Management of complex underground construction projects

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Abstract

The complexity of underground projects confronts many project clients with serious manageability problems. This complexity is the basis for this article, which analyzes the considerations that should be made when setting up a project organization in order to keep the process of implementation manageable. Project organization is analyzed closely, with a focus on the interface between project managers and functional managers and the information asymmetry between them. Some real-life examples will show that dealing with uncertainty and thereby increasing manageability are seldom accomplished by increasing available information, but rather by reconsidering the project organization.

Keywords: project management, multi-actor systems, information processing.

1 Introduction

Underground construction projects, particularly those in urban areas, ostensibly experience more significant problems than other infrastructure engineering projects. In many underground projects, technology is more challenging than in other infrastructure projects, increasing the chance of failure. Moreover, in underground projects the consequence of eventual failure is often more profound than in other projects, increasing the overall consequences of failure. As a result, underground projects have a reputation for being risky because they are susceptible to implementation problems. Society's growing demand for space, however, makes us heavily dependent on underground space to satisfy contemporary spatial claims.

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High levels of risk make underground projects more difficult to manage than many other construction projects. This article attempts to dig more deeply into the manageability of the complexity of these projects. This should provide ideas about how to set up a project organization to best handle the efforts this requires. To do so, the complexity of underground projects will first be analyzed in section 2. In section 3 the main manageability problem of organizations dealing with this complexity is identified. Subsequently, details from some real projects will show the virtues and drawbacks of some types of project organizations in the face of complexity, particularly in terms of their ability to handle manageability problems. Section 5 will briefly present conclusions about considerations that should be taken into account when designing an organization for an underground project.

2 Complexity

In this section complexity will be discussed in terms of characteristics of complexity in the configuration of projects (differentiation and interdependence) and two characteristics affecting the complexity of the project management process (uncertainty and information).

2.1 Differentiation and interdependence

Projects are built systems that consist of elements and connections [1]. These constellations of elements and connections have a certain degree of complexity. Baccarini [2] describes complexity with the terms *differentiation*, i.e. the number of varied elements, and *interdependence* or connectivity, i.e. the degree of interrelatedness between these elements. The complexity of a system increases as the differentiation of its elements and the extent to which they are interdependent increases. Underground projects often have a high level of both differentiation and interdependence, due to the often complex and vulnerable working environment and the important interface with the soil.

Not only can the technical/physical domain of a project be seen as a system: its organization can as well [2, 3]. In organizational systems actors are the elements and the relations between them constitute their interrelatedness. Organizational systems can therefore also be characterized by the concepts of differentiation and interdependence.

In the remainder of this article the focus will be on project organization. A project organization consists of the constellation of actors steered by the project client to realize the underground technological artefact. The project client is the actor who is put in charge by the project owner to implement the project. The remainder of the project organization consists of engineering designers, construction contractors and consultants. In this multi-actor system there is an important distinction between *project managers* (who are usually working for the client) and *functional managers* (engineers, who are working for the other actors) [3]. The differentiation between these actors is made in terms of competence, values, interests and resources (cf. [4]). Differentiation also incurs

interdependence in this system. The project management unilaterally requires the resources of the other actors. It also has decision-making authority, which the others usually do not have; the main interest of contractors, for example, is in making a profit. The focus in the remainder of this article will be on mechanisms that can be used to manage complexity in these multi-actor project organization systems. While taking effect in the operational project organization, at the early stages these mechanisms can be important considerations for the project owner when setting up a project.

2.2 Uncertainty and information

Based on Jones and Deckro [5], Williams [6] adds *uncertainty* to differentiation and interdependence as a third aspect of complexity. Galbraith [7] defines uncertainty as the gap between the information that is required and the information that is available. The challenge of realizing the technical system conditions for the information required and the organizational system should be considered on the basis of:

- The amount of information available within the project organization;
- The information processing abilities of the project management.

The pace of the growth of expertise, however, often has a hard time keeping up with the pace of the growth of complexity of underground projects. The natural response would be to involve more actors with information resources. But the uncertainty gap can also be narrowed in another way, namely by optimizing the project organization, thereby increasing the ability to process information.

3 Manageability

Given this complexity, what can project owners do to keep a project manageable? From section 2 it follows that the project organization should be able to deal with differentiation, interdependence and the processing of information. Owners commissioning a project should therefore keep the following in mind:

- How many actors can be managed?
- How potentially divergent are these actors' values, interests and resources?
- In what ways do the client, designer and contractors depend on each other for information and decision making?
- How is information in the organization processed?
- Do the information processing abilities meet the requirements for the particular technical system?

The interdependence between the project managers and the functional managers is based on the fact that functional managers generally have the most information about the system to be built and project managers have the decision-making authority In other words: project managers need the functional managers' information in order to make decisions and functional managers need the project managers' decision to apply their information in building the

technical system. In this relationship there is a strong divergence of values and interests between the client (project managers) and other actors (functional managers) [8]. The main interest of most private actors is making money, whereas the interest of the client is fully connected to the project's performance benchmarks (implementation time, cost, scope, quality [9]).

Information and expertise – the main instruments to cope with uncertainty – are thus resources of strategic value that parties are not automatically willing to share. Clients depend on actors who have more understanding of the system to be built, but with not necessarily the inclination to act in alignment with the client's interests. This situation is commonly known as the principal-agent problem [10]. Manageability can, in large part, be assessed by the existence of the principal-agent problem between project managers and functional managers. Moe [11], Müller and Turner [12] and Winch [13] characterize this problem in two ways:

- *The adverse selection problem*. Bad results may occur due to information asymmetry between project managers (principals) and functional managers (agents) or between client (principal) and contractor (agent). The agents in these relationships know more about the risks involved in a project than the principals. It is therefore difficult for the principals to make good assessments. Moreover, if a project must be completed with a challenging design or a tight budget, it is likely that the winning bid is not the best option.
- *The moral hazard problem*. The project managers are only looking out for their own interests. They will do what is best for themselves and only do what is best for the owner if their interests are aligned.

4 Ownership and management

Considering that it is difficult to keep up with the information required, information processing may provide an answer to the challenges of complex underground projects. When considering the project organization as a means to achieve better manageability, the commissioner should keep the complexity of the organization's configuration – i.e. differentiation and interdependence – in mind. Particular attention will go to the interdependence of project managers (clients) and functional managers (engineers), where the management of differentiation and interdependence manifests most particularly. A few examples will show the patterns of manageability in the project organization that are relevant when considering the commissioning of a project.

4.1 Project organizations in practice

Project organizations can be broadly classed into five forms according to how they deal with differentiation and interdependence. To describe these forms, multiple actors have been simplified into three main actors that are distinguished in the project organization: the client (project manager), the engineering designer and the construction contractor (both functional managers). One party can play more than one role. In addition to this, there are often other actors involved, such

as consultants and insurance companies. They are not considered part of the project organization, but may be important as a source of information. The client is the organization that is principally responsible for the performance of the project. Manageability will therefore be analyzed from the client's perspective.

First, a project owner may delegate a project to a designated project management entity, which acts as a client of both an engineering designer and a construction contractor. The engineering designer delivers a design to the client and the client procures a construction contractor to implement it. It is common that the engineering designer oversees the realization of his design by acting as a director for the construction contractor. The client remains responsible for the most important decisions on the basis of available information and the assessment of this information by the designer.

A second possibility is that the client has sufficient expertise to complete a design and to oversee its realization, and simply hires a construction contractor to build it. A third option would be to install a client who completes the design, but separates the roles of designer and director by hiring an external project director. The fourth possibility is that the engineering designer and contractor roles are combined in a 'design and construct' contract. In such a case the contractor acts as its own director and the client offers only framework guidance. The fifth possibility is that all roles, similar to the fourth option but including clientship, are united in one entity. In such a case, the owner provides only a framework and leaves interpretation and completion entirely to a contractor or group of contractors.

4.2 Manageability in practice

How do different types of commissionership retain control over the project and in the meantime generate or process sufficient information and expertise to minimize the uncertainty gap, so that performance benchmarks can be met? To find out, a few practical examples of underground projects will be presented. It should be noted that it is very difficult to value the different types of project organization definitively, as every single project is unique, and complexity differs from project to project. A project that is a bit less complex and was carried out successfully has not necessarily performed better than a very complex project that has encountered certain problems. Moreover, the level to which performance benchmarks were met may influence the assessment of manageability. This section will therefore show a few *patterns* of (un)manageability. All cases were part of research by the author.

4.2.1 Separate client, designer/director and construction contractor

The most vulnerable clients are those that are fully dependent upon other actors when making decisions about the technical system. Nevertheless, they are numerous. And the more complex a project, the more likely it is that the owner will hire external designers and contractors to implement it for the simple reason that the expertise of the client falls short. Two projects will show the hazards of this situation: the Souterrain project by the Dutch city of The Hague and the Central Artery/Tunnel Project by the Commonwealth of Massachusetts in Boston (USA).

4.2.1.1 Souterrain, The Hague

The Souterrain is a three-storey underground structure in the centre of The Hague, consisting of a tram tunnel (lowest storey) and a two-deck underground car park. The municipality of The Hague was the owner of the project. It set up a project organization within its own city management department. As it was not very skilled or experienced in tunnelling, it hired a private engineering designer who would also oversee (as a project director) the implementation of its design by a private contractor.

In the procurement phase, the preferred bidder for the construction job questioned a part of the design that would seal the construction pit to be sealed during construction work. This design was relatively unproven and had, for cost reasons, been put together with limited robustness. Neither the contractor nor the insurance company wanted to accept liability for this part of the project. The engineering design firm stood by its design. This put the municipality in an awkward position, as it did not know how to weigh the comments of the contractor and the insurance company. Were they sincere or were they acting strategically, so that they would not have to accept liability for any possible risk? The municipality, which did not have the expertise to assess the technology on its own, retained the engineering designer and decided to proceed with the existing design. The contractor did not block the process, as liability could now be waived and the project was very important for them. They had won the tender with a surprisingly low bid, which was an extra reason for the client to be suspicious about requests for changes that might result in additional work.

One and a half years after the start of the implementation, the tunnel under construction was flooded as a result of a breach in its seal. In the subsequent process to find a technique to finish the work, the contractor played hardball, strongly distrusted the designer and after threatening to withdraw was allowed to finish the project with its own design and its own – expensive – technology [14].

This case shows, first of all, the difficulty that project management has in valuing input from engineers who are considered to be more skilful than they are, but it also shows another dimension of the moral hazard problem. The question is not only whether contracted experts are willing to share their information, but also whether the information from different ‘agents’ may be contested and therefore be difficult for managers with less engineering expertise to assess.

4.2.2.2 Central Artery/Tunnel Project, Boston

The Central Artery/Tunnel Project was a scheme to rebuild Boston’s Central Artery, an elevated expressway that cut up the downtown area, repositioning it underground. The project was too extensive to be detailed here. Basically it was composed of many subprojects: a downtown tunnel, a connecting cable-stayed bridge, two consecutive tunnels under the harbour to the airport, and many additional sections. The tunnels had to be woven between many existing structures, both above ground and underground. It took about fifteen years to build all parts of the project.

Prior to the start of construction, the project owner, the Massachusetts Department of Public Works, had been downsized and was not equipped to

manage the whole project by itself. Therefore, the department hired a large management consulting firm to make preliminary designs and to oversee implementation. This meant that the management consultant was supposed to oversee the contractors and designers and the Department of Public Works had to oversee the management consultant. The size and internal variety of the project's technical system resulted in 38 different section design consultants being hired and 142 construction contracts being issued [15, 16].

During the work a large number of claims and changes were filed with the project's management. In many contract areas differing site conditions were in effect and during implementation many minor design changes were made that led to changes in contracts. All the claims and changes piled up at the project management's office. Many of these necessary changes are said to have been the result of flawed designs by the management consultant [17–19]. However, as the owner did not have the expertise of the management consultant, it depended heavily on the consultant's work and could not assess on its own whether the numerous claims for changes resulted from flawed work.

In the meantime, costs grew massively during construction. This was partly caused by inflation, but also by the numerous changes, along with various other reasons. The growing cost overruns and troubled decision making did persuade the project owner to reconsider its project organization. The owner put together an Integrated Project Organization (IPO). Previously, many positions were held by employees of both the owner and the management consultant. In the IPO the most qualified person would stay and the redundant position was removed. By doing so, the two organizations were melded into each other. The owner hoped to move closer to information resources by doing so, but in practice this impeded oversight even further. It saved costs but also removed the checks and balances that were in place within the project organization. Considering that the management consultant was paid cost-plus-fee, the management consultant did have some interests that diverged from the client [17]. As a result, it has been difficult, if not impossible, to assess whether the management consultant did a good job.

This project shows another example of the difficulty a client has in managing hired engineers, particularly when processing input from many contractors, and the inability of providing oversight when it depends heavily on an actor with its own values and interests.

4.2.2 Client as designer/director

A different interpretation of commissionership is found in the Stadtbahn tunnel construction in the German city of Dortmund. In 1969 a grid of three tunnels was planned in Dortmund's inner city. The work would take place sequentially for over thirty (eventually almost forty) years and, to this end, the city decided to set up a designated Stadtbahn construction department, equipped with some eighty engineers. This department has now finished the last stretch of its work. Although specifications for this stretch were drawn up by an external engineering agency, implementation by construction contractors, direction and oversight were managed by the Stadtbahn department's in-house engineers. This

department could also manage all decision making on technical issues, backed-up by a geo-technician and a specialist tunnelling engineer (from the same agency that had produced the specifications). The project managers from the Stadtbahn department and the functional managers from the construction contractors remained strictly separated throughout the implementation, in order for the Stadtbahn department to be able to provide oversight [20].

With its own expertise, the Stadtbahn department as client prevented dependency on the construction contractor's information. The most important external provider of expertise was uncoupled from the actual implementation of the project and, hence, had hardly any interests or values that diverged from the client's.

4.2.3 Designer/contractor as owner

Recent developments have added new types of commissionership to the traditional ones. Possible motives are the decentralization of expertise from government agencies to private firms in many countries, the unavailability of funding or the sharing in or exclusion from (financial) risk that can be obtained.

The Herrentunnel in the German city of Lübeck was designed, built and financed by a consortium of banks and construction firms. They could use the funding provided by the federal authorities to the City of Lübeck and will maintain and operate the tunnel for a designated concession period, after which the tunnel will be transferred to the city. In the concession period the consortium can earn back its investment by levying tolls on users. The city did not participate in the implementation and provided only a framework of conditions for a fixed link across the river Trave [21].

The benefits of this consortium are not only that the city gets a tunnel it did not have the money and expertise for, and that it does not have to cope with risks of construction, but it also reduces uncertainty since the primary decision-maker has direct input and access to information. As the interests of the banks and construction firms are similar, the construction firm no longer has an incentive to provide information strategically. This nullifies the moral hazard problem and as there is basically one actor for design, construction and maintenance, there are hardly problems of contested information.

4.3 Project organizations and the manageability problem

The inclination to include more information in project organizations to manage complex underground projects is a 'mono-actor' response to complexity. In reality, as the examples show, project organizations are multi-actor systems.

In such systems not only resources, but also values and interests may diverge. Due to principal-agent problems between project managers (client) and functional managers (designers and contractors), uncertainty may remain despite the availability of more information. The above shows that this problem can be tackled with alternative project organization set-ups. The expertise of the client is important in these set-ups. The cases show that simply hiring actors with information resources may not suffice; the ability of the client to process information in order to make decisions is important as well.

5 Conclusion

The natural response to complexity and uncertainty when commissioning and managing complex underground projects is to add more actors to provide more information. Although uncertainty is defined as the gap between the information that is required and the information that is available, more information does not always lead to less uncertainty, as the inclusion of more actors increases differentiation and interdependence and, hence, complexity. As a result more information resources do not always lead to more understanding. Information may be contested, used strategically, or difficult to process. Moreover, decision makers are usually not the actors with the most extensive information resources and the principal owners of these resources are often not the ones who make decisions. This all keeps uncertainty intact. Rather than attempting to increase information to reduce uncertainty in traditional project manager-functional manager relationships, avoidance of the principal-agent problem between those two types of managers may provide more support. When considering commissionership, owners should particularly keep in mind the way the foreseen actors in the organization will have to cooperate, how they depend on each other, and what this means for dealing with the inevitable uncertainty of these projects. A well thought through set-up may maximize manageability and thereby increase the chance of meeting project performance benchmarks. It may require project organizations that differ from the ones that are most familiar to many owners.

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