Bi-project management in engineering complex industrial construction projects

Velde, Robert R. van der; Donk, Dirk Pieter van

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Drs. Robert R. van der Velde and Dr. Dirk Pieter van Donk*

SOM-theme A Primary processes within firms

Abstract

Engineering large industrial construction projects is usually a complex task with several co-operating actors. This paper investigates such projects, characterised by two main actors: the owner of the installation (the client organisation) responsible for the engineering of the production process, and an engineering office responsible for the construction related parts. Usually, both parts are complex in itself. This paper focuses on the relation, dependencies and influences between the two parts. The main questions are what is specific in co-ordinating the two parts, how can co-ordination be achieved and how can disturbances be handled with without delaying the progress of the project as a whole. A framework, which distinguishes four areas is presented to understand the interrelationship better. Each of these areas must be paid attention to in order to control the complexities of these projects. The framework helps to understand the specific nature of bi-project management. Implications for effective bi-project management are presented along with a number of potential areas for future research.

Key-words: bi-project management, industrial construction projects, interaction, project control

* *Faculty of Management and Organisation, University of Groningen, P.O. Box 800, 9700 AV Groningen, The Netherlands, d.p.van.donk@bdk.rug.nl*

Introduction

Imagine that you are building a new plant. A few weeks before the production machinery will be installed, it turns out that the lay-out of the production lines can be improved. As a result part of the foundation is not supporting the machinery rightly and a lot of work is needed to find the best overall solution. This kind of problem is just one (although an extreme) of the numerous examples, we heard in studying project management in (re)building plants for the petrochemical or nutrition industry. We found that the actors involved are faced with an enormous challenge concerning the control of the project. Depending on the extensiveness of the industrial construction project (new or rebuilding), the investments that are involved range from 2.5 million up to 60 million Euro. Even minor improvements in controlling these projects can have significant effects on the final sum of investments. Industrial construction projects consist of two separate, strongly dependent sub-projects. One sub-project is concerned with the production-process-related parts, while the other is concerned with the construction-related parts. This construction sub-project is contracted by the industrial client organisation to an engineering office. Usually, the process-related part is more complex and uncertain; the construction-related part starts later and has to be finished earlier. This specific combination of two distinct, but related projects, having different duration; performed by two parties, having a customer-supplier relationship, is not yet addressed in the literature. Especially, questions as how to tune the two parts of the project and how to deal with disturbances in one part of the project influencing the other part, are specific to what we have labelled *bi-project management*.

At first glance, this may look like an example of multiproject management. However, multiproject management concerns situations in which one organisation deals internally with several projects simultaneously. It addresses the management and control of a portfolio of projects in the most effective and efficient way. A number of authors has addressed this kind of project management[1, 2, 3, 4]. In bi-project management two parties are involved, so the situation is definitely different. Construction projects have been dealt with in the literature, as well. For example, Low[5] recently states that ‘over a sustained period of time, the building industry has continuously strived for better methods of working to achieve time, cost and quality objectives’, a search which, as he states, ‘has led to promising results’. However, little attention has been paid to project-control-related problems in complex, multidisciplinary industrial construction, as dealt with in this article.

Nowadays, bi-project management (which will be elaborated upon in the sequel) is growing in importance. First of all, engineering offices struggle with the dilemma how to offer their clients a high service level, while at the same time improving the control of their own sub-project and as a result keeping the costs of rework low. Moreover, clients expect that an engineering office is able to react to changes in the production-process part, without charging extra costs or loosing time. Clients also expect guidance and support from the engineering office, as they are the ones with experience in other projects. Due to growing competitiveness in the market of engineers, the engineering offices simply can't afford to conduct 'over-the-wall' communication with the client organisation. In order to offer the client the service and quality asked for, the engineering offices should be willing and able to function almost as co-maker, assisting in finding 'the best' solutions at the lowest cost.

This article offers understanding of the nature of bi-project management and ways for improving control in these projects (in terms of time, cost, and quality) by applying an interaction-based point of view. Insights and concepts to improve the co-ordination between the two parts and thus the project control of industrial construction projects are presented. We restrict ourselves to engineering activities and development tasks and exclude the final physical realisation of the production plant.

This paper is organised in five main sections. First, the characteristics and problems of industrial construction projects will be considered in more detail. Second, attention will be drawn to different normal control practices, as applied in current practice. Third, a framework is presented to describe and analyse interaction between the two sub-projects, which results in a number of control mechanisms. Finally, conclusions and management implications will be formulated along with some topics for future research.

Main characteristics and problems of bi-project management

In our opinion, four characteristics distinguish bi-project management from other forms of project management.

First, a *great number of disciplines* are involved in industrial construction projects. Both sub-projects distinguished can be divided in a number of disciplines. The production-process-oriented sub-project is the most complex. Depending on the precise nature of the project, disciplines such as processing, piping, product routing and logistics, mechanical-, electrical- and instrumentational engineering and construction will be involved, represented by specialists from within the client organisation as well as from machine and installation vendors. Additionally, non-technical disciplines such as finance and personnel will influence the execution of the project.

Second, the production-process-oriented part of the industrial construction project (from pre-engineering to installation) is always undoubtedly *leading* with regard to the construction part of the project. Leading means that the investment involved is much higher (80 % vs. 20 %), but also that the construction characteristics are derived from the production-process characteristics. This can also be seen as a (industrial) customer - (construction) supplier relationship, in which customer demands define the activities of the supplier. The industrial client organisation expects the civil engineers to support the production process-oriented part of the project. Whenever mechanical or production installation related adjustments occur, regardless of the phase the project has reached, the construction implications have to be matched to the new requirements imposed by the changed production-process characteristics, as is illustrated in Figure 1. For example, imagine that the place of a production installation alters. As a result, the foundations of the installation, as part of the construction tasks, must be 'moved'. Depending on the stage of the project, that involves some or a lot of engineering rework concerning the foundations. In the most extreme case, foundations, which have already been constructed, must be removed. Rework loops of this kind cause extra costs, time pressure and, of course, additional complications in terms of project control. As a general rule, one might argue that changes in the process-oriented part save money or yield a better solution in a qualitative sense, while adaptations in the construction-related part cost money and time.

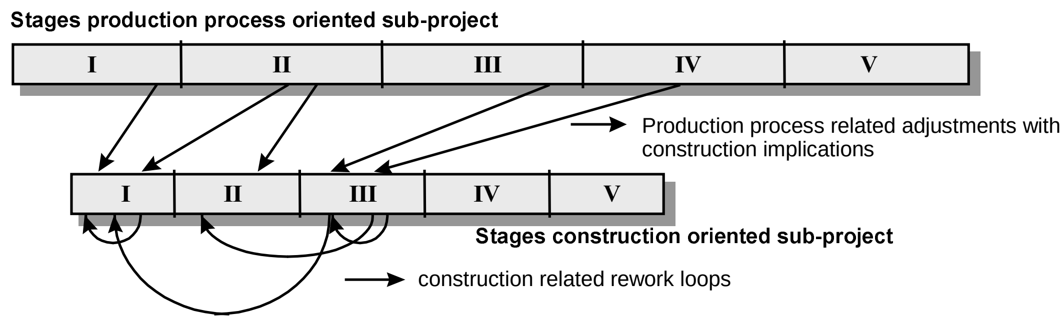

Figure 1: Production process related adjustments and construction related rework loops

Third, the *difference in time-span* of both sub-projects is an important characteristic of bi-projects. The construction engineers start their activities a considerable amount of time after the start of the production-process-oriented activities of the industrial client organisation. Usually, some basic starting-points with respect to the installations have to be established, for example those concerning the location and dimensions of the production installations. Only then can the construction engineers start their activities, such as engineering the exact location and characteristics of the foundations or the dimensions of the buildings 'surrounding' the production installation. Additionally, the construction engineers have to terminate the construction sub-project before the actual production installations can be placed and installed. As a result, the time-span in which the construction engineers have to conduct their activities, is quite narrow compared to the production-process-related sub-project, as is shown in Figure 1.

A last characteristic is the *different nature* of the two parts of bi-project management. Construction activities are normally ordered in a relatively conventional, linear process or step-by-step approach[6, 7]. On the other hand, the client organisation conducts a more iterative, dynamic and not easy to predict process, which it expects the engineering office to follow and to adapt to flexible, without asking extra fees for

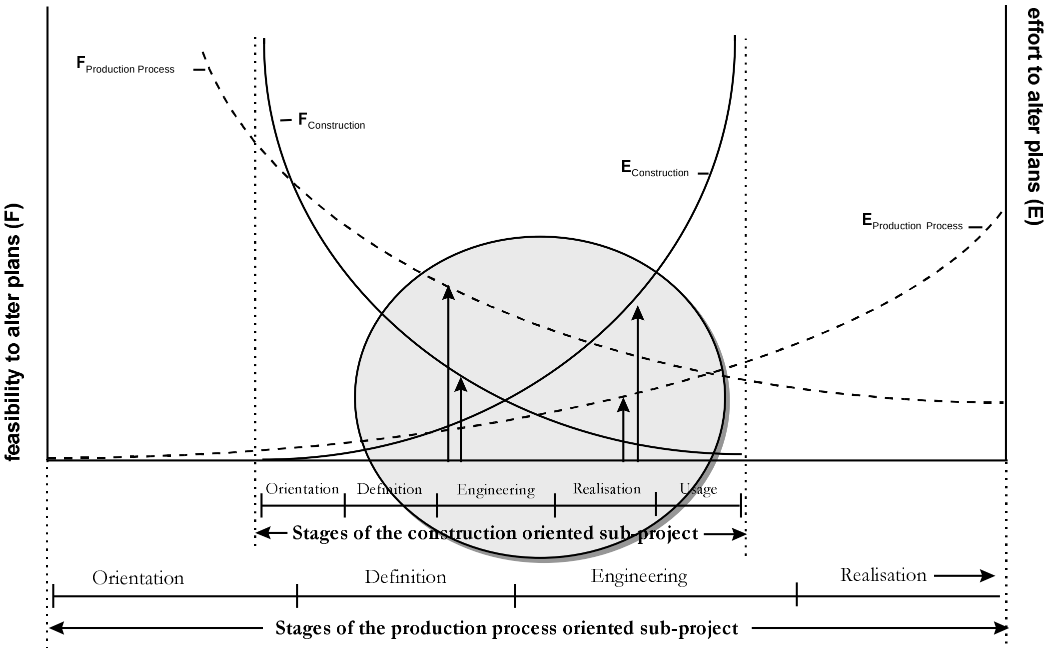

Figure 2: Feasibility versus effort to alter plans

rework. As competition is fierce, engineering offices must be able to meet these expectations. In that, especially the management of the relationship and interactions between the two parts of the project is pivotal.

Figure 2 illustrates the possibility of altering plans during the project phases related to the difficulty in realising those alterations. Time-dependent relationships and differences in project time-span certainly cause problems for the construction engineers. While the industrial client organisation can still change its detailed production- process specifications with relative ease, the construction implications can only be translated with great effort. The engineering of several construction parts has to be reworked at extra cost. At the same time, the rigorous time-scale constraint remains. As a result, at every new rework loop, the time pressure on the construction engineers increases.

The failure of normal control practices

A natural and straightforward reaction to the characteristics and problems mentioned in the previous section seems to be strict planning and control of the whole project. Usually, at least the following is pursued.

In order to control complex construction projects, a statement of work is used to describe and/or estimate the job to be done. This should designate the specifications that will be applied as specifically as possible. Its function is a kick-off for the control process of the individual actors. These control processes aim at coping with the 'Triple Constraint' (time, cost and quality). As the control process of the engineering office is most influenced by disturbances by the other part, it is interesting to look at control, there. Usually, it consists of the following elements:

- First, during the project, it will be checked whether the project meets its goals in terms of time, cost and quality. Often a systematised approach like Systems Management[8, 9] is used, in which project information concerning the three constraints is written down and checked with goals at the transition of one project stage to the next.
- Second, the process of controlling is a combination of written information and verbal commitments. Agreements are primarily made during institutionalised meetings. In addition, ad hoc communication is important as well; they are, in fact, essential in exchanging the information that is needed to perform the interrelated activities. Agreements are written down as much as possible to function as contracts and plans that reduce uncertainty. As visualised written information, technical drawings play an important role in the communication between the client organisation and the

engineers. The drawings are internally as well as externally revised at several stages during the project. They illustrate the reduction of uncertainty simultaneously combined with a growing insight into technical details.

- Third, quality management has earned a significant role in the functioning of actors in the construction industry[10] to attain acceptable levels of quality. There is some doubt if quality control procedures that work in production industries are suitable for the construction industry[10]. Still, organisations in the construction industry use a quality assurance system, consisting of handbooks, procedures, work instructions and forms to show their commitment to quality. Such a standardised, formal quality management system can be regarded as a blueprint for the way in which the organisation and its members ought to function and is therefore part of the control practices.

Despite the use of the control elements as described above, we learnt through interviews with engineers and client organisations in an extensive case-study, that in many projects these control mechanisms proved to be insufficient for at least three reasons:

- First of all, the construction engineers have little influence on the leading part of the industrial project.
- Second, the production process-oriented project part is more complex and dynamic than the construction-oriented project activities. Most production-process adjustments result from ‘growing insights’ in the complex production installations and the production-process they compose. The number of these adjustments should be kept to a minimum, but the detail engineering and optimisation of the total production process always have the potential to create changes.
- Finally, construction engineers cannot simply rely on a formalised process in which all changes concerning the characteristics of the production process, including the construction implications, are written down as precisely as possible. The parties involved, of course, should strive for this as much as possible. However, the experiences with industrial projects teach us that control mechanisms exclusively aimed at formalised control do not result in straightforward success.

The regular project management (control) literature[7, 9, 11, 12] does not address this kind of project management problems as well, nor does it offer methods and paradigms to solve the control problem. The next section tries to fill that gap.

A framework for analysing interaction

In building a framework for a generic and normative description of the interaction between the client organisation and the engineering office, we distinguished two dimensions: *internal-external* and *technical-organisational*. Internal and external relate to whether the focus is on the engineering office (and the construction-related part) or on the client organisation (and the production-process part). Technical and organisational distinct the ‘nature’ and type of information in the project: technical information related to the product as opposed to organisational information regarding process, responsibilities, agreements, etc.

Combining the two dimensions gives four main areas of attention, labelled as ‘basic inter-action structure’, ‘key-document structure’, ‘uncertainty’ and ‘influence’. The meaning of these areas will be explained below. Figure 3 illustrates the relationship between the dimensions and the four areas of attention. Each area emphasises a particular aspect of the interaction between client organisation and engineering office. Of course, these areas are not independent of each other. We will pay attention to the relationship between the quadrants (areas of attention) in the section regarding the key-document structure.

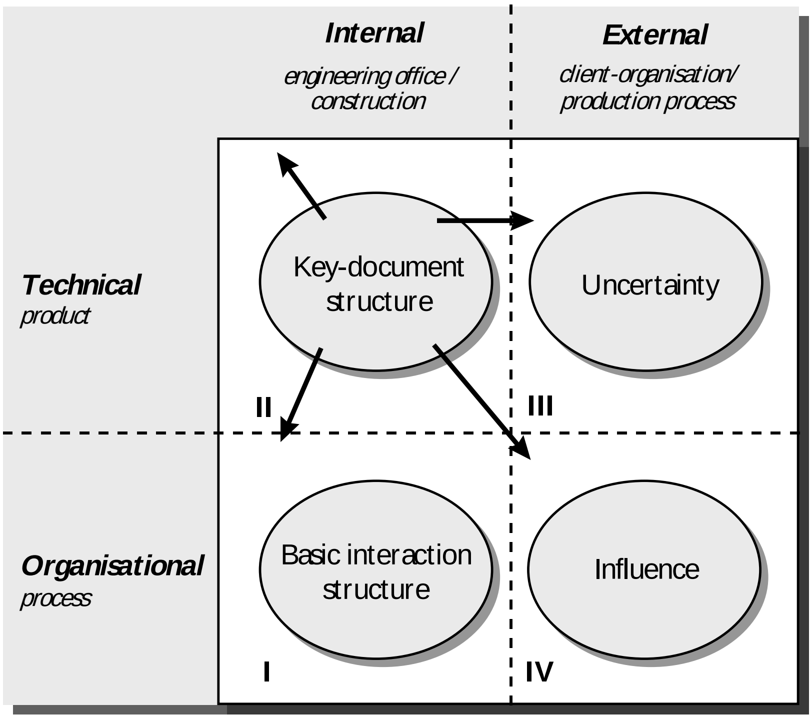

Figure 3: The dimensions and areas of attention

It is interesting to note that Figure 3 clarifies the fundamental difference between ‘normal’ construction projects and complex industrial construction projects. Project management in the engineering of a normal construction is primarily confined to the left part of the matrix in handling both process and product aspect within the engineering office. In industrial construction projects, project management not only concerns the left part but also, to a significant extent, the right part of the matrix. Each of the quadrants is embedded in bi-project management. Now, we will elaborate the framework and the four main areas of attention.

Basic interaction structure

The basic interaction structure evolves from verbal agreements between the client organisation and the engineering office in a very premature state of the project to a fully institutionalised structure which is used to exchange information during the project. The previous section, describing current control practices, dealt with this aspect of project control. Some additional remarks can be made here.

Written communication, mainly shaped by the exchange of meeting reports dealing with the ‘Triple Constraint’, is added with technical drawings containing important technical information. These engineering drawings are usually accompanied by documents that contain background information in detail and information concerning the implications for dependent disciplines or activities. Together they form the *key-documents* (see next sub-section). Depending on aspects such as the frequency and scope of back-up or ‘extra’ information needed and the amount of indistinctness and disagreement related to the information ex-changed, elements are added to the basic interaction structure. Examples of this are: ad hoc meetings, personal contacts, memos, phone calls and letters.

Key-document structure

The key-document structure formalises important aspects of a project at crucial moments in time in order to exploit these documents as tools for communication and making agreements. To highlight the different roles of the key-document structure, it is viewed from four different angles. Together they illustrate the relations between the quadrants of Figure 3.

First of all, documents have a technical role. The arrow above and to the left in Figure 3 emphasises this product orientation. Within this technical role, key-documents relate to the aspect quality: conforming to specifications as laid down in the documents.

In this, a first step is to reach commitment concerning e.g. the programme of demands as these documents shape the project from the start. They determine to a large degree the time, costs and quality. During the project the ‘product’ itself and the documents grow in detail. The documents exchanged between the client organisation and the engineering office must be regarded as the delivery of intermediate products.

The second role of key-document deals with the planning and control of the project. At the start of the project the overall project planning and project plans describing the activities to be undertaken are formalised and recorded into documents. Key documents match in most instances, with milestones of the project. This means that at the transition of one project stage to another, key-documents function as the physical products to enlarge project control. In other words, within this role key-documents more or less guard the control aspect time. This role is symbolised in Figure 3 with an arrow from quadrant II to quadrant I.

A third role of the key-documents lies in the process of increasing detail and decreasing uncertainty. This is depicted as an arrow from quadrant II to quadrant III. This role is concerned with the information-processing aspects of the project, which is sometimes referred to as the revision structure. The revision structure itself has several aspects. The key-documents evolve through several stages with disciplinary and interdisciplinary meetings within an engineering office. After these stages, key-documents are ready for external review with the client. The external review consists of several disciplinary and inter-disciplinary meetings as well. Finally, feedback and requests for additional information can occur before the documents are approved and are labelled as ‘final’. These final -or truly ‘key’ documents in many cases- indicate the transition from one project stage to another. From the point of view of the engineering office, the processing of project information (between two milestones) can be characterised as a process for each project stage. Such a process starts with the input of information to keep the ‘production’ of the engineering office going. In order to guarantee a continuous stream of input information needed, the engineers must continuously communicate their information needs with the client organisation. Input checklists can be used to ensure actual delivery. In addition, it is important to communicate the implications -in terms of time, costs and quality- of not delivering the requested information so that all actors involved can asses the uncertainty and risks. Finally, the output of this entire process consists of the approved documents. Examples of these documents are: engineering drawings, (detail) planning forms, budgets, and cost estimates. This structure of information processing is illustrated in Figure 4. A clear view

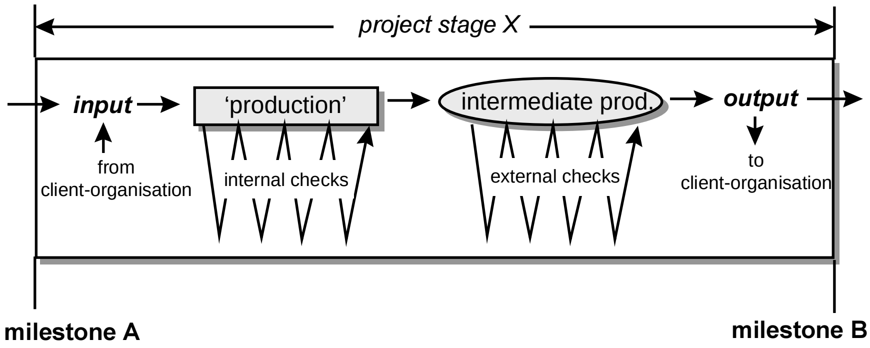

Figure 4: Information processing structure

and understanding of a systematised information exchange process enlarges the control of the (sub) project.

The final role of the key-document concerns systematising the entire interaction between the two parties in the project. A systematic approach helps in recognising opportunities for influencing the client-organisation (the arrow from quadrant II to quadrant IV). We already addressed the milestones as the moments of transition from one stage to the next stage. These 'interaction moments' with the client are used to exchange in- and output information, as described. For a good functioning of the project and in order to actually arrive at the key-documents in time, it is necessary to use the intervals as well. These 'interaction intervals' are concerned with internal and external checks, exchanging back-up information and ad hoc information exchanges. These intervals can also be used to guarantee that key-documents will contain the right information in time. As the engineering office depends on the information of the client (both to be able to do the right things and to be able to meet the time constraints), it must continuously look ahead to ensure information and thus progress. We will elaborate upon this in the section on Influence.

Uncertainty

Bi-project management in large industrial construction projects deals with a high degree of uncertainty and risk. Risk management has been generally recognised as an important area in construction[13, 14, 15, 16]. Due to the nature of bi-project management, it is especially relevant to investigate the nature of the uncertainties the construction engineers are confronted with and methods to cope with these uncertainties. In general, it is uncertain what will happen and when. This is true for the engineering office as well as for the client organisation. Because of the complexity of the production process to be engineered, ‘growing insights’ and the continuous optimisation of the production process, it is sure that parts of the project change. The engineering office just has to adapt to these changes,

Here, we view uncertainties as information-related shortcomings. These shortcomings can be formulated in terms of correctness, completeness and timeliness. The correctness of the information delivered to the engineering office is not always guaranteed, but it is not really a problem. Most information is checked several times. Nevertheless, design failures occur, but responsibilities are usually dealt with in contracts.

Both for the completeness and timeliness of the information delivered to the engineering office, it is important to apply a strong pro-active, bottom-up approach. At any time, the construction engineers must, as a result of their dependent position, convince the client organisation of the need to provide the information correctly, completely and on time. The implications in terms of time, cost and quality of not rewarding the information needs of the engineering office should be communicated as well. Whether the information needed is delivered in time, can be easily assessed. In order to check the completeness of information delivered, checklists can be used.

Although this may all sound familiar, the effect of bi-project management in this category of uncertainties is evident. The difference in time-span of both sub-projects causes that the development of detailed specifications of production installations and construction parts are not evolving in a parallel fashion. The construction engineers simply can not wait until they are offered information which is 100% complete, because they have to complete their work earlier. Another related problem is that information,

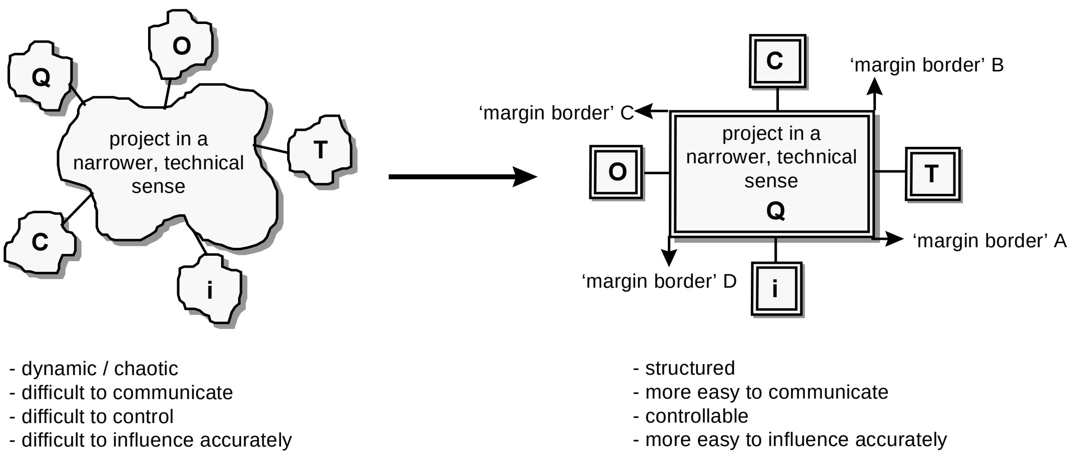

Figure 5: The black-box principle - quantifying uncertainties

that is correct at a certain moment, might become incorrect, as changes are made in the engineering of the installation.

During the construction sub-project, the engineering office needs detailed information, which the client organisation can not provide yet because it has not reached that level of detail itself. A natural reaction might be to insist on an exact and detailed answer. However, this introduces uncertain information which might prove to be incorrect in a later stage. Instead of asking the client organisation exact, narrowly formulated questions, it is more helpful to ask what the options, or what the margins of the specific technical specifications (e.g. the dimensions, weight or place production installations) are.

By indicating margins and 'margin borders' as the extreme values, a chaotic and uncertain system in terms of the elements of the Triple Constraint and the control aspects organisation and information[9] (T = time, C = cost, Q = quality, I = information, O = organisation) turns into a more controllable black-box. Figure 5 illustrates this 'transition'.

The margins are subject to discussion during meetings, as the project evolves into a more detailed stage. As a result, the black box and the related uncertainties decrease. At the same time, the level of detail and clarity of the project will increase. The result is a controllable and relatively linear process, as illustrated in Figure 6.

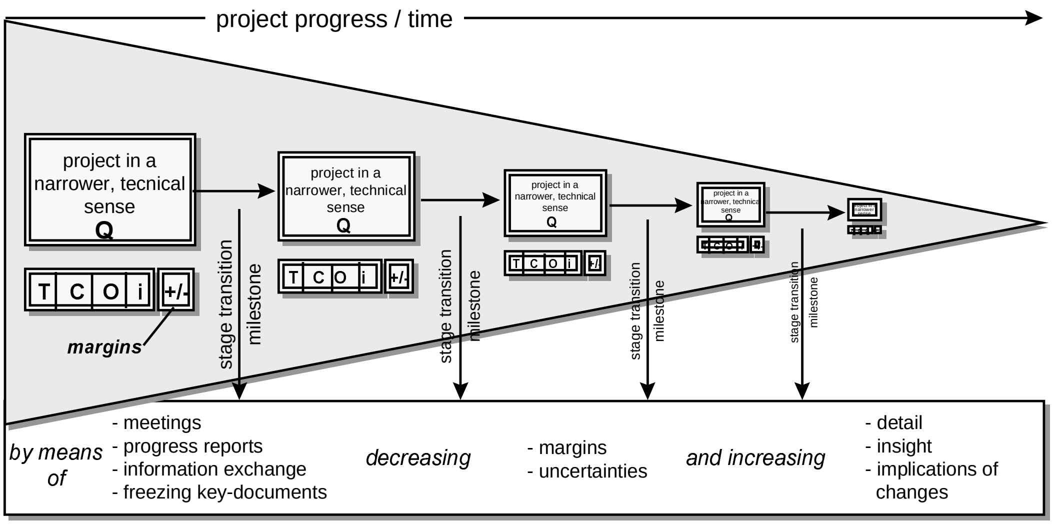

Figure 6: Project progress decreasing number of alternatives, black-box margins and uncertainty

Systematically quantifying uncertainties as indicated, is a helpful practice in increasing project control in industrial construction projects. Although the value of quality management is acknowledged, control of uncertainties and risks in a systematised process is lacking behind.

A theoretical background for the above can be found in the current discussions in the field of product development. Current practice in engineering can be characterised as a point-to-point search process, also called the "Shigley method"[17]. The attention in this approach is on what seems to be known with certainty, with an emphasis on "doing it right the first time" and keeping the number of iterations to a minimum. Our approach is based on Set Based Concurrent Engineering[17], that proposes to create a set of alternatives. Each alternative is limited by experiences and solutions, which have shown to be successful in the past. As a result, sets of solutions will be created, all aimed at the same purpose. In other words, several construction-related 'solutions' can be developed, based on the production-related starting points and focused on the final purpose of the machinery. As the project evolves, several of the possible solutions will be dropped. SBC widens the mouth of the development funnel[18], which is illustrated in Figure 6. Compared to the point-to-point search method, in which one solution is altered over and over again, SBC-engineering develops several solutions which will be minimally altered and eventually will present the most optimal solution. So far, this approach has gained little interest in the construction industry, but the potential advantages deserve more attention.

Influence

The final major area of attention in Figure 3 deals with the balance of power between the client organisation and the engineering office. Special attention is given to methods that help the engineering office to be less dependent and to increase its influence on the client organisation. This should result in improved project control.

We distinguish two categories. The first is a prerequisite for the second. The first category aims at structuring the internal organisation in such a way, that it can function as an efficient and effective base from which to interact with the client organisation. Aspects such as effective internal communication, knowledge exchange and quality assurance systems are included in this category.

The second category aims at effective interaction with the client organisation: labelled as "pro-active". Pro-active interaction means that the engineering office takes the initiative for changing its own position. We propose that that entails of at least the following elements:

- ❐ whenever possible, offer advise to the client organisation and record related agreements
- ❐ take as much initiative as possible, by pulling information from the client organisation
  - clearly formulate and communicate the information needed
  - make sure that the client organisation is confronted with this information need in time, which means, keep in mind the processing time for the information to be delivered
  - make sure that the information is delivered in time and communicate the implications of not having the information in time
- ❐ continuously communicate the tension between the different project-control elements and the changes in it with the client organisation
- ❐ increase the construction engineers' knowledge and understanding of the production process related project part to be able to anticipate changes.

The practical implementation of this method involves several elements such as 'input-checklists' for the information needed from the client organisation to check the aspects of completeness and correctness.

An illustration of the approach is given in Figure 7. It shows how a systematised

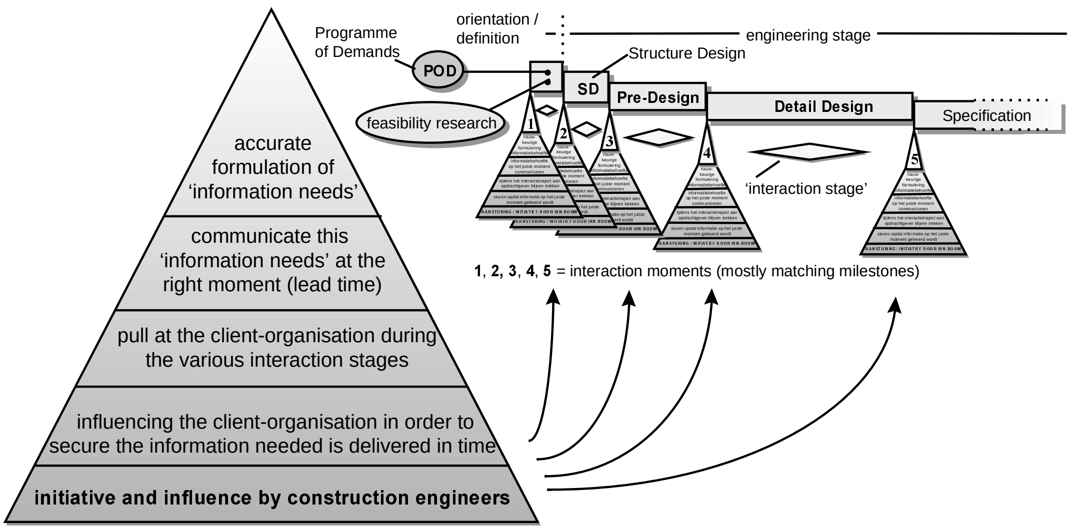

Figure 7: Proactive interaction approach

bottom-up approach can be combined with milestones, at which important information is exchanged, as dealt with in the section on ‘key-document structure’.

Conclusions and management implications

This article investigated a kind of project and project management not yet addressed in the literature, labelled as bi-project management. Bi-project management, as described here, deals with complex projects, in which two parties each manage a part of the project in a customer-supplier relationship, where one part of the project depends on the other part. Moreover, the dependent part must be finished in advance of the leading part, which is less predictable and controllable. It is concluded that normal project management techniques and methods are necessary, but not sufficient to control bi-projects. The framework developed in this article helps in describing and better understanding the relationship and interaction of the two parts of such projects. In addition, it is used as a normative, prescriptive frame to develop guidelines on the four areas distinguished, which aid in improving project control.

What lessons can project managers in this kind of projects learn from this article?

Most importantly, project managers should put effort into structuring the interaction between the two parts of the project. The framework presented in this paper, aids in recognising the various aspects of the interaction upon which attention should be focused. The article shows that project control is a multidimensional phenomenon.

In addition, we will list some recommendations for managing bi-projects.

Bi-project management needs, as any project, a clear and well-documented basic structure for responsibilities, communication and milestones. The normal project management literature is relevant to establish that base. Any engineering office in this kind of projects should be able and willing -as professional supplier- to help its clients to do such, while keeping in mind the fundamental difference in nature of the two parts of the project.

Key-documents play different roles, which should be taken into account.

Uncertainty and change are normal features in bi-project management. An engineering office can help its clients by developing an understanding of the production-process-related part and the uncertainties and risks involved. Developing knowledge about specific characteristics and associate risks in engineering installations in various industries is then beneficial. Explicit attention for risks through identifying, analysing, planning, monitoring, controlling and communicating uncertainties and risks[19], should become an integral and dominant part of project management in industrial construction projects. Knowing the risks and realising that information on details is vulnerable for change, should lead to an attitude in construction engineering of postponing work to the latest possible moment.

A systematised information exchange, will enlarge the control of both sub-projects. Once again, the engineering office should guide and influence its client in a pro-active approach of what information is absolutely necessary at what moment in order to be able to complete the project as scheduled. Showing the consequences of not receiving the information is part of the guidance given.

Finally, the project managers of the engineering office should be open minded for alternatives to the step-by-step approach, which is usually employed in 'pure' construction engineering. An approach like Set Based Concurrent Engineering offers an alternative.

Future research

In this article, improving control of bi-project management has been primarily discussed as improving the interaction between the two parts of the project. The sub-projects themselves have, to some extent, been dealt with as black-boxes. Opening these black-boxes will improve our knowledge about the possibilities to co-ordinate the parts and thus improve overall project control. More specifically, future research should address at least the following topics.

First of all, effort should be paid to better understand the roots of uncertainties and risks in this kind of projects. What indicators for risks can be distinguished? Is it possible to relate such indicators to project parts, disciplines, specific industrial construction projects (e.g. petrochemical industry, nutrition industry) or type of production technology employed. Also, the kind of project management approach that is used, is possibly important. Such knowledge is useful in planning the production-oriented part and better tuning the construction part.

Another, related, area is the way in which the construction-related part can be managed, so as to be better equipped for uncertainty and changes. Two interesting research themes emerge.

A first theme should address questions like: what activities can be postponed? What are absolutely minimal specifications to go on with engineering and how does information structuring help in that?

The second theme relates to the usefulness of Set Based Concurrent Engineering. Currently, engineers strive for solutions that minimise building costs, within specifications. Set-based approaches may cost more in engineering and building (because, for example, the building is ‘oversized’ to some extent), but save on rework and timeliness. Research should aim at finding trade-offs for balancing between such costs.

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