, Project Cycle Time, System Dynamics

1. Introduction

Successful management of innovation in the construction industry is becoming increasingly crucial to the performance of companies in this sector. However, this is a daunting task as rapid changes in clients' requirements coupled with a high rate of technological innovation have increased the difficulty to deliver projects in line with planned time objectives.

One of the influencing reasons explaining the project poor time performance is the level of "project complexity" in the project [1-2]. However, the factors driving "project complexity" are not yet well defined. There is an urgent need for developing a framework for project complexity in construction projects. This is important as project management activities such as planning, co-ordination, control, goals determination, organisational form, and project resources evaluation and management are all affected by the level of complexity in a project [3-4]. The effectiveness of these processes and techniques is a strong determinant of the project cycle time, hence the link between project complexity and project cycle time.

Therefore in this paper, there are two issues to be investigated. First, what are the factors driving "project complexity" in construction projects. Second, what is the impact of these factors on the project cycle time. It is important to remember that different project complexity factors exist simultaneously in the project, however their relative influence on the project cycle time is independent [1]. Whilst it is implicitly known that all these factors contribute to make the project difficult and complicated to manage, it is not fully known how each factor taken individually affects project time performance. The paper aims to address these issues

2. Project Complexity Factors

Although there is an implicit acknowledgement that projects come with varying levels of project complexity [2-3,5-6], there is still a great deal of confusion about the factors driving this complexity especially in the context of construction projects.

For this reason, a new project complexity framework, which is grounded on the generic project management literature related to project complexity mentioned earlier, has been developed in the current research. The framework indicates that project complexity in construction project is driven by the following factors

- **Infrastructure Size (IS):** This refers to the size of the infrastructure to be delivered at the end of the project. It is determined by the number of elements (components, parts, functions, ...) included in the infrastructure
- **Infrastructure Interconnectivity (II):** This represents the degree of "integration" between the different elements of the infrastructure. If this is high, a change in one element will cause substantial rework on the other elements and this require significant coordination efforts in the project.
- **Infrastructure Newness (IN):** This represents the portion of the infrastructure to be innovated from previous projects delivering the same type of infrastructures. A high level of IN indicates that most of the elements of the infrastructure are new to the project and needs to be designed for the first time
- **Project Uncertainty (PU):** This reflects the knowledge gap in the project at its start. If it is high, this means that people working on the project have a limited knowledge about the techniques and methods required to execute the project tasks and a substantial amount of knowledge creation and dissemination will take place in the project before tasks can be completed in the project.

3. Simulation model description

The System Dynamics (SD) simulation model [7] presented here is grounded on and combines the findings of (i) the construction project management literature and (ii) previous SD models in which many feedback structures central to project dynamics have been identified, simulated, and validated.

The simulation model includes several phases reflecting the evolution of construction projects over time. Each phase is simulated through a model incorporating several interlinked sectors such as planning, execution process, human resource management, work allocation, and productivity.

The core structure in the phase model is the execution process sub-system which simulates the mechanisms determining the execution of the project work. Project tasks execution is represented through the transformations affecting the state of the tasks in the project phase from the initial state of "Tasks for planning" until the final state of "Tasks released" (See Figure 1). These transformations are determined by the project activities, which include planning (gathering information about a task execution), base-work (executing a task for the first time), quality assurance (checking tasks for flaws) rework (correcting flawed tasks), and internal co-ordination (communicating with other project workers).

The planning activity generates the necessary information, which enables to carry out the execution activities in the project. During the planning phase, the working team identify project tasks; perform evaluation of the current capabilities and requirements, specify the resources needed to complete the project, identify risks and challenges, determine key project participants, and define sources of required functional support needed to carry out the project work.

Once tasks are planned, they are not released immediately for execution. The information generated by the planning process is kept for a while until a sufficient amount of information is available to allow the start of the development work execution. The development process starts by the execution of the project activities. This is done through the base-work activity, which is defined as the execution of a development task for the first time. Completed tasks are checked for possible flaws. If a task passes this checkpoint successfully, it is approved. Otherwise, the task will have to be corrected (reworked). Approved tasks are put on hold until enough information is generated and released to other phases in the project.

Sometimes, if some tasks are found flawed, the tasks which are connected to them and already approved may have to be reworked again. Once these tasks have been approved for rework, they have to be co-ordinated by the development teams responsible for generating flawed tasks due to execution and the development team who executed the tasks which become flawed due to product interconnectivity. These teams meet to decide about the best course of action to rework the extra flawed tasks. This activity is referred to in the model as "co-ordination

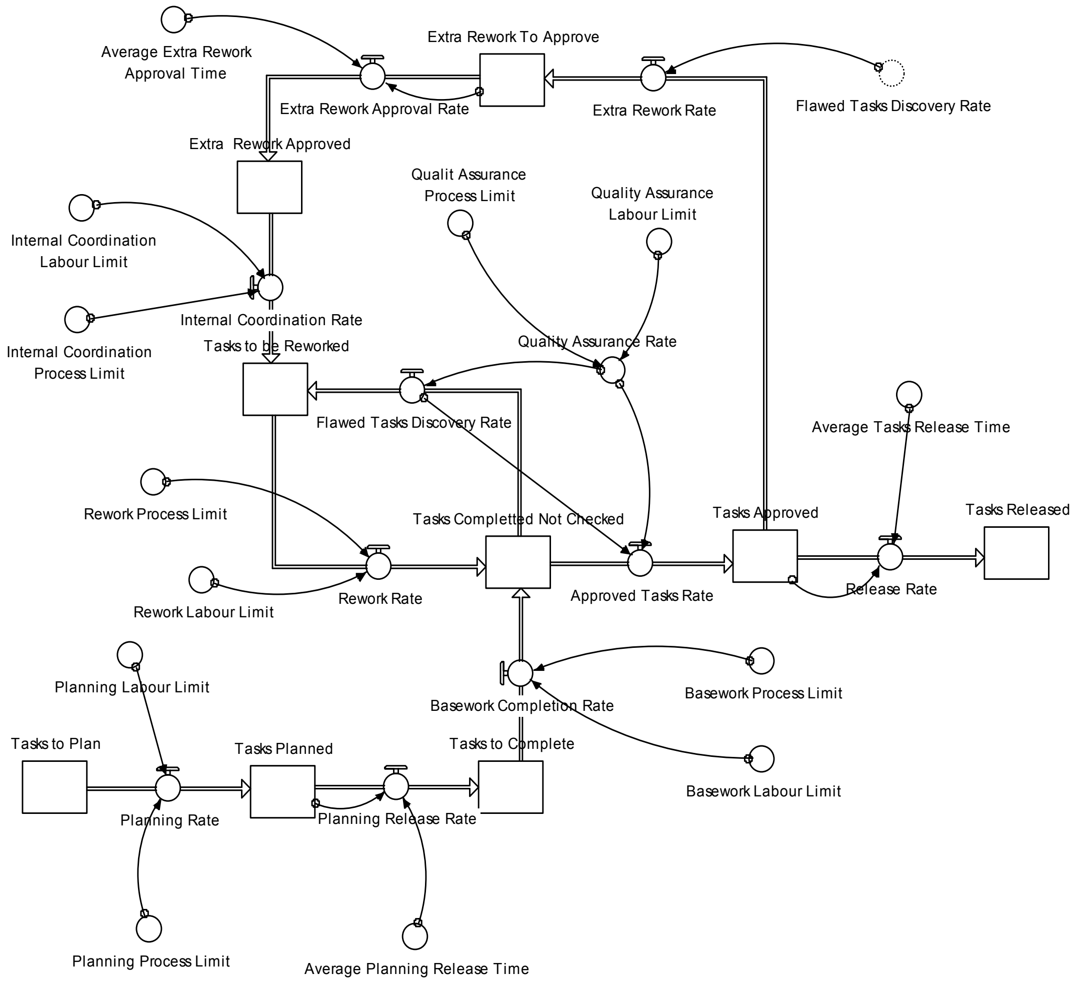

Fig. 1: Evolution of tasks states in the execution process subsystem

The effect of the project complexity factors on the project operational variables is represented through a set of non-linear functions, where each non linear function links an input variable representing the project complexity factor to an output variable representing the effect of the project complexity factor on the project operational variable it affects. As such it is easy to represent the effects of the four project complexity factors on all the operational variables in the project.

Validations tests were performed on the model[7]. The qualitative structure of the model was validated through workshops involving several project teams in the organisation. The quantitative structure of the simulation model was validated by a thorough check of the model equations and variables and by performing extreme conditions tests on the model. The behavioural reproduction tests were performed through comparison of the simulation model outputs and the real world behaviour of a large set of variables on different phases of the project.

3.1. Scenario and results analysis

The experiments on the model were conducted by varying the level of the four "project complexity" factors (IS, II, IN, PU) where each factor was assigned three different levels defined as **"Low"**, **"Reference"** and **"High"** [8]. A scenario represents a project in which each of the four project complexity factors is assigned one of the three levels. For example, a project in which PU is low, IN is reference, II is reference and IS is high is a scenario. Given that we have four project complexity factors each accepting 3 possible levels, the number of possible scenarios is equal to the number of combinations of 4 factors and 3 levels, that is (3^4) or 81.

The simulation model was run for each scenario and the project cycle time was evaluated. In order to understand the influence of the project complexity factors on project cycle time, the average cycle time, for every level of each factor, is presented in Table 1. For example, the average development cycle time for all projects with low PU is 638 days and for all projects with high II is 1285 days.

	Low	Reference	High
PU	638	1150	1378
IN	939	1084	1144
II	766	1115	1285
IS	884	1120	1215

Table 1: Average project cycle time for all levels of the project complexity factors (In days)

An analysis of these results suggest that the impact of the project complexity factors is as follows

Project Uncertainty (PU): Project cycle time is affected by project uncertainty as it tends to increase when the level of PU changes from low to reference to high. However, the increase is not of the same magnitude when PU level increases. Project time goes up much more sharply when PU increases from low to reference than when it moves from reference to high.

Infrastructure Newness (IN): The impact of IN on project time is less dramatic than that of PU. Changes in cycle time show an ascending trend as IN moves to higher levels. However the scale of the change in project cycle time is not substantial especially when IN changes from reference to high.

Infrastructure Interconnectivity (II): II is an influencing factors on project cycle time as the latter climbs as the level of II moves upward. However, the results show that the influence of II tends to be more significant when it changes from low to reference than when it changes from reference to high.

Infrastructure Size (IS): IS appears, to be the project complexity factor associated with the lowest influence on project time. Of course, the cycle time grows as IS increases, however to a less extent than the other project complexity factors. Furthermore, the change in the project cycle time is more important when IS changes from low to reference than when it changes from reference to high.

4. Discussion and Conclusion

The simulation model built in this research and its associated results have yielded some interesting findings. It is crystal clear than project complexity factors have an inflating effect on project cycle time and this is valid for each of the four project complexity factors. The implication of this is that project managers must be aware of this finding as they make the strategic decisions (which determine the level of the project complexity factors) during the formative phases of the project. This is important as these strategic decisions are "fairly immutable after project initiation"[1].

Regarding the effect of each of the project complexity factors, the results show that Project Uncertainty is a strong determinant of the time required to complete the project. Projects involving medium or high PU are associated with far longer completion times than projects with low PU. When making decisions determining the level of PU in the project, project managers must make a trade-off between its effects on the project cycle time, and the other objectives of the project linked to the competitive environment, pricing power, project financial rewards, and so on.

The impact of Infrastructure Newness on project time is less acute than that of project uncertainty. This finding has important consequences for the management of construction projects. Unless the target is to build a low innovation infrastructure, there is no significant difference in terms of the impact of IN on cycle time when its level is medium or high. Other considerations (financial, strategic,...) should be taken in account when faced with these two decisions (medium or high IN).

The structure of the infrastructure (Infrastructure Interconnectivity) is influential on project cycle time. Projects in which the structure is tightly linked take longer to complete than projects in which the linkages are less integrated. Therefore, whenever possible project managers are advised to choose a low II structure as this reduces cycle time. If, this is not possible, then the impact of II is not very different if an infrastructure with medium or high interconnectivity is built. In this case, the decision should be driven by other performance criteria than project cycle time.

As intuition suggests, products including a higher number of elements are finished later than projects including a low number. So, it is preferable to reduce the number of elements in a project. However, the results indicate that once this number is above a certain level (medium or high IS), its effect is significantly reduced.. In this case, other performance criteria should guide the decision making process to set the level of IS in the project

Although this research has addressed some important research questions regarding the factors affecting project complexity in construction projects and how they relate to cycle time, it can be extended in different directions. For instance, it is possible to include other performance indicators (cost, quality) in the model. In addition, it would be interesting to see how these factors interact with some operational decisions such as Concurrent Engineering. Another extension will be to explore the trade-off between the structural complexity (IS and II) and innovation (PU and IN) and its impact on project performance.

In conclusion, it can be said that this research has shed some light on the impact of the construction projects strategic decisions on project cycle time using an innovative tool (computer simulation modelling). Further research is, however, required to further improve our understanding about the relationship between strategic, operational, and the performance of these projects.

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