

Design for Flexibility in Construction Management Practice

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Abstract

Construction projects are often found to be difficult to manage using traditional methods based on PERT / CPM. Researchers have distinguished between linear contexts where traditional methods are useful and complex projects where new methods are needed. The traditional model is based on the premise that the project manager can spell out in complete detail the specifications of tasks much before the start of the project, so that the baseline can be constructed and the progress monitored with respect to this baseline. In a dynamic or volatile environment that exists in many construction projects, this assumption is not only unreasonable but often invalid. Certain types of construction projects are complex engineering systems that have a management or social dimension that depends on the environment in which the project is executed. The numerous interacting components give rise to behaviors that are difficult to predict and understand. This paper addresses some of the issues involved in the design of management control systems for complex

construction projects. We propose that the management system must possess built-in flexibility as an option to address project complexity so that the desired project outcomes are achieved. We also suggest a design based on modular architecture to enhance the flexibility of management response in construction projects.

Keywords: Flexible construction management, modular design, project complexity

Introduction

Construction projects are often found to be difficult to manage using traditional methods. The traditional methods based on PERT / CPM network based approach, with an overarching emphasis on critical path or resource constrained critical path are found to be inadequate for some types of construction projects. This results in time and cost overruns in many construction projects. Several researchers have studied projects that are not amenable to management by traditional methods. There is an old Japanese saying, "if all you have is a hammer, then everything

looks like a nail". There is a felt need for a theory and mechanism to address the issues in managing complex projects. Several researchers have proposed that such a new approach needs to be based on flexibility in management processes as opposed to the rigidity of the traditional methods based on variance control at task or milestone level. This paper addresses some of the issues involved in the design of management control systems for complex construction projects with built-in flexibility so that the desired project outcomes are achieved

Literature Survey

Rittel and Webber [1973] distinguish between "tame" and "wicked" problems. Tame problems are those that can be successfully managed using the traditional approach. In the project context, customer requirements are stable over time, the project outcomes are predictable and project managers can employ the traditional tools and techniques to monitor the progress. Tools and techniques based on PERT/CPM have been found to be useful in such contexts. On the other hand, wicked problems are those that exhibit dynamic and behavioural complexities. These include complexities arising out of delayed response and multiple feedback loops resulting in non-linear interactions between the parts of the project.

Systems that can give rise to such unanticipated (in the linear paradigm) behaviour are said to have emergent properties. Emergent behaviour may turn out to be, in retrospect, either desirable or undesirable. Such behaviour is similar to incidental interactions identified in Ulrich and Eppinger [2003]. In a project context, methodologies such as System Dynamics have been tried to understand the dynamic behaviour. Such models attempt to capture the cumulative effects of work backlogs, reworks, policy responses such as adding resources,

overtime, etc. and factors such as fatigue, changing scope and so on (Lyneis et al. [2001], Stermann[1992], Williams[2005]).

Flexibility in product variants is well established in the automobile industry where platform components and processes are used for common parts between variants (de Weck [2006]). Fricke and Schultz [2005] address the trade-off between customization and differentiation across multiple product lines using platform products in the automobile industry. The ability to balance between the conflicting requirements of customized products and standardized platforms is a source of competitive advantage.

Multi-objective designs are useful in high technology product designs such as large radio telescope arrays (Cohan et al.[2004]), and staged deployment of satellite constellations (de Weck et al.[2004]). While embedding such flexibility in a system to allow for future expansion leads to sub-optimality and short term penalties (in terms of cost of development and weight / size of system), it offers significant long-term benefits. (de Weck and Kim[2004]). Cutcher-Gershenfeld et al. [2004] provide a procedure for balancing different approaches.

In the context of product design, Ulrich [1995] defines product architecture as a scheme by which the function of a product is allocated to physical components. Thus, according to Ulrich, the decoupling across modules is achieved by a modular architecture. Architectural trade-offs have been explored in other contexts as well. Maier and Rechtin [2000] identify four competing tensions out of the several possible conflicts faced during system design and development. These are: Performance, Schedule, Risk, and Cost. System architects face the task of not only identifying and quantifying but also balancing and resolving these tensions.

Kazman et al [1999] discuss the architectural tradeoffs in software design and explore tradeoff opportunities in system modifiability, availability, performance and quality. Bass et al [2003] propose an Architecture Tradeoff Analysis Method (ATAM).

Moses [2004] finds that robustness and adaptability are distinct from flexibility and agility. The distinction is based on the assumption that flexibility and agility require intervention by an external agent (usually human). In contrast a robust system possesses the ability to autonomously deliver the desired functions in spite of changes in the environment or internal variations. Similarly, adaptability refers to the ability of a system to change internally (self-modification) and autonomously (without external intervention) in response to changes in the environment. On the other hand, a flexible system is usually modified from outside the system by a human agent (such as project manager). Agility refers to the rapidity with which the system can be altered to meet the changed circumstances and newer challenges.

Several researchers have devoted their efforts to study the effect of modular design on flexibility of system. Sosa et al. [2003] note that modularity of the system highly impacts the design team interactions. However, critics of the modular approach find that flexibility obtained through modular design involves a trade-off. Gonzalez-Zugasti and Otto [2000] show that some performance may need to be sacrificed locally to obtain goals of the overall platform design. Some functions are duplicated in different modules. Whitney [2004] finds that total modularity is not always desirable and overall system cost and requirements such as space and weight may increase as a result of modular design resulting in less energy-efficient designs in which side effects are also harder to control. Whitney[2004] claims that modular

architectures tend to have more parts, tend to be uncoupled or decoupled and favor "business performance" while integral architectures have fewer parts, tend to be coupled and favor "technical performance". The trade-off issue in modularity is thus between an overall lifecycle view and a high performance technical efficiency view. Braha [2002] proposed a method to decide on a team size based on a maximum number of attributes or functions that a team can handle, and therefore the number of modules gets decided as well. However, Holttta and Salonen[2003] find that there is no agreement among researchers on the degree or extent of modularity, that is, deciding upon the number of modules, which ultimately decides the number of functions that needs to be carried out by each module.

Construction Projects as Complex Architectures

Complex projects exhibit characteristics of "wicked" problems described by Rittel and Webber [1973]. While "tame" problems are amenable to the traditional work breakdown approach, in wicked problems, the outcome of a project as a complete system is not understood by studying the behaviour of its parts, such as tasks, resources or precedence dependencies. Consequently, in wicked problems, one cannot rely upon the management of independent work-packages for managing project outcomes. In other words, one cannot adequately manage "wicked" problems using "tame" problem solving techniques such as PERT / CPM or other network based techniques. Well-defined and pre-decided management processes and controls are of little use in managing such complex projects due to emergence of unpredictable system behaviours.

The traditional model for project management is based on the premise that the

project manager can spell out in complete detail the specifications of tasks much before the start of the project, so that the baseline can be constructed and the progress monitored with respect to this baseline. In a dynamic or volatile environment that exists in many construction projects, this assumption is not only unreasonable but often invalid. Projects that are severely time-constrained or subject to uncertainty, for instance, projects where customer requirements continuously change over time, are particularly vulnerable to complex behaviour (Tatikonda and Rosenthal [2000]). Practitioners of the traditional approach have attempted to circumvent the problem by using time buffers on the task or elsewhere in the network. However, such methods largely continue to rely on a linear control paradigm and ignore the complex behaviour of systems subject to perturbations (Williams[2002]).

Construction projects are complex engineering systems that have a management or social dimension that depends on the environment in which the project is executed. A complex system typically has numerous components and their interactions are difficult to understand and predict. Management of complex projects requires what Senge [1990] calls "systems thinking". The mental model suggested for managing complex projects is one of understanding the interactions between the sub-systems that make up various parts of a whole project. The management concern in the quest for an appropriate control mechanism for such projects is that while a construction project may exhibit complexity, it is futile to design a control system that matches in complexity. In other words, one cannot provide a contingency plan for every foreseen possible outcome. On the contrary, it would be desirable to have a management control system based on simple guidelines arising out of understanding the behaviour of system so that the complexity of control does

not increase with the complexity of the project being managed. Thus, instead of a rigid control system based on parameters such as progress variance, one has to look for a control system that ensures that the overall project objectives are satisfied without significantly adding to the management overhead. Such a control system needs to be designed for flexibility in response to a range of system behaviour so as to contain the complexity.

Flexibility as a tool to manage Complexity

Flexibility refers to the ability of a system to perform under a range of operating conditions. Usually the range of operating conditions as well as expected behavior is pre-specified. Flexibility in management response can be specified and designed for in many ways and at different levels. There can be several approaches to incorporating flexibility. Flexible response emphasises thinking in terms of multiple objectives such as reliability, maintainability, reconfigurability and extensibility. Such thinking produces robust schedules that are more reliable even when several of the initial assumptions go awry during execution. In the construction management context, one can think of flexibility as the ease with which the management processes can be adapted to address unplanned situations or environments as they emerge during execution.

Flexibility in management process emphasizes the exploration of alternatives so as to delay the design freeze point as much as possible and incorporate the latest technologies and information on user needs to the extent possible. This is particularly useful in the context of future uncertainty and emergent user requirements. Ambiguity in "true" customer needs and specifications can be addressed by such flexibility in delivery. At

the upstream design level, this implies a generic development with details emerging as the project progresses. This approach is in contrast to the traditional engineering practice that requires that designs need to be frozen as early as possible. The management process can thus be viewed as flexible, emergent, and with scope for multiple responses and expandable to match the situation.

When a system is flexible, it can operate not only at different pre-specified levels of control variables, but also can be reconfigured to operate back and forth between different levels, providing a range of options to the decision makers during execution. Such reconfigurable systems can reversibly achieve distinct states in order to respond and achieve desired outcomes within pre-specified conditions. However, such transitions may not always be seamless or lossless in terms of time and cost of changeover.

Flexible Architecture for Construction Projects

The architecture of a system is an important determinant of its complexity. During the architecture design phase, several possible designs for flexibility are explored before converging on an approach. As systems grow in size, a stage is usually reached where the numerous inter-connections make the system so complex that it becomes unmanageable. The behaviour of the system is no longer linear and predictable.

More generally, reductionism relies on the assumption that a divide-and-conquer strategy will work in managing projects, and that understanding the behavior of each element and defining each interface correctly and completely will ensure a properly working system. This assumption brings with it a host of other attitudes and methods, generally called top-down, that assume that things can

be preplanned and scripted, and that following the script is the way to get a successful result. In contrast to top-down is bottom-up, in which requirements and system design are expected to emerge over time and by means of trial and error process of interactions between different components. Under these assumptions, no complete script can be written, not all of the events and decisions can be anticipated or scheduled, and the final result is unknown. On this basis, a step-by-step design process beginning with definition of the architecture is impossible.

A related management control concept is one of agility where the control is not only flexible but also changes itself in response to changing environment. In the production context, agility is often accompanied by lean approaches that signify the ability to quickly change over from one pattern to another. In the project context, one can think of similar capabilities to change over quickly as the environment changes.

Flexibility through Modular Design

One way to achieve such flexibility in control is through the use of modular design. Modular design is a well-established paradigm in certain contexts such as product design, where it serves to decouple the complexity of a part or component from the rest of the system. Such components are tightly coupled internally while loosely coupled externally. This design encapsulates the complexity within the module with minimum opportunities for interaction with external components. However, in other contexts with network-like structures, such as in the management of construction projects, identification of tightly coupled platforms may not be straight-forward.

Modular design offers several advantages. At the design stage, such decoupling between work packages helps in assigning work to

different teams based on a modular structure. At the operations stage, a modular design helps to easily locate and isolate the problem component. Modular design also allows ease of maintenance since the entire module can be replaced or outsourced immediately to restore operations, while the module can be sent for testing and repair. An additional advantage is that individual modules can be upgraded, if needed, depending on available technologies and changes in market without compromising system performance. Modular design increases options for outsourcing and allows the use of off-the-shelf mass produced components resulting in economies of scale and scope. In terms of business performance, modular design develops organizational capabilities for executing platform projects that are variations of projects executed earlier by the organization. Such projects share modules that are identical or similar to modules earlier, thus the organization develops core competence in managing such projects. All these become possible because the modules are loosely coupled with the rest of the system.

In a product development context, a modular architecture includes a one-to-one mapping from functional elements in the function structure to the physical components of the product. Similarly, one can obtain a modular architecture for development by assigning one-to-one responsibility for development to different development teams. In contrast, a non-modular architecture, such as an integral (or integrated) architecture includes a complex (non one-to-one) mapping from functional elements to physical components and/or coupled interfaces between components.

In a construction project context, a modular architecture can be thought of as a set of linkages arising out of the work breakdown structure with loose coupling between the

work packages. When work packages are tightly coupled, such as when work packages carried out by different contractors are lined up in close precedence sequence, the design is not modular. Any delay by any component propagates and has a cascading detrimental consequence for the following work packages. Similarly, when common resources are used along parallel paths, delays can be transmitted across the paths. Designing schedules to exhibit independence between modules is not trivial. Even in engineering systems where component behaviour is well predictable, a fully modular design may not always be possible. In organizational and social systems where projects are executed, modular design is much more difficult to obtain. However, where possible, modularisation allows flexibility in change of scope arising out of changing customer specifications, changes in technology, or changes in due date commitments. It also allows rapid response to changes in availability of resources and raw materials. This results in greater robustness of schedules. Thus, a traditional PERT/ CPM schedule can appear to be technically attractive because it is tightly coupled. However, such schedules lacking in flexibility show unacceptable behaviour in execution. Small perturbations in a task, resource or any component can result in cascading and magnified consequences for schedule performance.

Conclusions

While several researchers have explored the benefits of modular design, the extent of benefits that can be obtained and the extent to which modularization should be implemented is still subjective. There is no consensus on performing tradeoffs between the flexibility obtained through modular design and performance efficiency obtained through integrated designs. The existing body of literature has numerous examples of modular architecture in the context of product

development. However, the concept of flexibility as an option and use of modular architectures to manage complexity in construction projects has not been adequately explored.

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Biography

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