READER
Dynamic Control of Projects

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Preface

These bundled transcripts of the ProfEd Mastering Project Complexity are part of the study materials for the course Dynamic Control of projects (CME2200 2017-2018), covering the ONLINE lectures. In the appendices you can find the related articles to study. Enjoy!

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Module 1: Understanding project complexity: development of models

The project management discipline still has to further improve its performance after sixty years of existence, despite the many great examples that have been delivered. That's the story that we are repeating over and over again as researchers in the field of project management.

It was Brigadier-General Bernard Schrieffer who coined the term project management for the first time in 1957. Since then the track record of project management has been far from great. Admittedly, if we make such a blunt statement, we first have to identify what project success actually entails. It is not the same for all involved. Success is clearly a subjective measure. It varies over time. It varies by project type. So how to define success in such a way that we can all use it to our advantage? Since the views on success can be so different it is best to agree up-front, what the success criteria will be.

In an early stage of the project, during the opportunity framing, three questions will have to be answered by the joined integrated project team: 1) What will we deliver? 2) How will success be judged? and 3) Who has a say in answering 1 and 2? The biggest advantage of this approach is that it guides the scope of the project (what it is and what it is not), it maximises the chance of success and it gets people aligned towards a common goal. Look at opportunities outside your direct influence.

By agreeing the success criteria, a common goal has been identified. By subsequently focusing on and agreeing the success factors the means to achieve that goal will be identified. Traditionally the project management standards will have identified the required activities and processes that have to be executed to deliver the project. For instance the Project Management Body of Knowledge, or PMBoK for short, has identified 11 knowledge areas with related activities that are required for delivering a project. But unfortunately just applying these activities is not a sufficient requirement for successful completion. Projects might still 'fail' despite executing these activities.

What are the causes of these failures? Many volumes of project management literature have been filled with these causes. To name a few: underestimation of the costs due to lack of experience, deliberately underestimating the costs to win the contract, unclear and incomplete specifications, changing the scope during execution because of a lack of sufficient interaction in previous phases, over-optimistic in implementing novel technology, the firing of unforeseen risks, inflation, an over-optimistic project leader or unrealistic management. We can extend this list for a while. One reason that is surfacing nowadays more and more is the increased complexity of contemporary projects. Sometimes used as an excuse but quite often a real and emerging issue. And even if this increased complexity is recognised, the consequences are largely underestimated.

This brings us then to the subject of this course on mastering project complexity. What is the complexity that we are facing in current projects? How is complexity described from a more theoretical perspective?

It is difficult to find an unambiguous definition of complexity in literature. Baccarini, as one of the first, defines project complexity as consisting of many varied and interrelated parts. To operationalise this he broke complexity down into the number of varied elements and the interdependencies between these different elements. Later on Williams went a step further and distinguished structural complexity and uncertainty as constituting elements of complexity (Figure 1).

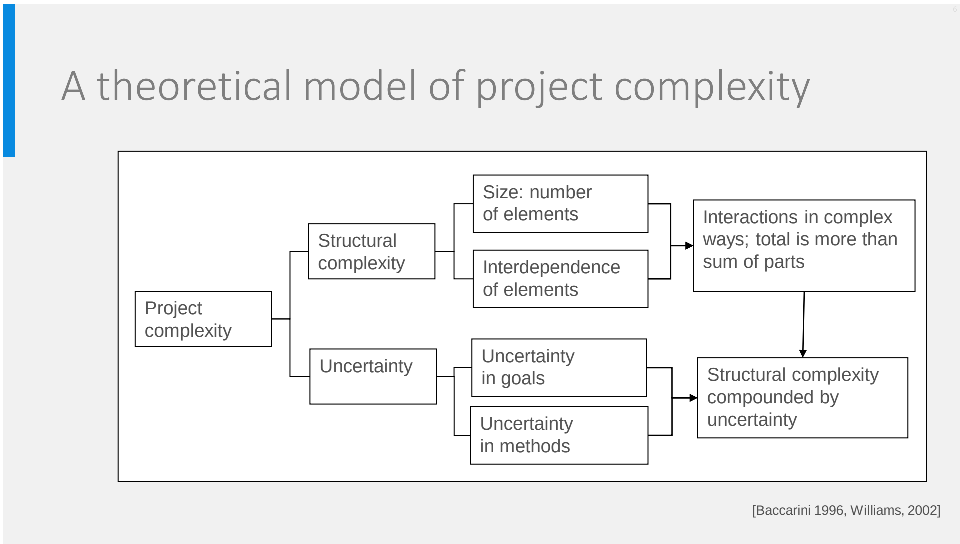

Figure 1: Model of project complexity

These main elements of complexity, structural complexity and uncertainty, are also recognized in the model of Hertogh and Westerveld (Figure 2). They distinguish detail complexity and dynamic complexity. Detail complexity is characterised by a high number of components with a high degree of interrelatedness, and dynamic complexity is characterised by the potential to evolve over time and the limited understanding and predictability. Detail complexity is knowable, and project managers are often able to handle this. Dynamic complexity has uncertainties. Project managers cannot predict for certain the outcome of their actions.

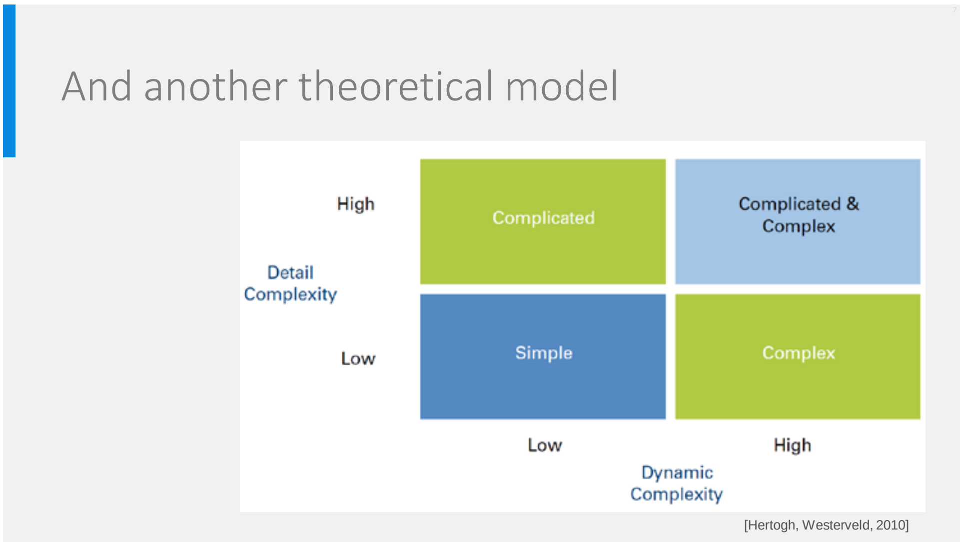

Figure 2: Model of Hertogh & Westerveld (2010)

These are just a few examples of complexity models that have emerged over the years enabling project managers to identify the complexity and think about responses to deal with the emerging complexity. Maybe stating the obvious, but complexity is not necessarily related to large capital costs or the size of the project. A relatively low cost project can be very complex whereas in some instances a high cost project can be simple. Complexity is not only about size. It is the increasing number of interfaces and their dynamic character over time that makes a project complex.

In the research at TU Delft we found that project complexity can be subdivided in three distinct areas: technical complexity, organisational complexity and external complexity (Figure 3). This classification has been developed based upon a thorough literature review and detailed investigation of a large number of projects in both the process and the construction industry. Technical complexity is the traditional view of project managers and engineers and mainly focuses on the content. The softer and behavioural view is covered by the organisational complexity and the broader external view of stakeholders, the environment of the project and sometimes the politics is covered by external complexity.

T **Technical Complexity** (17 elements)	O **Organizational Complexity** (17 elements)	E **External complexity** (13 elements)
High number of project goals	**High project schedule drive**	Level of competition
Non–alignment of project goals	**Lack of Resource & Skills availability**	Instability of project environment
Unclarity of project goals	Lack of Experience with parties involved	Company internal strategic pressure
Uncertainties in scope	Lack of HSSE awareness	**Lack of experience in the country**
Strict quality requirements	Interfaces between different disciplines	Remoteness of location
Project duration	Number of financial sources	**Interference with existing site**
Size in CAPEX	Number of contracts	Required local content
Number of locations	Type of contract	**Lack of company internal support**
Newness of technology (world–wide)	Number of different nationalities	Political influence
Lack of experience with technology	Number of different languages	Dependencies on external stakeholders
High number of tasks	Presence of JV partner	**Variety of external stakeholders' perspectives**
High variety of tasks	Involvement of different time zones	Number of external stakeholders
Dependencies between tasks	Size of project team	External risks
Uncertainty in methods	Incompatibility different pm methods / tools	
Involvement different technical disciplines	**Lack of trust in project team**	
Conflicting norms and standards	Lack of trust in contractor	[Bosch-Rekveldt, 2011]

Figure 3: TOE Model for grasping project complexity (Bosch-Rekveldt, 2011)

The purpose of the models is to support the identification of the elements that contribute to the increased complexity of projects. Once again: the aim of using such models is not to reduce the complexity, because that will be almost impossible, but to become more aware of the contributing factors and adapt the style and approach of managing the project to the perceived complexity. So we are not trying to reduce or remove the complexity, but we are identifying ways of coping with the complexity. Reducing the complexity is considered almost impossible due to the fact that the complexity is highly subjective and highly dynamic. So reducing the complexity in one instance might generate additional complexity in the next instance. So learning to cope is probably much more effective. Or even increasing complexity can be beneficial, such as adding a functionality to create broader support. In this way the project manager is able to prepare and commit rather than to predict and control!

Module 1: Understanding project complexity: subjectivity

If you ask a project manager about the complexity of her project, she most probably will answer confirmative. Yes: it was indeed complex, yes. As long as "complexity" is used as a black box, the project manager can hide behind this complexity and if the project would fail, that would be due to its complexity…

That is why we are so much interested in understanding project complexity and unravel the black box of complexity. But: there is not an objective measure for complexity, in our view. What is considered complex by one, might be perceived differently by others. Let's explore this subjectivity!

What do you see in Figure 4; the old lady or the young woman? And the saxophone player or the young lady?

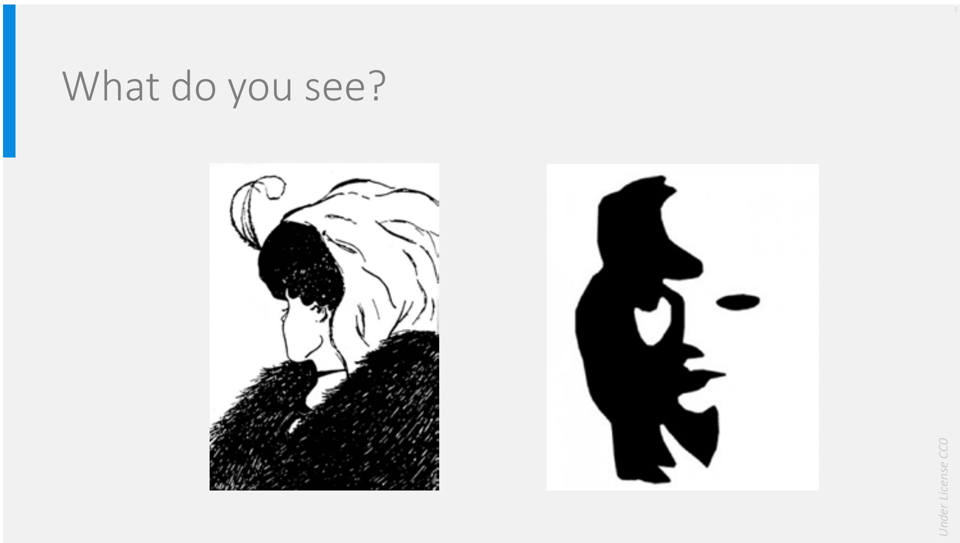

Figure 4: Subjectivity

And if I would ask you about the complexity of one of the biggest projects ever realised in process industry, what would be your answer? The project director of this mega project was not particularly impressed by the complexity of his project, and he knew how to manage it. His approach was remarkably simple: "*In order to manage this huge project, I split it up in 12 sub-projects and nominated a number of dedicated project managers to manage the interfaces between these projects.*" In this way this project was successfully delivered with at the top of the activities a workforce of 55 thousand workers. You probably cannot find a project with more interfaces and stakeholders than in this example….. Would you call it complex?

Where does your perception come from? Without losing ourselves in psychology, we combined two models developed by Scherer, Stewart and Lusk, combining perceptual judgement and related cues (Figure 5). These cues can be seen as "triggers" or, in our case, elements of complexity. In the end, the perceived complexity of a project is created by the selection of certain elements of project complexity (cues) followed by a judgement of these elements. And then the sum of these forms the perceived complexity.

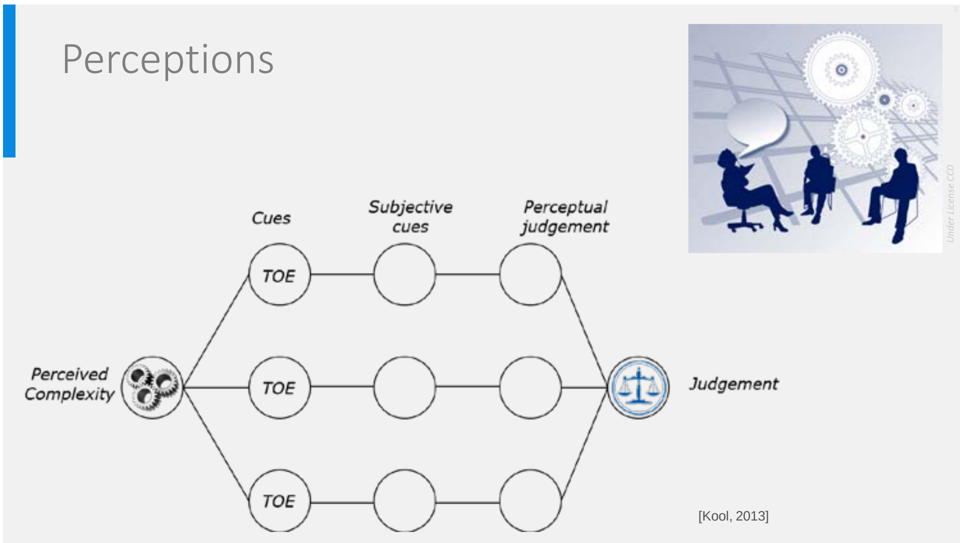

Figure 5: Perceptions

Researching this concept, we found that which elements you recognize, is related to three main sources (Figure 6):

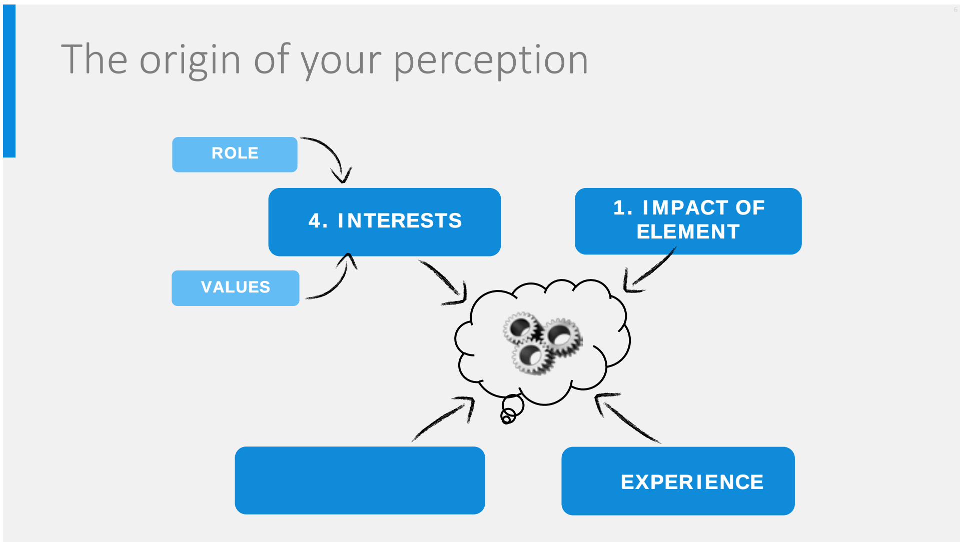

Figure 6: The origin of your perception

First, the perceived impact of that element and the influence you have on that element. Second, your experience. Third, the specific project context or contextual variables. How you judge either of these three, is related to your interests, which in turn are influenced by your role in the project and your personal values. Let's give an example to make things clearer.

As a starting project manager, you might have the feeling that some elements causing complexity in your project you can simply not change and hence you might simply neglect them – focus on your own circle of influence. Stay in your comfort zone. A more opportunistic project manager might escalate early on, in an attempt to still have influence; although in an indirect way. And there are other strategies to choose. It is up to you to choose your approach, and in a way to pick the right battles!

And be aware: being educated as an engineer might introduce some bias! We engineers are typically trained to decompose and we might be used to find solutions by proper analysis behind our desks. Shouldn't the project environment get more attention?

All the sources mentioned earlier contribute in a certain degree to the perceived complexity but the contribution of each source is, for each individual, situational dependent.

So complexity perceptions will be different for different players involved. How to deal with this? Some people are afraid of differences in perceptions: these differences can only lead to trouble. Others see the benefit and value of these different perceptions, as they lead to new information about the project and can lead to more beautiful projects!

Ideally, we would plea for the adoption of so-called perception-based management: differences in perspectives can be helpful, once recognised! This perception-based management starts with the awareness of different perceptions of complexity. Perception-based management in our view is an application of organisational learning, using a shared mental model (Figure 7). What do we mean with a shared mental model?

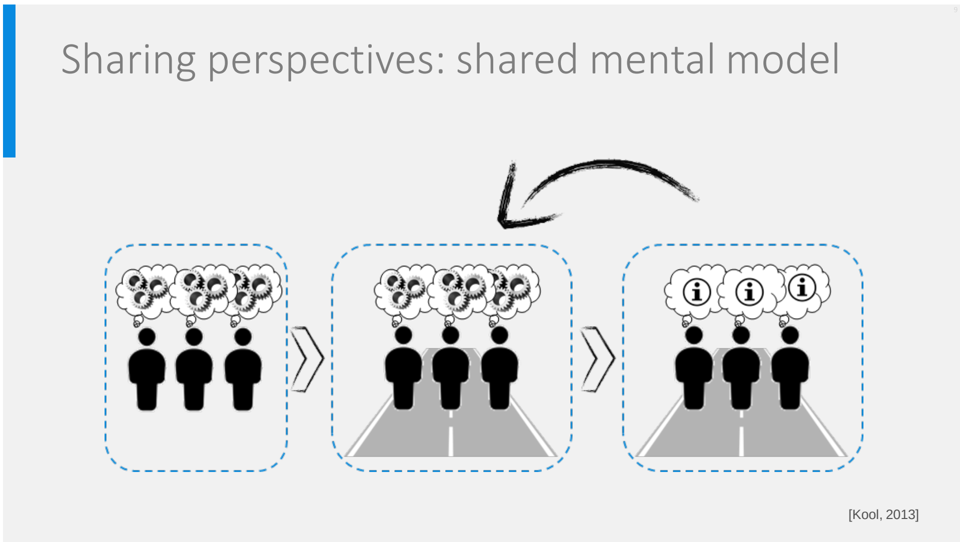

Figure 7: Sharing perspectives

The creation of a shared mental model starts with a definition of the projects' objectives and a set of general norms and values which express the norms and values lived by the project and the practitioners involved. Project start up meetings and project follow up meetings, for example, are a key enabler to allow the involved practitioners to build such a shared mental model. This shared mental model is meant as a starting point; it will lead to actions for those involved but it will also be subject of debate, allowing for reshaping the model.

The theory that perception-based management is necessary within large construction projects is also supported by Hertogh and Westerveld (2010) who mention the subjectivity within the assessment of uncertainties within large construction projects and also indicate that different perceptions are 'the reality of projects'. Both issues are addressed with perception-based management.

So….perceptions matter! It is our firm belief that one management approach is not applicable for all projects. One size doesn't fit all. We have to fit the approach to the purpose of the project or in other words adapt the management approach to the requirements and the context of the project. The perceived complexity will be the trigger to scale or fit the management approach to the type of project. Horses for courses so to say.

Module 2: Complexity assessment models

When we developed our complexity framework, between 2007 and 2009, we started doing a literature study on complexity models in general. To our surprise, the majority of the models found at that time were simply adding up several indicators of complexity.

To give an example: a project with many stakeholders and known technology would score equally complex as a project with innovative technology and a limited amount of stakeholders. We see things differently (Figure 8), but mainly one-dimensional measures were used.

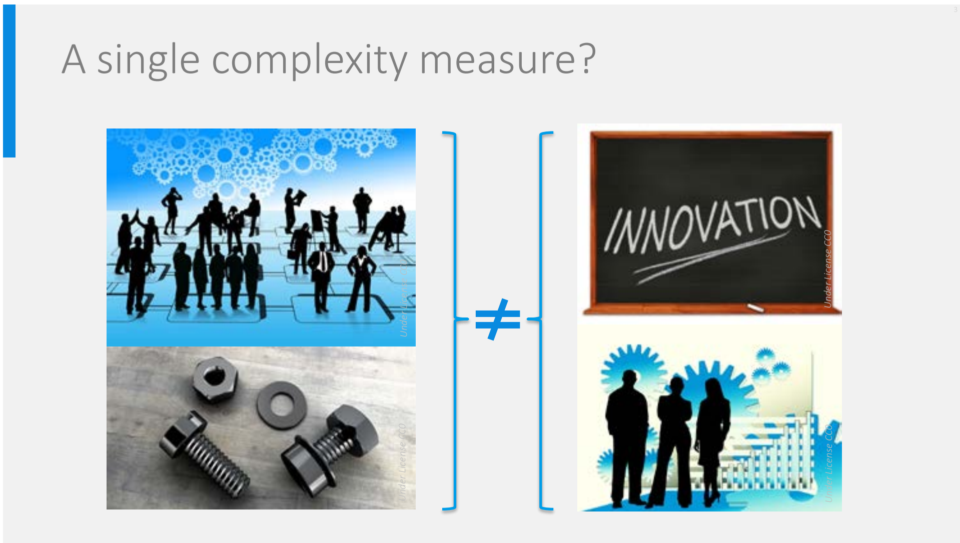

Figure 8: A single complexity measure?

So, although there was quite some attention for project complexity in literature, we could not find a solid framework, originating from both theory and practice, that fully appreciated the richness of project complexity of, specifically, large engineering projects.

That's why we decided to develop a complexity framework ourselves (Figure 3). First we gathered as much as possible potential elements, both from detailed literature study and numerous interviews with practitioners. After careful consideration we included 47 of the found elements in our complexity framework, consisting of two layers. The first layer is formed by the 3 dimensions that we distinguish: technical, organizational and external complexity. The second layer is formed by 47 elements that are each assigned to either the T, O or E dimension. The final list of 47 elements was validated in two subsequent studies involving more than 100 projects.

Let's first look where our first layer comes from. Projects in fact are sociotechnical systems in which there is an interplay of technical aspects and their impact on society. In the distinction of the T, O and E categories, in fact a systems perspective and an actor perspective can be recognized. The systems perspective is recognized particularly in the technical dimension and the actor perspective in the organizational and external dimensions. Although these perspectives seem really different (and in fact they are), we strongly suggest using them alongside each-other, in order to grasp complexity from all areas.

The elements in each of the three dimensions were gathered by interviews with practitioners in the process industry: project managers, as well as team members and owner representatives. In total 18 interviews were performed, and in the analysis, after 14 interviews, no new elements were captured, indicating data saturation.

Elements were included in our final framework if we gathered evidence from both theory and practice, or, if this was not the case, if either the theoretical evidence or the practical evidence was coming from at least 3 sources. As said before, the framework that was constructed was subsequently evaluated, with data from more than 100 projects in different industries.

This is how the framework looks like (Figure 3). As you can see, the elements in the T-dimension cover goal related elements, scope related elements, task related elements etcetera: mainly content focussed. The elements in the O-dimension cover items related to experience, trust, project team composition, resources in general, etcetera: mainly related with organizational aspects within the broader project team. The elements in the E-dimension cover the relations with external stakeholders, market conditions, politics etcetera: mainly elements related to the context the project is performed in.

We will certainly not claim that our framework, published back in 2011, is the one and only way of characterising project complexity. But it is effective and it helps increasing the awareness.

Extensive literature study in 2016 revealed numerous frameworks and papers about project complexity models. Comparing these frameworks with ours showed that there are two main streams underlying the frameworks. On the one hand, the stream where complexity is seen as a descriptive property of a system, and on the other hand the stream where complexity is seen as being subjective by nature. Our framework belongs to the second stream: we are not strictly adopting a systems approach, although we surely admit that project management does benefit from a systems' approach.

Let's now go back to the 2x2 model of Hertogh and Westerveld (Figure 2). They distinguished detail and dynamic complexity, with detail complexity being characterised by a high number of components with a high degree of interrelatedness, and dynamic complexity being characterised by the potential to evolve over time and the limited understanding and predictability.

In fact, they state that only when uncertainties are involved one could speak of "real" complexity, because this complexity cannot be simply decomposed. Mapping the elements of our TOE framework to the detailed / dynamic dimensions is an exercise that can be helpful in determining which approach would be effective to manage the specific complexity.

When doing this, you will notice that where the TOE elements fit the detailed / dynamic complexity framework is very much context dependent. In one project, an element like number of stakeholders might be placed into the detailed complexity area, whereas in another project the same element could be placed into the dynamic complexity area, or the combination of both (Figure 9). This is no exact science; it just depends!

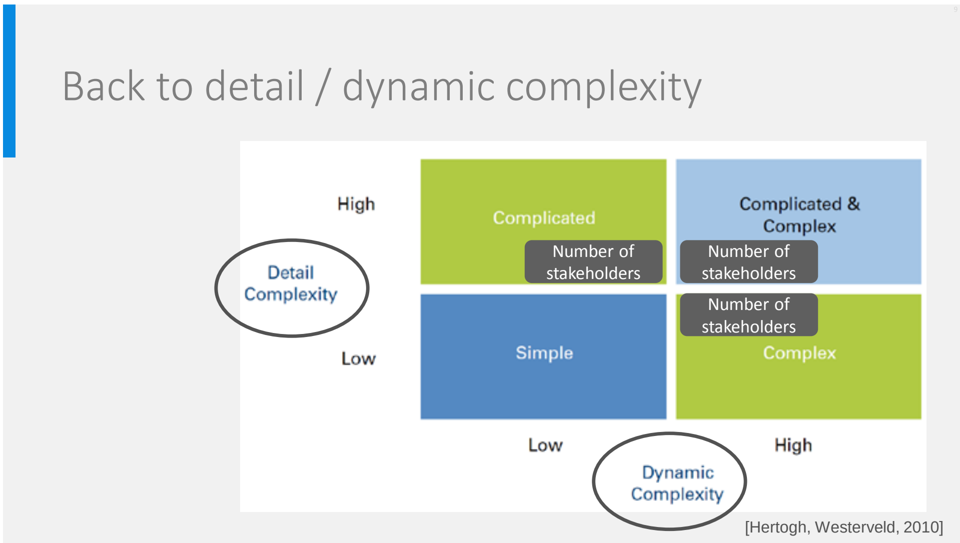

Figure 9: Mapping a TOE element in the detail/dynamic complexity grid

Let's look at some research results to see if there are any complexity elements that seem more prominent than others.

In various researches in different sectors (process industry, construction industry, ICT and high-tech product development), we investigated the complexities faced in contemporary projects. We found several similarities in the top-lists of complexity causing elements. A high project schedule drive was mentioned in all sectors and the variety of external stakeholders' perspectives in all sectors but the high-tech industry. Several elements were mentioned in two sectors, like uncertainties in scope, dependencies between tasks, involvement of different disciplines, lack of resources and available skills, interfaces between different disciplines, interference with existing projects and political influence.

Quite some of these elements were shown to have a direct relation to project performance. So there is something to win here: when we are able to recognize them early in the project and if we learn ways to deal with them!

Module 2: Complexity & the project life cycle

How does complexity evolve over the project life cycle?

It probably depends who you ask and what is their role and experience. In earlier research, we concluded that project team members predominantly saw an increase of project complexity in the project execution phase. Others, being business representatives, more involved in the early project phases, concluded a decrease of project complexity after the final investment decision.

Who is right? Well, probably both: their involvement explains their position. The closer they are involved in a certain stage, the higher their complexity-judgement. Please remember: project complexity is a subjective phenomenon!

The project managers we interviewed actually were split between the above opinions: half of them observed a decrease in complexity and half of them an increase. This increase then was often related to poor recognition of complexity in earlier project phases, hence stressing the importance of front-end development. Plotting complexity evolvement through the project life cycle could look like a wave or a cyclical process (Figure 10).

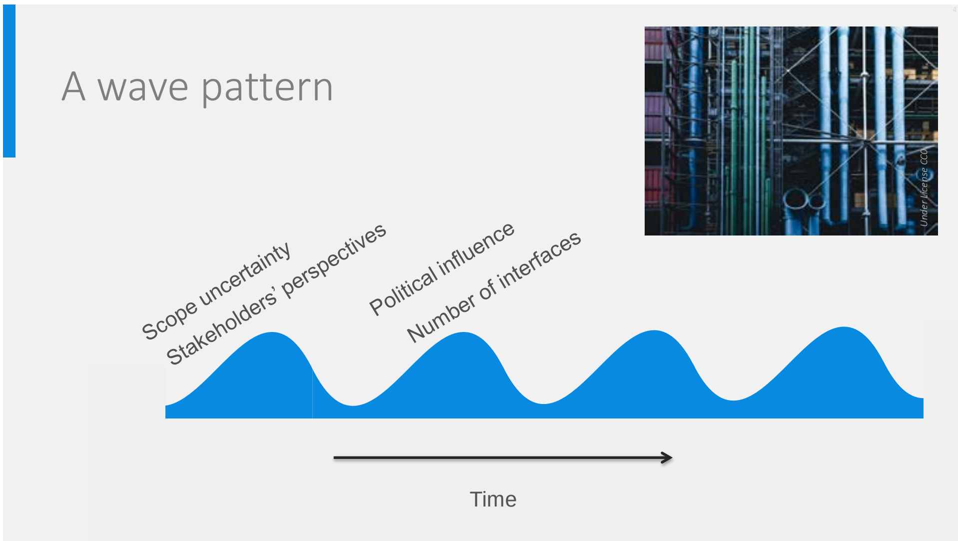

Figure 10: A wave pattern

This wave is just a one-dimensional complexity measure, so doesn't tell us anything about its emphasis. In other words: very different complexity elements could play a role in different phases of the projects. One should expect different types of complexity, apart from its general size!

Hence we could talk about the evolution of complexity, rather than about a simple de- or increase.

Let's look at an example of the development and construction of a new facility in the oil and gas industry. The business manager involved mainly recognised the complexity of the deal making in the front end phase. All stakeholders involved, a lot of uncertainties, the market condition that influenced the decision making. The engineering manager mainly recognised the complexity in the implementation phase as a result of expanding scope. Lots of interfaces to manage, political influence, and local context. And the project manager, a man with a lot of relevant experience, did not recognise any change in complexity during the project life cycle. He didn't really experience particular complexities anyway.

So how could a complexity framework be used in our projects? In our view, it all starts in the front-end development phase of the project. In the very early project phase, even before a project manager is appointed, a line manager sits together with a resource manager and they jointly try to assess the complexity of the project under development. What elements probably will play an important role in the project? Depending on where they expect complexities, they could select a project manager that is both available and skilled to deal with the complexities expected.

Once the project manager is on board, she starts her assignment by completing the TOE complexity framework for the particular project: in which areas could complexity be expected? An initial complexity footprint is created, which is set in sand rather than carved in stone. This footprint is expected to change throughout the subsequent project phases.

The project manager composes the project team based on the early complexity assessment and also uses the complexity assessment as preparation for an initial risk workshop, as the TOE framework provides a helicopter view: an extensive list of categories where risks could be expected. The application of the TOE framework, however, is not limited to identifying risks.

Next to risk management, the result of the TOE complexity assessment could be used to enhance stakeholder management or to strengthen certain monitoring & control areas, to name a few. The exercise of completing the framework in the different project phases can stimulate team integration and facilitate discussion and communication in the project team and amongst relevant stakeholders.

Comparing the complexity assessments of different stakeholders for one particular project will enhance a shared understanding about the project at hand: perception-based management.

From our experience, a structured approach to create awareness for the foreseen complexities can be beneficial for broad alignment amongst the relevant stakeholders. You could see it as a means to stimulate communication between parties.

We have seen that complexities evolve during the lifecycle. Therefore we suggest a repeated complexity assessment, performed with the main players involved. For example at the start of a next project phase, in order to check whether you have the right skills and capabilities in the project team. The focus could go from external complexity towards technical complexity, towards organizational complexity, when the project progresses.

We saw in our research that project complexity as such really goes beyond the particular technical complexities. We as engineers are generally well trained to deal with such technical complexities. We simply neglect external complexities and we get headaches from the organizational complexities that mess up our daily work!

Module 3: Management approaches and complexity

In order to better manage project complexity, we need to know what strategies we can choose from.

Therefore let's look at management approaches that are widely recognised in nowadays projects. Let us first start with an example.

The example of the Betuweroute, a rail freight line in The Netherlands, that was delivered in 2007. In the 90's the railway line was planned, and there was great opposition against the line. People didn't understand the need for this and said: 'Not in my backyard.' One of the problems was that the project was planned without sufficient interaction with stakeholders. We can show this in figure Figure 11.

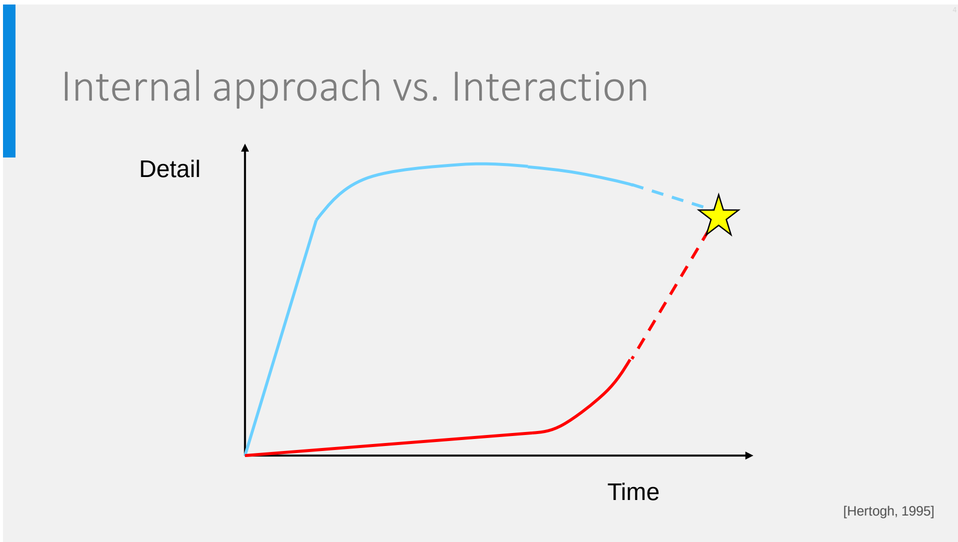

Figure 11: Internal approach

In the graph, the horizontal axis shows the time, the vertical axis the level of detail. The project organisation started to plan the line. They work enthusiastically and sincerely, and soon they develop a basic design. They also start developing the plan into more detail, to know all the consequences. At this point in time they present their design to stakeholders, such as citizens along the line. These stakeholders now quickly need to catch up in the design process. Often a conflict will arise because stakeholders are not satisfied with the chosen detailed solution, due to the fact that it does not match his needs and expectations. And they are also dissatisfied, because there was no interaction. They felt neglected. This is our first management approach: the internal approach. There is not much chance that they will come together.

Better is to have more interaction, to align stakeholders, as you can see in Figure 12. They team up.

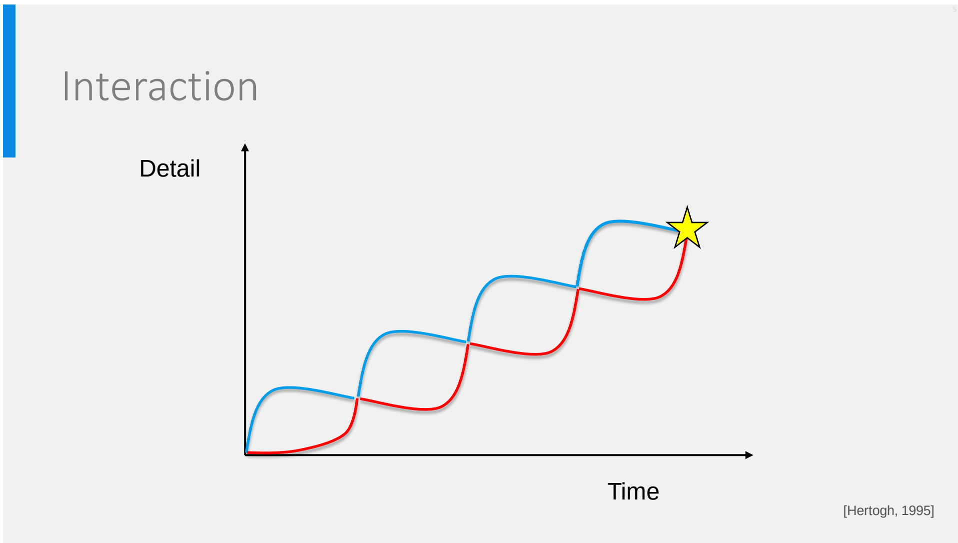

Figure 12: Interaction approach

Some years ago, we performed case studies into 15 large European infrastructure projects to investigate what management approaches were typically applied. The Betuweroute was one of these projects. Other projects were highways, high-speed lines, long tunnels and waterways. At the end of the lecture, I will give an example of The West Coast Mainline. In the research we distinguished four management approaches. The internal approach is one of these four.

Interesting is that we can relate these four management approaches to detail and dynamic complexity. Maybe you remember that detail complexity is characterised by a high number of components with a high degree of interrelatedness. And that dynamic complexity is characterised by the potential to evolve over time and the limited understanding and predictability. When detail complexity is high, we say the system is 'complicated', when dynamic complexity is high, we say the system is 'complex' (see Figure 2). When both are high, it is both complicated and complex.

As mentioned, we can link four management approaches to this scheme, see Figure 13.

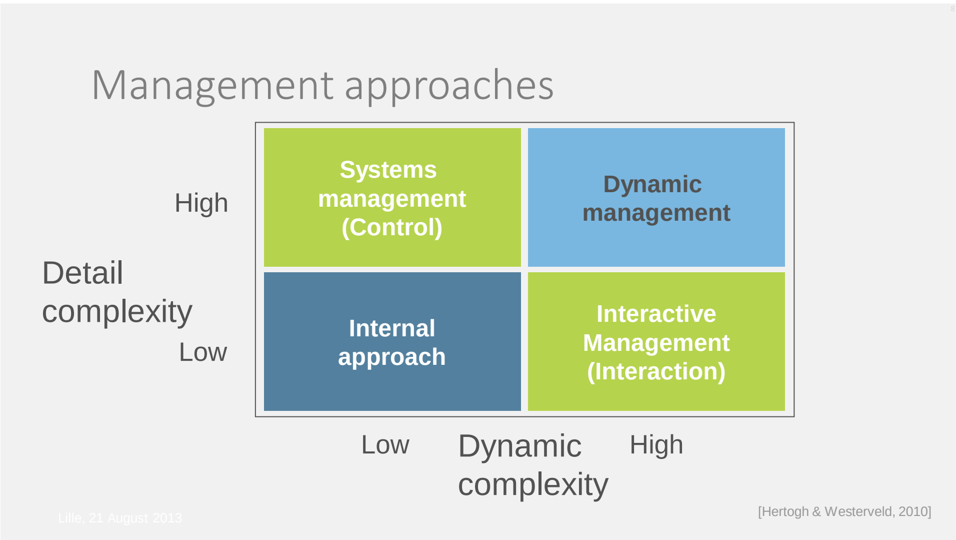

Figure 13: Management approaches

When both are low, we call the appropriate approach the internal approach. When detail complexity is high: systems management. This is basic project management. When dynamic complexity is high, the suited approach is interactive management. And fourth, for the complicated and complex systems: dynamic management.

We will reflect upon these four mainstreams.

The internal approach is characterised by the absence of structured management. As we saw at the example of the Betuweroute, the focus on content is key. What we observed in our research is when this approach is used in our large projects, the results were bad, because the projects were not that simple.

Decisions are unpopular with stakeholders, without sufficient interaction with them.

We found that this approach is still often used, for instance in cases when something unexpected happened. Project teams tend to be nervous, and forget to interact, and to look further than the content. In general there are various aspects that stimulate a content focused approach. Lack of management attention, specialist project managers, financial tensions, organisation that are unfamiliar with each other and a project team showing “groupthink”. So to summarize this approach: the key focus is on content and the orientation is dominantly internally oriented.

Let’s look at the second approach: systems management, basic project management.

Systems management is characterised by decomposition in different aspects: time, end product and organization as well as certain management processes. Decomposition in time means that a project is divided in a logical sequence of phases, decision gates, and corresponding activities. Decomposition in end product means that the main deliverable is split up into various elements and sub-elements. Decomposition in organization means that a so-called Work Breakdown Structure (WBS) is used to divide the work of a project into smaller, manageable pieces.

This WBS can act as the basis for the organization breakdown structure (OBS), cost breakdown structure (CBS) and risk breakdown structure (RBS). These breakdown structures are used in the corresponding management processes.

Management processes are applied in order to complete the project, divided in phases, within the boundaries of time, cost and quality. The focus of systems management is on a rational and “rigid” control of these aspects.

Systems management assumes that we can predict and control. But … can we really? Can we really strictly control our projects? Reality is less straightforward and asks for interaction!

With interactive management, we refer to a management strategy build upon alignment, redefinition of the problem and change of scope, using short term predictability and the application of variation (in strategies and by using what if scenarios).

When we look at interactive management, there are some pitfalls too. When stakeholders’ wishes are tried to be met too much, this might result in lots of discussions, no decisions, no progress and false expectations.

Certainly there are some tensions between the earlier mentioned systems management and interactive management (Figure 14). Whereas systems management is decisive, interactive management seeks for support. Systems management focusses on the hard results, and interactive management focusses on appreciation. Systems management focuses on content, whereas interactive management focuses on cooperation and external influences. Systems management focusses on stability, rigor, in interactive management dynamics are anticipated! Hence we need an approach that combines both: dynamic management.

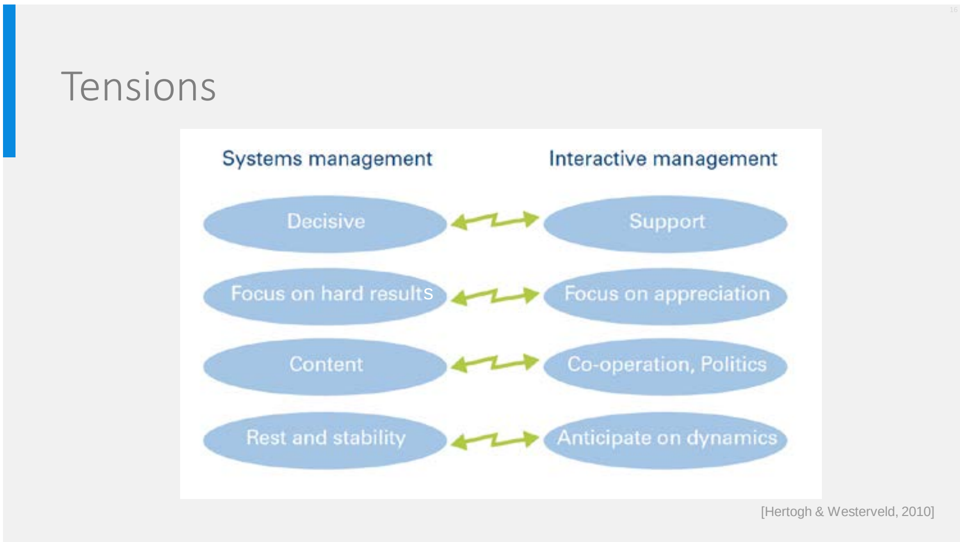

Figure 14: Tensions systems management & interactive management

Dynamic management is a balancing act between systems management and interactive management. These different management approaches fit different types of complexity.

We can illustrate dynamic management by the example of the West Coast Mainline. Around 2003 the project is big trouble: massive cost overruns, dissatisfied stakeholders, and bad quality.

Around 2003 a new strategy was presented that showed a fine balance between systems management and interactive management. The West Coast Mainline used an extensive consultation with stakeholders in which objectives were aligned of all stakeholders, such as railway industry, local authorities, ngo's, citizens, etc.

The attitude towards stakeholders was: "Be absolutely open and honest in your communication, 'straightforward talking'. Tell the stakeholders good news as well as bad news! The easiest thing is to create false expectations, but people will remember them." These lessons we also found at other projects of our batch of 15 projects.

We conclude: Fit your approach to the complexities expected!

Module 4: Mastering project complexity

The final task in this course is to decide how you want to cope with the complexity of your project. Growing complexity is a reality of the present day projects and we have to live with it. It will not be possible to rule out the complexity altogether or to reduce the complexity in such a way that life will be as easy as it once used to be. Complexity is there and it will stay. And complexity even provides opportunities for making projects more valuable! How do we master it, that's the challenge we'll discuss.

For managing projects, the standard or waterfall approach is still our starting point. This approach might not be perfectly suited anymore when the project becomes increasingly complex. That does, however, not mean that we can get rid of the standard approach altogether. We should start thinking about what to additionally apply or how differently to apply certain activities or tools from the standard approach. Some elements of agile project management might be applicable in this situation. In other instances we will fit the approach to the situation. We call this fit for purpose or adaptive project management.

We have explained that the complexity of the project is a subjective matter. What one project manager might consider complex will not be automatically perceived as complex by another project manager. In a controlling style of management you will do your utmost to iron out the differences and to get the project team members aligned behind a common view on complexity. In many cases this will be near impossible and even unwanted. Rather than ironing out the differences we can try to build on the various perspectives present in the team. Different opinions, different eyes will see other opportunities, possibilities and/or threats. Making use of the diversity present in the team in this respect will enrich the scope of the project, will identify a variety of opportunities or threats and most probably will at the end add value to the project deliverables. By looking at the project with different pairs of eyes potential solutions will be generated that would not surface when we try to align everybody in an extreme manner.

Let's look at the example of the West Coast Mainline upgrade project. This is one of the busiest mixed-use railways in Europe, linking London with major urban areas in the northwest. After severe problems in the first and second round of the upgrade, the approach changed completely.

In the preparation of the 3rd round of the project, all stakeholders were actively involved and a joint vision was created. By increasing the number of players, in fact complexity was increased, but the solution to a successful project phase came closer!

At the Delft University of Technology research has been done into the interventions applied in dealing with project complexity in actual projects. We divided the interventions in controlling and connecting interventions: the first type of interventions are more into systems management (or the control approach) and the second type of interventions are more into interactive management (or the "hands-off approach").

We found that practitioners actually apply a mix of connecting and controlling interventions, see Figure 15. We saw that connecting interventions were sometimes used to enable controlling interventions and vice versa. To give an example: inviting all parties in the project to jointly perform a risk workshop at project start. This connecting intervention contributes to the more controlling intervention of risk management.

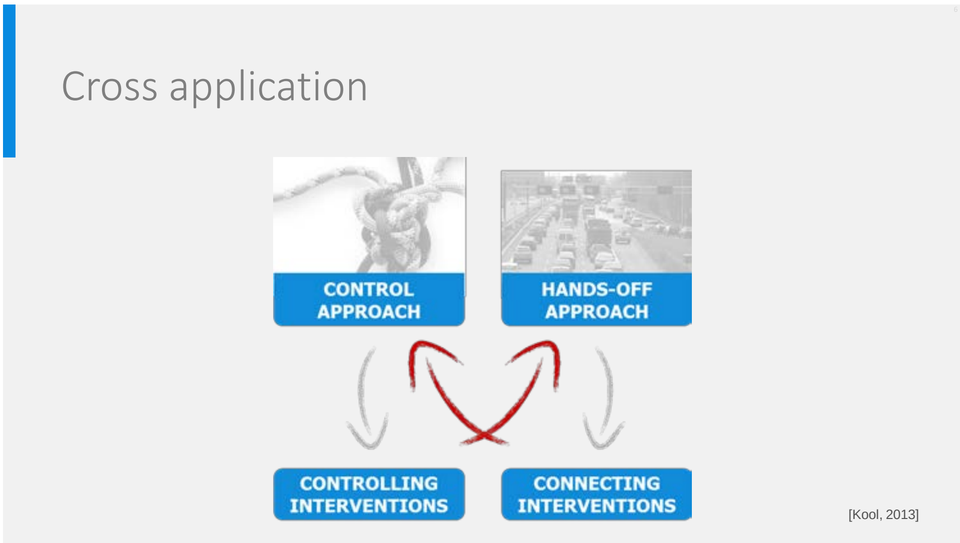

Figure 15: Cross application of control & hands-off

In the context of an infrastructure project, we have some suggestions for interventions for the Project Delivery Organization. Steer on a clear mandate from the principals. This mandate must provide enough time, budget and space to execute the project.

Connect to the local stakeholders instead of controlling them. The research showed that the connecting approach is much more effective to increase project performance.

Connect to the contractor but control if necessary. The contractor needs a connecting approach but if the contractor fails to meet demands and expectations the controlling approach should take over.

That controlling interventions enable connecting interventions adds to the implementation of dynamic management: next to the balancing act between systems approaches and actor approaches, the approaches actually cross-fertilize! We need this awareness to truly apply fit-for-purpose project management.

Back to the perceptions. Our research suggests that different perceived complexities can positively contribute to project performance, if they are managed well. This management of perceived complexities is referred to as perception-based management and we argue that this perception-based management should become one of the core focuses in the management of project complexity within large and complex construction and engineering projects.

This is how we propose perception-based management (Figure 16).

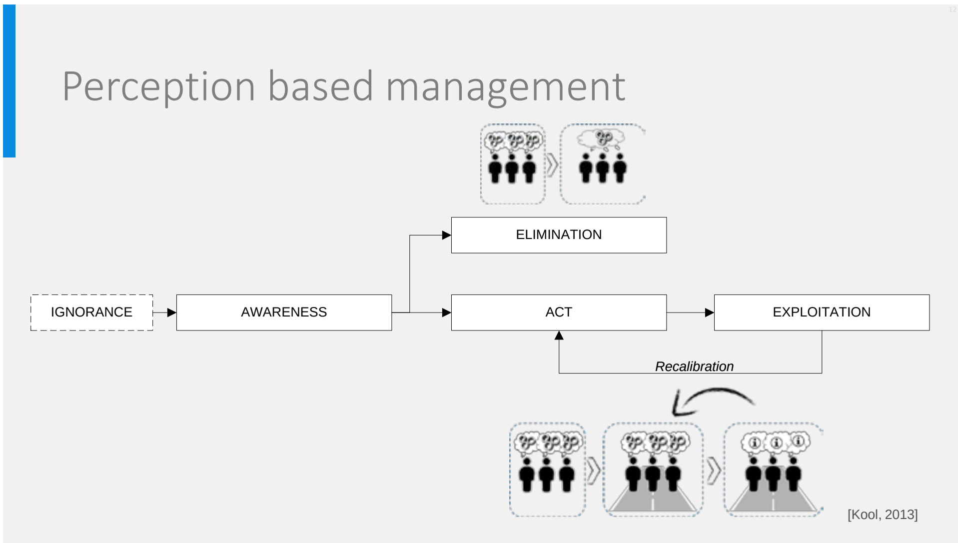

Figure 16: Perception based management

First of all, it assumes an awareness and acceptance of the different perceptions of complexity; elimination will not help. “Act” respects these various perceived complexities and stimulates a shared mental model. And further exploiting implies regular adaptation of the shared mental model, building upon the perceived complexities. Let’s embrace complexity!

To support this statement, we would like to conclude with the example of the A2 Tunnel in Maastricht, The Netherlands. It took years to get the project started. The project was initially considered as an infrastructure project; nobody was willing to invest. This situation changed upon the broadening of the project towards an area development project. Widening the goals, enlarging the project, including more and more stakeholders. This actually made the project viable!

In the end, mastering project complexity is about being aware of the complexities in your project, knowing your palette of management approaches and making the right choices in application. Like the focus of project management; it is about managing communications and expectations. Structure helps in this process but is not a sufficient requirement. Since complexity is in the eye of the beholder a balance must be found between prepare & commit and predict & control management styles!

Module 4: Value creation

How to create value in a project? A project in a dynamic environment?

Please let me give you the example of the following project in the Netherlands: the A2 Maastricht. Maastricht is a city in the south east of our country (Figure 17).

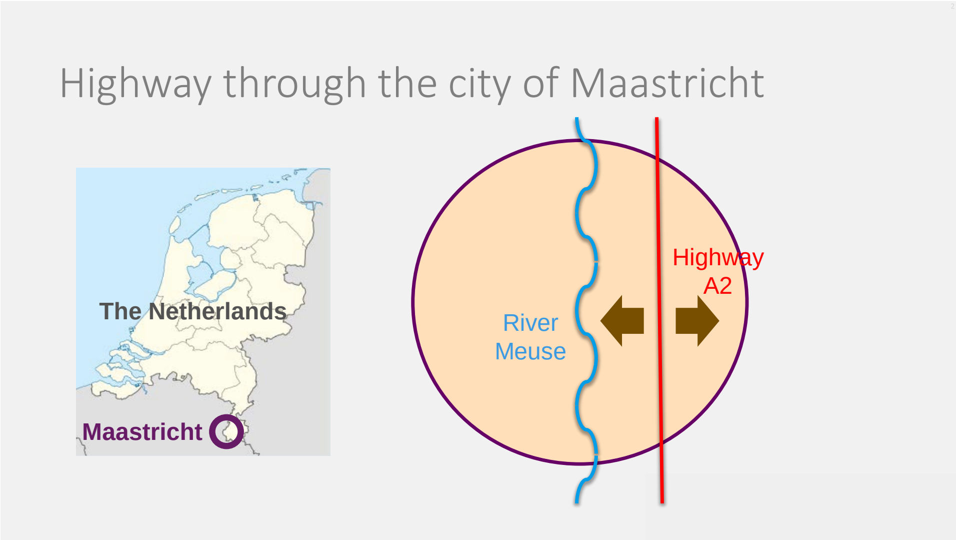

Figure 17: Highway through the city of Maastricht

Through the eastern part of the city runs the busy highway A2. At both sides of the highway, people live closely to this highway. In fact, the highway divides the city into two parts and creates unacceptable levels of air pollution and noise. For decades there have been plans to bring the highway underground by means of creating a tunnel at the current location, but sufficient support and funding were lacking. Apparently, this solution was too costly for the value it created.

Another solution was to bring the highway outside the city, eastward. This solution was not feasible, because it would cross a valuable nature area and led to much opposition of people living there. Moreover, too much traffic on the highway has a destination Maastricht, so one way or the other, a link with the city needed to be created in this solution.

From these two potential solutions, still the most attractive solution was a tunnel, but there was a need to create more value for the money invested. At the beginning of the 21th century, this solution was found by reframing the overall plan.

Until then the project was dominantly an infrastructure project, focussing on congestion and the need to increase traffic flow. The extra value was found in transferring the project from an infrastructure project to a city development project. Hence increasing the scope of the project and increasing its overall complexity. By doing do, the earlier mentioned tunnel solution became feasible.

For those who are interested, some technical details about the final solution.

It was decided to create a 'double-deck tunnel'. The upper part is for local traffic in the city, the lower part is for traffic that doesn't have the destination Maastricht. This double deck tunnel has sufficient capacity for the cars and lorries. And specifically for the civil engineers among you, interesting is that this is the first double-deck tunnel in the Netherlands. This is a costly solution, and without creating extra value, this solution could never have been built. How did they find the extra value to make the plan feasible?

The extra value was found by bringing the highway underground in a tunnel, in several ways extra value can be created on ground level.

Firstly, the space of the old highway comes available for other functions. Plans have been made for real estate development: offices and apartment buildings. Depending on the market, in total 1,000 new apartments and a maximum of 30,000 m2 of extra commercial real estate will be realised up to 2026. This city development contributes financially to the infrastructure to make the project feasible. A major part of the new space that is created by bringing the highway underground, was designed as a green zone that has been generating extra support for the project. The project is named after this green zone: the 'green carpet'.

This will give the area an environmental upgrade. And of utmost importance, by bringing the highway in a tunnel, the city will be healed!

To complete the feasibility of the project, the province, and the cities of Maastricht and Meerssen also financially contributed to the project, approximately one fifth of the public funding.

Of course there were threats to overcome, such as the technical risks at the design and construction of the double-deck tunnel, and the financial risks of the real estate. Finally, these risks have been mitigated and the tunnel was opened in December 2016.

Wasn’t this solution possible some decades ago? In other words: why did it take so long, before finding and realising this solution? I am convinced that this solution was not possible in the previous century. The solution found was very much a solution that fits in the current time frame. Let me give three reasons for this.

Firstly, the reframing to a city development project marks a change in thinking and practices over the years. Traditionally, the dominant function to focus at was traffic. But over the years, liveability becomes more and more important as a value. That was important in gaining support for this plan.

Secondly, the addition of scope. The idea that real estate can financially contribute to an infrastructure project is relatively new in the Netherlands. The first project in this way of public-private partnership has been realised at the beginning of this century.

Thirdly, traditionally the central government was responsible for highway projects: planning, funding and realising. Only recently, this kind of projects is co-initiated, and co-funded by regional governments. This was also an incentive for the Minister of Infrastructure to give extra money, to encourage other regional governments to contribute to highway projects elsewhere in the country. Interesting is that in this project, the project director wasn’t a civil servant from the central government as usual, but the former director of city development of the city of Maastricht.

It is interesting that because of problems with the financial feasibility of the project, creativity has been stimulated to find extra value. That is what we also see at other projects that have a main financial challenge: people came up with new, attractive solutions and packages, that will generally not be found in projects with sufficient funding. Apparently, financial tension can be a stimulus to come up with new solutions.

To conclude our case of the A2 Maastricht/ Green Carpet, you see that dynamics in society gave room to reframe the project, and to add extra scope. Rather than reducing complexity, in fact the project's complexity was enlarged!

Reframing and adding of scope created extra value and made the broader 'city development' project feasible, by gaining sufficient political and societal support.

Interview practitioner 3.1: Paul Janssen

Could you sketch your project a little bit for us?

The Rotterdamse Baan will be the new connection between Rotterdam and the centre of the Hague. Connection of course for cars, it will be a motorway. And it is a very strange project because on one side we are in the middle of the city of the Hague and on the other side it is a rural environment and right here now we are just on the construction site where a new road will be constructed just above us.

I can imagine that there are some complexities that you face in a project like this, are there any you can mention?

Well, a complexity is like I said: on one side we are just in the city, with all things that can happen there, on the other side a rural environment where we have also all kind of problems. And of course we are in the Netherlands so water is always a complex factor, with any project.

And water in what sense?

Well, actually we are here already below sea level, the point where we are standing now. But also all the little rivers, canals that have been digged here in the former years. We found some canals which are built by the romans, just after Christ, and we had to cross them.

You just indicated that actually the environment of the project is very different. Can you explain how you manage with those differences, so those different environments?

Talking, talking, talking. We have a lot of you could say ways to cope with the people which surround us, and of course they are the experts when it's about the environment. They live here, they work here. We are only here their guests for a couple of years. So we are very anxious to know what's on their minds. It's both inhabitants, but also people concerning about the landscape, this is a very – well just here above us- a very old landscape, but also talking about all kinds of animals, from very little fishes here in the river here, to enormous bats.

How do you deal with these difference in terms of management? Do you approach different parts differently?

Yeah. Because big organisations, well you have to be very official with them. On the other side we have a very little kind of factories. And of course, the inhabitants, well we don't cope them with very big contracts or something like that. It is a way of knowing how to talk to one another.

I understood that sustainability is one of the -well sort of- main drivers of your project? Can you elaborate a little bit on that?

What our goal is here is to build the most sustainable tunnel of well let's say Europe. And sustainability in the sense of noise, when the tunnel is in function, air quality, air pollution. But also about the consumption of energy. Tunnels consume a lot of energy and we are trying to reduce that kind of energy. So, in the end you will see here all our buildings will be coped with solar panels, for instance. Sustainability is a major goal in our project.

And would it be right to state that by putting sustainability so high in your goals that it in fact increases the complexity of the project?

Yes, of course. Because it was one of the factors for the contractor to gain the project, so we have to control them also on these kind of factors. And like I said, it is not only in construction face, but also when the tunnel is in function, and it will be in function for 100 years.

Can you also tell us something about the collaboration between you as a client and the people from the contractor?

Well we believe in a cooperation very tight, so we are actually here on the construction site. We are working here from one in the same building. We have a lot of things in common. We try talk instead of sending mails to one another, and well this is a bit awkward in this period where everyone uses the mail. We try to avoid that as much as possible

Do you have recommendations for your colleague project managers to better deal or cope with complexity?

Treat your project like your relationship or your marriage. If you look at the contract everyday it won’t take long, and you won’t have so much fun

Interview practitioner 3.2: Marco Eykelenboom

Could you briefly sketch what your project entails?

Briefly is difficult, but I will try. It's a project which is about an integration of couple of new units in an existing refinery. We are going to build a new hydrocracker unit to produce more diesel. We are also going to interlink that new unit with loops facility, to create loops to a base stock.

What were the most serious complexities, or what are the most serious complexities that you face?

I'm still facing it. It's interactions on the project with all the people involved. It looks like all these people have an own view on what needs to happen. And what you can tell is on those interfaces between the various entities on the project you see a lot of trouble to understand from each other what are you really trying to do.

Is it really only interfaces, is it behavioural only, or is it also technical complexities or is there a balance?

Actually, it is both. I wish I could put my finger on one of them. What we see is that interaction on technical problems is much more down to earth for engineers, they can actually deal with that. They will find solutions to flaws what they actually encounter every day. What's more problematic on the project is the behavioural interactions with people. It's much more difficult to actually understand that we are doing this together.

And how did these change over the project life cycle or are they still changing?

What brought us a bit in trouble in the beginning of the execution face, so the construction face of the project, was to keep everything in sync with each other. So we saw moments that we were running out of sync with what we really intended to do in accordance with the schedule, which means that you get an overwhelming amount of additional interfaces with new groups of people coming in and trying to do something out of sync with what is there and it means that we hav to deal with that and that cost quite some additional complexity to the already difficult task that we had in front of us.

How did you deal with the complexities that you mentioned? Or are you still dealing with them?

Yes, still dealing with them. The biggest issue is actually to make sure that we are in a purpose of building a plant. So it means every time someone brought up a complexity, they come from their own perspective on why it was so difficult from their perspective, and they are probably right, probably so. Now if you do a step back and start to see how the value could be contributed to the end game or the end stage where you want to be, then it brings a total new perspective to the entire team. So people see that no matter what the problem of one team or one group of people is, we are still in the game of building the entire facility and that is a very helpful way of breaking through in situations that people get that locked in their thinking.

Is it also a matter of letting go then for people? That they say you have a plan, but it is good to deviate from that plan? Is that what you are saying?

Yes, a project manager would always say that it is never good to deviate from a plan, but the real life is that we are almost always deviating from the plan, because every day is an interaction of a web of

-you know- commitments and promises from people and if it does not fit totally then we are deviating from the plan. Now, realising that that in itself is not wrong, it’s just a state where we are and now we have to move out of it together, that is the breakthrough in thinking. So, if people tend to pause a moment and just look back in history and how come that we are in this bad state and who caused that, and this is the blame game. It causes that people are actually very much defending on their position and situation and it actually kills the opportunity to move out quick and actually move forward, because that is what a project wants.

You mention the complexities here mora as almost technical complexities, initially you said it is the interfaces that are the complexities. Are people willing to approach he interfaces in a similar way as they approach the technical complexities?

Yes they are. What I experienced over time is that similar to what you do with technical issues, you can also see it in interfaces, you can also see it in how people relate to each other, so behavioural aspects. So besides the technical operational side of things we see exactly the same in how people interact with each other. The moment they see value, in there is a way that we can be stronger together, there is suddenly a move forward into the right direction. So there is a very much, very high I would say, forward looking and value added thinking if you are willing to actually willing to reach to someone else and see that the both of you are stronger.

Did you bring in additional, say, help forces so to say to help you manage those behavioural stuff?

Yes we are in a pretty big project so it means that it provides an interest and a benefit to the project to actually get people which are skilled in how to actually deal with the dynamics in teams. So what did is, we hired a consulting company which actually brought all kinds of techniques and interests in how you could actually create an environment which is stronger to perform from a technical site. It really helps. It is really one of those methodologies which could be added to the skill set of a project manager. That you are not doing it by yourself, by yourself alone. There are people out there who have a better view on how to deal with this kind of complexity.

What was the initial response of people, or reaction of people when you first brought in this ‘behavioural staff’?

It is a difficult thing for most people because it means that you have to be open minded for new ways of doing things. Imagine the world that all the engineers are very beta skilled, so very good in data and number crunching and understanding how analysis work and how to deal with information. They are in a processing mind. The moment you start to almost confront those people with their lack of training from a social interaction skillset, it needs an open mind to actually understand that this is a piece of tool in their toolbox. They look at it as a potential threat or danger that they are basically pinpointed down to some sort of flaw in the way they operate, which is not, it is just a lacking in knowledge in that field.

Do you have recommendations for your fellow project managers to better manage project complexity in the future?

If I would say something, it would be relationship. Focus on the relationship. So the project is one big web of relationships with people. It is sub-contractors and main-contractor, main-contractor and owner. Everywhere you look are relationships, amongst teams, amongst teams of one group of people. Even within the owner we see people working with each other. So, if you would focus on the relationship and understand what it means to be in a trust and respectful environment, then suddenly the world of opportunity is in front of us. And that is one the things I hope that in the future project managers should have a much keener eye on. It is not only a technical solution that we are providing. It is an end game of building a plant together.

Should we do something to our curriculum to that end?

If I would say, yes. I am technically trained, I am an engineer by background. I wish I was much stronger in psychology and sociology.

Thanks for your time

Thank you

Interview practitioner 4.1: Gerard Meijer

How would you characterize the projects in your sector?

The projects in our sector can be characterized by three elements. One element is that we always have to realize some kind of ICT component like the development of some kind of software system. Or configuration implementation of a standard software package. Or we have to install hardware. Another component is a big organizational change. Every project has to deal with new procedures and new way of working. And last but not least is that in our sector we have to deal with low predictability of the project. We have a partnership with a Standish group. This is an American organization which measures thousands of projects. Yesterday evening I checked the numbers and large projects fail most of the times. Five percent of large projects are successful. Medium large projects 15 percent and small projects 57 percent. So there is a lot to do and improve in the projects in our business.

What are typical complexities which you observed in your projects and programs?

Typical complexities and factors which influence our projects are for example the lack of clear and concrete requirements and a clear goal. The starting point of a project is to have a clear goal. We often account for a senior responsible owner, a client, who is not capable to define a real business goal and no clear requirements. And as the project moves forward, we see that the concreteness increases but the damage has already been done. We have to deal with a lot of scope creep, we have the experience that sometimes the project is multiplied by two or three times the original budget. Another complexity factor is the immature suppliers in our branch or stakeholders whenever a project has a big impact on the organization. We have to deal with stakeholders, we have to deal with hidden agendas, we have to deal with politics and abusive power. That kind of stuff.

What kind of management approach then would you apply, for those complexities?

There is no one size fits all management approach. For example if you have a project in deep crisis, with an immature supplier, with an immature organization, bad contracts and already damage on budget and schedule performance, then you need a very directive and visionary management style. People want to be guided, they want to see a solution. Another example is if you have a project with no complexity on the technology stuff, it is known technology, you have to coach the project members. Another example is a research and development project, then we have to deal with very high skilled and very professional team members with a right attitude. So you only have to coach them and create an environment in which they can do their things and can work nicely.

How could we make our management more adaptive?

I think it starts with to be aware of the different styles. I think you also have to be aware of your own style. What we experience is that project managers have a preferred style and preferred styles can be combined with certain projects. But the next thing is you have to play with these different styles. You have to dare to use different styles in several situations. What we encounter is that there are a lot of project managers and a few of them have the guts to do thing in some situations to change their style. So you have several kinds of projects but you also have several kinds of situations. Suppose you are talking with a ministry or the boardroom. You encounter some things which are no very clear, what do you do? Do you avoid the situation, are you looking for a compromise or do you compete with the environment? There is also another way of looking at dealing with situations so there is not only the characteristics of a project which determines the way you handle things. Also the way you are talking at that moment and how you intervene in these kind of situations.

Do you have any recommendations for your fellow colleagues to better master project complexity?

Two lines. The first line is be aware of several factors in your project which influence your project result. Which make it more difficult. Like a lack of concrete requirements, an immature supplier or an immature organization or a lot of resistance against change. So be aware of those factors and be aware of the measures you can take. And other hand be aware of your own style. Your preferred management style and the styles you like or absolutely don’t like. Because there are some deadly combinations, the left one or the right one you know.

Thanks a lot!

Interview practitioners 4.2: Rob Kretzers

Could you briefly sketch your project?

The project that I led was in Qatar, in the middle east. It was a complex project integrated between upstream and downstream facilities build by more than 52000 workers and having an onshore plant with twelve big sub-projects in themselves.

What were the most serious complexities that you faced?

There are of course many complexities with this scale of a project and one of the big complexities was of course that we had 12 sub-projects with many thousands of interfaces between the teams and the projects that they were leading, and also of course the complexity of having 52000 people coming to your site, and also the interferences with for example the community, and also you had to bring through global procurement many goods and materials and you had to arrange the logistics to make sure everything was safely brought onto the site. These are just some of them.

How did these complexities change over the lifetime of the project?

You prepare them very well these complexities in understanding them, but then the environment changes. I will give you one example. We started with making an estimate of productivity to build this plant and then assumed that we need 35000 people. In the end the productivity was 50% worse and we needed 52000 people. That was not the only complexity which was changing, there were also concurrent projects happening in the same industrial area. They got delayed by more than a year and we had assumed that we would get certain disciplines from those projects so that there would be a nice peak shaving and that did not happen. For example, as a problem that you can face, despite your good preparation.

Despite the work as other examples or complexities in the process site of the project?

Yes, the complexity in the process is because you have many, many interfaces between the sub-projects, typically what happens the first thing that you have to design and build are your utilities. Then meanwhile your other subprojects are developing their processes and they figure out and find out they need more utilities than you originally had assumed then you get a knock-on effect on the design of your utilities which you also have to build first. So that is a very delicate situation where you don't want to design for overcapacity in your utilities because you also need to be close to your budget. So those things happen typically, it is a risk which is understood and the mitigations are often there to see if you can still ad something additionally later by having several building blocks parallel to one another in your utility complex, which we had to do. We had to add another gas turbine later on in the project.

How did you deal as a manager with the complexities that you mentioned, how did you manage it?

Now first of all you manage these complexities by identifying up front, particularly as risks. So you see them as risks, and of course you put your mitigations in place to manage those risks. But again, the mitigations might not be sufficient like I just described about the productivity which was far more bad than we had expected. Now it means then as a manager that you will have to face the unexpected. Now what is important there is that you as a manager can keep your head above the water so that you as a manager have the capacity to deal with the unexpected. Thus not only yourself as manager but also when you build your team you always need to build in your team enough capacity to deal with that so that people always have the time to look ahead and also have the time to reflect on the mitigations that they need to take if risks develop even worse than they had anticipated them.

Do you have recommendations for your fellow project managers to better cope with project complexity?

I think that as a project manager, like I said a bit earlier is key that you have capacity. So one of the things that I did, I always had a young person with me who would help me to deal with the complexities that I was facing and that created then sufficient capacity in myself, in the do-er really, to overcome whatever would be facing us. And you have to stay calm. So if you start to be stressed-out, your team will look at you and the whole team will go into a stress mode, instead of that they have the capacity and the power to really overcome what they are facing.

That young person, did you use him as a sounding board? Him or her? Or as a gofer, or how do I look at it?

In all the aspects that you just mentioned. What important when you have a young person with you, they also often are the ears and eyes in the organization. They will pick up signals from three, four or five levels down of your organization. Also people will approach them, they feel it's hard to go to the top of the organization in some cases. But then going to a fellow who is of the same age and background as themselves. That helped me to stay in contact also three or four levels down in the organization. But also as a gofer and as a sounding board and also as a learning ground for that person to really build themselves up. But particularly I did it only every one and a half year choose someone else. So they move in and out. So that for both parties it stays sharp and alive

What is your main advice for a young starting project manager?

I think my main advice is to pick up a project which is very broad and not big. Don't go on a project solely which is very big and only do a small part of it. Pick a broad and small so it is broad. So that you, hands on, learn the job. Even if you feel that 'did I study for that so many years to do this job? ' What you will learn the first three to five years of your career is very close to the work front. And it will help you in the decades of project management afterwards. It helped me a lot when I just started with a small project installing two pumps in the Pernis refinery 35 years ago.

Perfect, thanks Rob for sharing your time and experience.

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Appendices

Module_1.2_subjectivity_white_paper

Module_2_grasping_project_complexity_TOE_framework

Module_3.1_ManagementApproachesHertoghWesterveld

Module_3.2-complexity-lean-agile

Module_4_Smallprojects_fitforpurpose_approach

The Westcoast mainline

Z7_Systems_Thinking_WEB

White paper[*]

Perceptions on project complexity: ignore or exploit?

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Abstract

Project complexity is still a hot topic within project management research. Understanding and dealing with this complexity has become one of the major focusses. However: there is no such thing as 'the complexity' within projects. Practitioners within construction projects appear to have different perceptions on complexity. People that are for example working within the same organisation, on the same projects and with comparable roles, can identify entirely different elements of complexity within the same project. We call this phenomenon *perceived complexities*.

Our research focused on understanding these differences in perceptions and their consequences within large infrastructure construction projects. We identified different sources of perceived complexities, the implications on project performance and the implications for project management. The results stipulate a management approach which exploits different perceived complexities and show that the right attitude can make a difference in dealing with complexity in large construction projects.

Keywords project complexity; infrastructure / construction industry; project performance; perception based management

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1. Introduction

Project complexity is a phenomenon which is often accused of being one of the causes for project failure in large projects (Neleman, 2006; Williams, 2002, 2005). It is also believed that complexity within construction projects is growing which leads to great challenges for the management of these projects (Hertogh and Westerveld, 2010). Several authors have addressed these challenges and formulated possible solutions in recent studies (e.g. Favari, 2012; Giezen, 2012; Vidal et al., 2011) most of them using a top-down approach to identify, assess, and design valuable management tools. This research used a bottom-up approach to identify and assess these tools within the current construction practice. It identified several tools used in practice to deal with project complexity and encountered differences in practitioners' opinion on the exact definition of complexity within a specific project. We called this phenomenon 'perceived complexities' and identified several sources as drivers for these perceived complexities. We assessed the impact of these different perceived complexities on project performance and developed a management approach which uses these differences for the benefit of the project; called *perception-based management*.

This research is part II of the research on 'project complexity in the Dutch construction sector' that was initiated by Kennis In Het Groot (KING) and the Rijksprojectacademie (RPA) in 2012. These two organisations are knowledge institutes within the construction sector and aim to exchange knowledge between construction projects and to create new knowledge that helps these projects. This research is an example of such knowledge creation. In 2014, KING and RPA merged into the new organisation Neerlands Diep.

In part I of the research, the TOE-framework to assess complexity in projects in the process industry, distinguishing technical, organisational and external complexity (Bosch-Rekveldt et al., 2011) was used in a survey to assess project complexity amongst 164 respondents working in 35 Dutch construction projects (Bosch-Rekveldt, 2013). As a result of the part I research, project complexity in these Dutch construction projects was described and different perceptions on project complexities were observed. Subsequent research was required to investigate in-depth what were the rationales behind the complexity assessments – part II of the research. This part II research at the same time identified management approaches that are used in current practice to deal with these complexities.

Part II of the research is described in this paper. The main research question to be answered was *how do different perceived complexities impact project performance of Large Construction Projects (LCPs) and what are the implications for the management of LCPs?* To answer this question, this research selected five of the original 35 projects for this in-depth research. By designing a case study and performing interviews with key persons within these five projects it constructed knowledge to better understand differences in perceived project complexity and a management approach to deal with these complexities.

This paper first describes the theoretical framework used to capture project complexity, perceptions and complexity management (Section 2). Next, it describes the case study set-up used to perform the research (Section 3). The results, described in Section 4, give an overview of identified sources of perceived complexities and identified interventions dealing with project complexity. Section 4 also elaborates on the implications of different perceived complexities for project performance and highlights the approach that looks the most promising to positively influence this performance: *perception-based management*. The paper is ended with the discussion (Section 5) and the conclusions and recommendations for the research community as well as practitioners (Section 6).

2. Literature review on project complexity, perceptions and managing project complexities

A literature study was conducted for three reasons: (1) to find what is known about project complexity and how this research would embed within current knowledge; (2) to see how this research could describe perceived complexities in a meaningful way and (3) to find what is known about dealing with project complexity and how this research could confirm or reject these existing theories. These three topics are elaborated subsequently.

2.1 Project complexity

Literature defines project complexity with general terms and acknowledges a split between complicated and complex: complicated refers to the many components of a project that interrelate; complex refers to the unexpected things that happen due to this interrelation (see Table 1). Complex projects are believed to be complicated and complex at the same time.

Table 1: Categorisation of different definitions of project complexity

Source	***Complicated***	***Complex***
Baccarini (1996)	Many different & interdependent parts	-
Williams (1999)	Structural uncertainty	Uncertainty
Thomas and Mengel (2008)	-	Chaotic, dissipative and adaptive systems
Whitty and Maylor (2009)	Independent structural complexity Independent dynamic complexity Interacting structural complexity	Interacting dynamic complexity
Hertogh and Westerveld (2010)	Detail complexity	Dynamic complexity
Koppenjan et al. (2011)	Structural complexity	Dynamic complexity
Favari (2012)	Complexity of projects	Complexity of environment
Ireland et al. (2012)	-	System of systems
Davies and Mackenzie (2013)	System	Meta-system

Recent authors have exerted to operationalise this definition to make it useable in practice: they designed frameworks to assess the project complexity in construction projects distinguishing elements contributing to complexity (Bosch-Rekveldt et al., 2011; Maylor, 2010; Vidal et al., 2011). Since the TOE-framework of Bosch-Rekveldt (see Appendix A) was used to explore project complexity in part I of this study, it was also used in part II.

This research contributed to this literature that has the objective to operationalise the definition of project complexity. It supports a better understanding of the assessments of complexity within projects: by understanding how a perceived complexity is constructed by practitioners it is better understood how the assessment of project complexity by practitioners takes place.

2.2 Perceptions

A perception can be described as the way an organism interpreters its environment. It is not the intention of this research to investigate in-depth how perceptions are constructed within organisms but it has used an adapted version of the Brunswik Lens Model (Brunswik, 1952) in order to describe the different perceived complexities of construction practitioners. This model was originally developed to describe how organisms would perceive their surrounding but was soon used within judgement theories to understand human judgements on varied cases (Bisantz et al., 2000) and was therefore found very suitable to be used to describe the perceived complexities of construction practitioners. They do so by selecting certain cues (i.e. components) of the environment and judge these cues which lead to a judgement on the environment. This research showed that the elements in the TOE-framework (see Appendix A) can function as cues that practitioners select and judge in order to come to their judgement on project complexity: this combined selection and judgement of TOE elements is what we called a ‘perceived complexity’.

2.3 Managing project complexity

Literature seems to distinct two main approaches to deal with project complexity: the control-approach and the hands-off-approach. In a control-approach, projects are seen as systems that can be controlled, predicted and planned. In a hands-off approach, it is acknowledged that projects cannot be forecasted and therefore by definition not can be controlled. Theory argues that a combination of the two approaches results in the most effective approach to deal with project complexity – in fact a third approach. How different project management-approaches, found in literature, can be categorised in the main approaches is shown in Table 2.

Table 2: Categorisation of different project management-approaches to deal with project complexity

Source	***Control-approach***	***Hands-off-approach***	***Combined-approach***
Baccarini (1996)	Integration	-	-
Williams (1999)	Traditional approach	Soft techniques	-
Austin et al. (2002)	ADePDO	-	-
Hertogh and Westerveld (2010)	Systems management	Interactive management	Dynamic management
Thomas and Mengel (2008)	Traditional approach	Management based on understanding	Combination
Koppenjan et al. (2011)	Predict-and-control	Prepare-and-commit	Combination
Leijten (2012)	-	Centralise risks in decision making	-
Favari (2012)	Plan and control	PM-2	-
Bértholo (2013)	-	The shadow of projects	-
Best et al. (2013)	Controlling	Connecting	Actuating
Davies and Mackenzie (2013)	Integration	Flexibility	Disciplined flexibility
Locatelli et al. (2013)	Systems engineering	-	-

The management approaches are brought into practice with the help of interventions. This research used the model of Best et al. (2013) to identify the specific interventions in practice. They distinct controlling interventions (aimed at controlling the project), connecting interventions (aimed to connect people and thoughts) and actuating interventions (aimed to push someone towards an action or decision). Controlling interventions contribute to the control-approach, connecting interventions to the hands-off-approach and the actuating interventions to both, see also Table 2.

3. Case study

The research design consisted of an embedded multiple-case study (Yin, 2003). Five construction projects from KING/RPA network were selected and functioned as cases. These five were selected out of the 35 projects that participated in the part I research. The five cases were selected such to cover a wide variety in typology, thereby enhancing the representativeness of the five cases for the Dutch construction industry. All cases were in the preparation or construction phase during the research which increased validity: this made sure that respondents were ‘living’ and experiencing the complexity during the interviews and did not had to rely on their memories.

All projects involved the construction of a civil structure (wet or dry) or a utility construction. There were one or more public bodies represented in every project and there was always a public client. With CAPEX (capital expenditure) in a range from €35 million to €500 million or more and several stakeholders involved, all projects could be called ‘complex’ if rough outlines were to be regarded. One project was still in the preparation phase, meaning that it was not been put on the market to find a contractor. One was in the design phase (a contractor was awarded with the D&C contract and was designing the project) and three were in the construction phase, where two of them were expected to be completed within a year from the research. For one project however, the scope was changed during construction phase which led to preparations that could result in an extension of the construction phase. Table 3 gives an overview of the five projects selected for the case study.

Table 3: Overview of the selected projects and their corresponding phases

#	***Project***	***Phase***
1	New metro and bus station in urban area	Preparation phase
2	New ship lock in rural area	Design phase
3	New museum in rural area	Construction phase
4	New metro station in urban area	Construction phase
5	Expansion of a train station / development of the near area around the train station	Construction phase / preparation phase

The five cases contributed a total of 30 interviewees. The participants for each project were selected by the project manager and can all be classified as construction professionals. This self-selection ensured cooperation and is furthermore in line with the view that this research is of explorative nature: since no hypothesis is formulated whatsoever there is no desire to conduct research on a specific type of respondent within each project. It was however the aim to account for all types of actors within each case (civil principal, Project Delivery Organisation, contractor and NGOs).

These respondents were first asked to assess project complexity with a survey based on the TOE-framework (appendix A). This survey resulted in three elements that were the most contributing elements to the complexity of the project according to the respondent. In-depth interviews were used to understand this top-3-list, its origins, its consequences and the way it was handled by the respondent.

The interview minutes were transformed with the help of descriptive research into three secondary data-sources: (1) case reports which provided an overview of all respondents within one case; (2) descriptions of the perceived complexities based on the adapted lens model and (3) a list of distilled interventions dealing with complexity. Explanations for perceived complexities and their implications were found with the help of explanation building (Miles and Huberman, 1994).

The results of the research were internally validated by confronting the participating project managers of the five cases with the results. They were also externally validated with literature and an expert meeting consisting of a debate on the findings of this research and in which approximately 30 construction practitioners participated.

The research (and interviews) focussed on two main topics:

1. The practitioners' subjective definitions of complexity
2. The tools that they applied to deal with this complexity.

In the research, these two topics came together when it turned out that the differences in complexity definitions could actually be very well used to deal with those complexities.

4. Main results: the value of differences in perceived complexities

The five cases showed that there is a gap between the definitions of project complexity provided by theory and by practitioners. Practitioners tend to base their perceived complexity on the degree of influence they have on the project complexity. Also, practitioners' perceived complexities can be split in either problem-focussed (i.e. negative attitude) or challenge-focussed (i.e. opportunistic attitude). The theoretical definition, however, is merely based on interrelating components which do so unexpectedly (see Table 1).

The five cases also showed a possible positive relation between different perceived complexities and project performance: this led to the proposition that differing perceived complexities lead to better project performance than non-differing perceived complexities.

The data analysis identified the origins of perceived complexities, an overview of applied interventions dealing with project complexity and a detailed description of implications of different perceived complexities. All three will be elaborated subsequently and next, perception-based management is further detailed.

4.1 Origins of perceived complexities

A perceived complexity is created by the *selection* of certain elements of project complexity followed by a *judgement* of these elements (the elements are in this case the elements from the TOE-framework that were selected). The sum of these separate judgements forms the perceived complexity for any individual. This research found four different sources for perceived complexities. Three sources contribute to the *selection* of certain TOE-elements by practitioners to build a perceived complexity upon:

(1) the perceived impact of an element and the influence of the practitioner on that element;

(2) the experience of the practitioner and

(3) the context of a project or contextual variables.

The fourth source contributes to the *judgement* of the TOE-elements:

(4) the interests of the practitioner, which in its turn is influenced by the role and/or personal values.

These four sources all contribute in a certain degree to a perceived complexity, but the contribution of each source can differ for each individual practitioner.

4.2 Overview of applied interventions dealing with project complexity

The list of encountered interventions dealing with project complexity from the 30 interviews was reflected against literature. This confirmed theories in their statement that practitioners apply a mix of connecting and controlling interventions. These two types of interventions contribute to the *control-approach* and the *hands-off-approach*. It was however also found that connecting interventions were sometimes used to enable controlling interventions and vice versa, see Figure 1. This cross-application of intervention-types enabling other types has not been mentioned in researched theories and seems to be an addition to current literature.

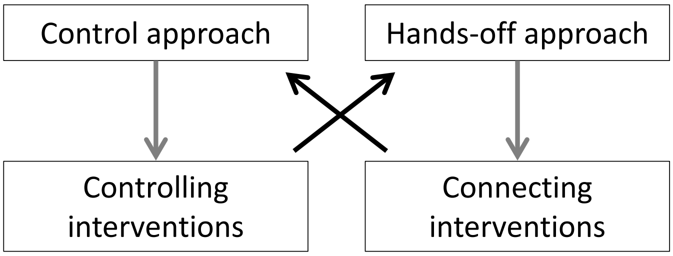

Figure 1: Cross-application of control and hands-off approach

The relation between perceived complexities and interventions dealing with complexity was also researched: it was found that there is a relation but the details of this relation are unclear. Based on the research, it cannot be concluded if certain perceived complexities lead to certain interventions or if certain interventions (or: the feeling of influence) lead to certain perceived complexities. This is a topic for further research, see also Section 6.2.

4.3 Implications of different perceived complexities

The way of handling perceived complexities is determined by the level of awareness, the acceptance of the differences and the judgement of these differences. Without awareness there is no possibility to act upon the differences. Only in one of the five cases, some unawareness of complexity was observed, leading to poor project performance in view of the respondents. Regarding the acceptance of different perceived complexities, some respondents indicated that they rejected differences in perceived complexities and rather would strive for a single definition. The majority of the respondents actively acted upon different perceived complexities. Based on the case studies, the following ways of handling different perceived complexities were concluded: they can be ignored, eliminated, controlled and/or exploited, see Figure 2.

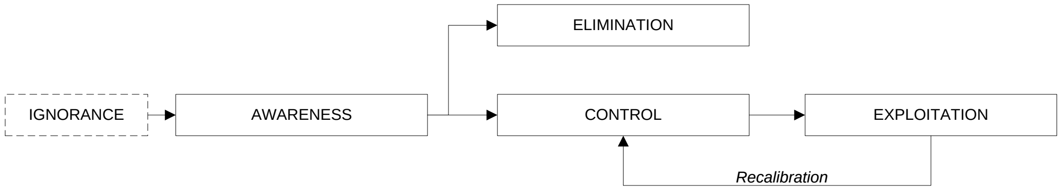

Figure 2: Different ways of handling different perceived complexities

Interventions dealing with complexity were often applied in order to manage the collaboration with another party. This research acknowledged the Project Delivery Organisation, the contractor, the civil principals and the local stakeholders and advised the Project Delivery Organisation in the way they could manage their collaboration with these role-groups. This resulted in the following recommendations for the PDO:

1. *Steer on a clear mandate from civil principals*. This mandate must provide enough time, budget and space to execute the project.
2. *Connect to the local stakeholders instead of controlling them*. PDOs apply too often a controlling approach. This controlling approach tries to *manage* the stakeholders but does not engage them in a connecting and fully transparent way: local stakeholders are not being truly involved in the project with the controlling approach. This is however desired and this research showed that the connecting approach is much more effective in increasing project performance.
3. *Connect to the contractor but control if necessary*. The contractor needs a connecting approach but if the contractor fails to meet demands and expectations it should be engage with a much more controlling approach.

The research also found interventions dealing with project complexity that were mentioned by a large number of respondents: they were seen as general interventions to manage overall complexity. Five general interventions were mentioned:

(1) interact *physically* with each other;

(2) separate roles within organisations and individual people;

(3) build informal networks to enable acting between rules and protocols;

(4) find adequate people and

(5) apply perception-based management.

What we exactly mean with perception-based management is detailed in Section 4.4.

4.4 Applying perception based management

Perception-based management is the management approach which focuses on the different perceived complexities of all involved practitioners and thereby applying project learning. This research found four different ways of dealing with different perceived complexities: they can be ignored, eliminated, controlled or exploited (Figure 2). The latter two, control and exploitation, are part of the same model since first perceived complexities need to be controlled before they can be exploited. It is believed that this combination leads to the most improved project performance.

Perception-based management consists of two stages: first all involved people have to agree on a shared mental model which centralises projects' interests and indicates the shared objectives of the project. Next all practitioners have to bring the shared mental model into action by basing their actions on the shared mental model. The proposed model is shown in Figure 3. It must be emphasized that a shared mental model is not the same as having a single unanimous view on the project: it rather indicates what individuals see as the objective of the team performance and how these objectives should be reached (Arnold and Silvester, 2005). This is also emphasized by George and Jones (2008): they describe the shared mental model as one of the five key principles of organisational learning. Team members must use this shared mental model to frame problems and opportunities: at the heart of this shared mental model lie a set of work values and norms.

Perception-based management contributes to project performance in two different ways: it contributes to a good collaboration with the shared mental model and it uses the untapped knowledge of all practitioners to apply project learning. This project learning is necessary because of the emergent and unpredictable character of large infrastructure construction projects: they cannot be predicted and therefore need to be learned ‘along the way’ with the help of project learning.

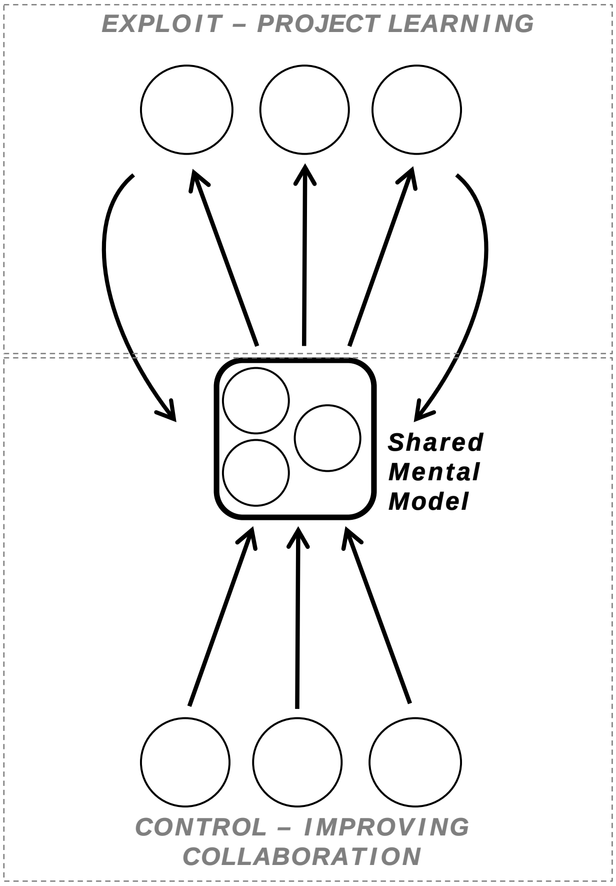

Figure 3: Double loop perception-based management

This research acknowledged three major interventions that contribute to the application of perception-based management:

1. *Create the appropriate preconditions*. These preconditions consist of awareness, the right ambiance, a good mandate from civil principals, the right kind of people and awareness of the consequences of certain contract types.
2. *Create a shared mental model*. This shared mental model contains the common project goals and shared norms & values. It is used to give direction to the actions of the individuals within the project.

3. *Focus on project learning*. Practitioners must feel free to question the shared mental model and thereby reshape the shared mental model. This enables the use of untapped knowledge (*unknown knowns*) because practitioners can continuously apply their knowledge by questioning the shared mental model. Perceived complexities can furthermore be used in applications of project management such as *Building Information Modelling* or *Joint Risk Finding*.

A clear intervention that resulted from the case study was the project start up meeting (PSU): this was suggested to be an excellent activity to exchange perceived complexities. Also after the PSU, a project team could be encouraged to regularly review their perceptions on the project's complexities.

Proving the correlation between improved project performance and the application of perception based management went beyond the scope of this research. It was however noticed that the two projects that made progress and were marked as performing well (by both researchers and participants), were at the same time the two projects where all involved stakeholders acknowledged the benefits of differing perceived complexities. However, more research is needed to determine the (statistical) relation between these two concepts.

5. Discussion

As every research this research had its limitations and the outcomes therefore need to be discussed severely. We identified four important limitations.

The first limitation is the fact that the description of perception-based management assumes awareness and respect for different perceived complexities. These assumptions were validated and confirmed in the expert meeting but this expert meeting also indicated that it was sometimes necessary to impose a perceived complexity to others for the sake of progress. This immediately shows a possible drawback of perception-based management: it might become too time-consuming. When to impose and when to apply perception-based management is a topic for further research: this research did not collect the right type of data to answer this question.

The second limitation of this research was present in the explorative nature of it: the outcomes of this research lack sufficient data to formulate sound conclusions. The outcomes are therefore merely strong hypotheses which can lead to further research.

The third limitation was the representativeness of the cases for the Dutch construction industry: because all cases were member of the KING/RPA network they were more than average interested in new developments in the construction industry. The selected cases are therefore likely to be the 'top notch' of project management which could have led to a more promising current situation than average.

The fourth limitation is the lack of attention for strategic behaviour of actors; this could influence perception-based management severely but the data did not provide enough data to determine this influence.

The findings of our research are not ground-breaking: social sciences have developed the concepts of a shared mental model and project learning in much more detail (Ahern et al., 2013) or derivatives of those such as double-loop-learning (Reyes, 2012). This research merely confirmed that these concepts are also important and valid within the construction sector and it is our suggestion that social sciences and applied sciences combine their forces in the search for management approaches and approaches to deal with project complexity.

As stated before; this research was originally designed to explain different perceived complexities and identify valuable tools in dealing with complexity. During this research we encountered perception-based management as a used and promising tool, thereby uniting the two directions of our research. Future research has to centralize the proposition of perception based management as a starting point, testing the approach top-down in several real-life construction projects.

6. Conclusions and recommendations

This section presents the conclusions, followed by research recommendations and recommendations for the practitioner community.

6.1 Conclusions

The main question to be answered was *how do different perceived complexities impact* *the performance of LCPs and what are the implication for the project management?* The results of this research showed that different perceived complexities can contribute negatively to project performance if they remain unmanaged but they contribute positively to project performance if they are managed. The management of perceived complexities is referred to as perception-based management and this research argues that this perception-based management should become one of the core focuses in managing project complexity within large construction projects.

Based on the findings of five case studies, this research acknowledged three basic aspects that contribute to the application of perception-based management: (1) create the appropriate preconditions; (2) create a shared mental model; (3) focus on project learning.

An expert meeting validated these results but also indicated that practice is often a balance between perception-based management, which exchanges perceived complexities, and the imposition of a perceived complexity. When to apply which form of management could be a topic for further research.

6.2 Research recommendations

Three directions for further research have been formulated:

1. *The relation between improved project performance and perception-based management*. This research led to the hypothesis that project performance is positively influenced by perception-based management but future research must quantify and determine this relation. A case study can be designed to see if project performance and perception-based management are positively correlated. This would first need a more detailed description of perception-based management. This description can then be used to identify the applied type of perception-based management within the researched cases (ignorance, eliminating, controlling or exploiting) and to which degree they do so. The influence of strategic behaviour of individuals should also be regarded in this more detailed description. By eventually linking the *type* and *degree of perception-based management* to *project performance* (which should be derived quantitative using an existing and proved method), it can be determined if the two concepts are indeed positively correlated.

2. *The origins of perceived complexities*. This research found at least four sources and also proved that different sources contribute in different degrees to a perceived complexity. Future research can determine this contribution and use the used lens model more sophisticated to statistically prove the sources for the selection and judgement of TOE-elements. This would require a more detailed design of the lens model which is supported with statistical methods. Practitioners that function as units of analysis should be selected based on their role: by comparing practitioners with identical roles in different projects the research can determine the influence of the role of a practitioner.
3. *Dealing with project complexity*. This research confirmed the existing theories that the management of project complexity must use a combination of the control-approach and the hands-off-approach. The cross-application of interventions between these two approaches and the question how practitioners can balance this approach, especially towards specific actor-groups, can be a topic for future research. This would require a case study in which projects that are already finished participate: it can then be reconstructed how project complexity was perceived, managed and what the objectives and actual effects of these interventions were. This research could at the same time research the relation between perceived complexities and applied interventions dealing with complexity: this research showed that there is a relation but it does not understand the specifics of this relation.

6.3 Management recommendations

Applying perception-based management seems beneficial. One of the interviewees noted that only because of his participation in this research, he was more open for perceived complexities of other project team members. In order to become aware of perceived complexities, it is recommended to ask the team members to complete the TOE-framework survey and discuss the findings in the team or to jointly perform a complexity assessment in a different format. It is about jointly undertaking such an assessment in order to come to a shared mental model thereby exploiting the fruitful differences in perceived complexities.

Creating a shared mental model within construction projects must become a central activity within project management which is repeated once in a few times in special arranged sessions. Being aware of and working with a shared mental model means that space is being created for everyone's perceived complexity and that perceived complexities of those who are not sitting at the table are impersonated by others. Discussions and conceptual fought need to be embraced rather than avoided; rushing into solid conclusions does not benefit project performance in the long run.

Once established, the shared mental model needs to be brought into action by all involved individuals. People must be encouraged to take responsibility and to act upon the agreed shared mental model: there must be a sense of ownership within every individual. Trust seems to be a key issue in this: both individuals and organisations must focus on the construction of trust within their relationships.

Appendix A: TOE-framework used in the survey (Bosch-Rekveldt, 2011)

Technical Complexity (17 elements)
High number of project goals □
Non–alignment of project goals □
Unclarity of project goals □
Uncertainties in scope □
Strict quality requirements □
Project duration □
Size in CAPEX □
Number of locations □
Newness of technology (world–wide) □
Lack of experience with technology □
High number of tasks □
High variety of tasks □
Dependencies between tasks □
Uncertainty in methods □
Involvement of different technical disciplines □
Conflicting norms and standards □
Technical risks □

Organizational Complexity (17 elements)
High project schedule drive □
Lack of Resource & Skills availability □
Lack of Experience with parties involved □
Lack of HSSE awareness □
Interfaces between different disciplines □
Number of financial sources □
Number of contracts □
Type of contract □
Number of different nationalities □
Number of different languages □
Presence of JV partner □
Involvement of different time zones □
Size of project team □
Incompatibility between different pm methods / tools □
Lack of trust in project team □
Lack of trust in contractor □
Organizational risks □

External risks □
Number of external stakeholders □
Variety of external stakeholders' perspectives □
Dependencies on external stakeholders □
Political influence □
Lack of company internal support □
Required local content □
Interference with existing site □
Remoteness of location □
Lack of experience in the country □
Company internal strategic pressure □
Instability of project environment □
Level of competition □
External Complexity (13 elements)

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Grasping project complexity in large engineering projects: The TOE (Technical, Organizational and Environmental) framework

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Abstract

This paper presents a framework for characterising project complexity in large engineering projects, which can be used to adapt the front–end development phase of engineering projects to the particular complexity. Recently, a large number of project complexity related papers were published, demonstrating the evident importance of "complexity" in current project management research. However, no generally accepted framework is available to support the characterising and understanding of project complexity that appreciates the richness of project complexity in large engineering projects. Therefore the TOE (Technical, Organizational, and Environmental) framework was developed, based on a literature survey building upon existing work and on new empirical work consisting of eighteen interviews about six projects in the process engineering industry. As a result of an inductive approach, this framework presents the elements that contribute to project complexity from a theoretical as well as a practical perspective. The framework can be used to assess the complexity of engineering projects, and subsequently adapt the front–end development phase of projects in order to better manage the complexity of the project.

Keywords: Project management; Project complexity; Large engineering projects

1. Introduction

Project failure in terms of cost overrun and time delays is a common practice and is being investigated for years now (Flyvbjerg et al., 2003; Hall, 1981; Morris and Hough, 1987; Thamhain and Wilemon, 1986). One of the reasons for project failure would be the increasing complexity of projects (Williams, 2002, 2005), or an underestimation of the project complexity (Neleman, 2006).

As a key example, the process and energy industry is suffering from increasing project complexity (IEA, 2006). With the increasing energy demand, this industry is under high pressure to improve its (project) performance (Mc Kenna et al., 2006). According to the International Energy Agency the fields with "easy accessible oil" are already exploited and new fields are to be exploited under more difficult circumstances, for example in deep water or remote areas, increasing the uncertainties in the projects. Increased uncertainties would contribute to the project complexity and hence increase the chance on budget and schedule overruns (IEA, 2006; Williams, 1999).

In the nineties, project complexity was already taken as one of the factors to classify engineering projects (Shenhar, 1998; Shenhar and Dvir, 1996). Their classification method was based on four levels of technological uncertainty and three levels of system scope. This method can be characterised by its strong focus on technological complexity, primarily related to the content of the project under consideration. Complexity however still was treated as a sort of black box; what factors exactly would cause complexity in projects was not further detailed. The need for new paradigms for complex projects was expressed as well as

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the need to include soft systems methods for project modelling to support its management (Williams, 1999).

More recently, research has been undertaken to better understand project complexity (Bosch-Rekveldt and Mooi, 2008; Dombkins and Dombkins, 2008; Geraldi and Adlbrecht, 2007; Hass, 2007; Maylor et al., 2008; Vidal and Marle, 2008; Williams, 2002 see also Section 2), and to sketch the relationship between complexity theory and project management (Cooke-Davies et al., 2007). In addition, there are suggestions to look at project managers' competence development in the view of project complexity (Remington and Pollack, 2007; Thomas and Mengel, 2008), e.g. specific complexities in a project might require specific competence development (Bosch-Rekveldt et al., 2009). The College of Complex Project Managers (Australia) even developed a "Competency Standard for Complex Project Managers" (DMO, 2006).

The large number of recent, project complexity related papers demonstrates the evident importance of "complexity" in current project management research. The mentioned studies do provide valuable theoretical insights and, in some cases, do link theory and practice. The management of large engineering projects would require a framework for project complexity. This framework could then be used to – further – adapt the front–end development phase of these projects to the particular project complexity with the aim to better manage the project. In view of the authors, however, currently no solid framework, based on both theory and practice, is available that supports the characterising and understanding of project complexity and fully appreciates the richness of project complexity of, specifically, large engineering projects.

1.1. Research question

In order to develop a framework as mentioned before based on theory and practice, the main research question to be answered in this paper is:

> What elements of the project do contribute to project complexity and how should these be included in a framework to characterise project complexity in large engineering projects?

1.2. Research approach

An inductive research strategy was chosen to answer the research question (Blaikie, 2009). This paper aims to synthesize the existing theoretical and empirical work in this area with new empirical work. It does not aim to test certain theories, which would require a deductive approach. Rather, it aims to establish a detailed description of project complexity, hence using an inductive approach.

First, a literature survey was performed in which elements were gathered that are assumed to contribute to project complexity. Next, case studies were performed in which elements, contributing to project complexity, were identified from eighteen interviews about six different projects in the process engineering industry. On purpose, the interviewees were not aware of the literature study results while being interviewed, hence strengthening the empirical evidence (Yin, 2002). The results from the literature search and the case studies were then used to develop, building on existing work, a detailed framework to grasp project complexity in large engineering projects. A detailed framework was aimed for because of its foreseen future application for tailored project management. Different types of projects require a different management approach (Shenhar, 2001), and, using the complexity framework, the management of the project could be made contingent upon the specific complexities in the project.

This paper shows the development of a detailed framework to grasp project complexity in large engineering projects, taking into account the starting points of this paper as discussed hereafter.

1.3. Starting points of this paper

Amongst different researchers, there is some debate about the exact definition of a complex project and the differences between "complicated" and "complex" projects (Maylor et al., 2008; Whitty and Maylor, 2009). In their view, a project would only be complex when uncertainties play a role, if not, the project at most would be complicated. Rather than further elaborating this debate, this paper considers complicated projects to be (potentially) complex — to a certain level. A framework to grasp project complexity could be beneficial for "complicated" projects as well as "complex" projects.

Aiming to understand project complexity does not necessarily assume controllability of project complexity. The authors believe that understanding project complexity should be decoupled from the "natural" engineering desire of a "predict and control" approach. Rather, an understanding of project complexity is suggested to support the management of projects, where management is not exclusively following the "predict and control" strand, but also includes a more process oriented "prepare and commit" strand (de Bruijn et al., 2003). Further, understanding project complexity in order to better manage projects is not automatically focused on reducing project complexity.

In this paper, a distinction is made between "project complexity" and "project management (or managerial) complexity": project management complexity is seen as a subset of "project complexity", e.g. the part of project complexity related to managerial complexity. We chose such a broad approach with the aim to grasp all aspects of project complexity and not limit ourselves to managerial complexity.

Despite the intrinsic dynamic character of project complexity during the different phases of a project, this paper primarily focuses on elements contributing to project complexity that can be assessed before project execution is started. This was done because the intended use of such a framework is in early project phases; see also Section 6 of this paper.

1.4. Structure of the paper

The literature survey is presented in Section 2, followed by the case study results in Section 3. The resulting framework to

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grasp project complexity in large engineering projects is presented in Section 4 and further discussed in Section 5. Section 6 discusses the foreseen use and developments of the framework, as well as limitations of the research. Conclusions and recommendations for further research are given in Section 7.

2. Project complexity elements from literature

The starting point of this paper was a literature review. A literature review was performed, followed by the identification of elements that are suggested to contribute to project complexity according to the current project management literature.

2.1. Literature review

The literature review focuses on different definitions of project complexity and sketches the main developments in project complexity thinking.

2.1.1. Project complexity definitions

To identify elements that contribute to project complexity, first definitions of complexity were investigated. In line with the work of Geraldi (2008), the lack of a clear, unambiguous definition of complexity of projects, or projects in a complex environment, was observed in literature. Although the complexity of projects and their environment obviously influences important decisions on and in project management, complexity as such is often taken intuitively or from previous experiences. Or, as stated by Parwani (2002, p. 1): “Complexity refers to the study of complex systems, of which there is no uniformly accepted definition because, well, they are complex”. Despite the inherent difficulty of defining complexity and the different views on complexity (Flood, 1990), a high level definition of project complexity should include structural, dynamic and interaction elements (Whitty and Maylor, 2009). Describing projects as complex adaptive systems or socially constructed entities (Cicmil et al., 2006), complexity in projects could then be considered to be related to such structural elements, dynamic elements and interaction of these; broader than the technical or technological domain.

2.1.2. Structural complexity and uncertainty

The goals and methods concept (Turner and Cochrane, 1993) classified projects according to whether the goals of the project are well defined or uncertain and whether the methods to achieve these goals are well defined or uncertain. Baccarini (1996) then published a review on the concept of project complexity in construction industry, in which he proposed an objective measure of project complexity being related to many varied interrelated parts, to be operationalized in terms of differentiation and interdependency. He further elaborated both organizational and technological complexities. Williams (1999) further operationalized the concepts of Baccarini and Turner. To investigate aspects of project structural complexity, Williams described measures for product complexity which influence project complexity. He suggested that concurrent engineering was causing more reciprocal interdependency, adding to a project’s complexity. Further dimensions of structural complexity included multi-objectivity and multiplicity of stakeholders. In addition to the work of Baccarini and Turner, Williams assumed that uncertainty added to the complexity of a project and therefore could be considered as a dimension of project complexity. Xia and Lee (2004) then measured the complexity of information systems’ (IS) development projects along two dimensions: organizational/technical and structural/dynamic. They concluded amongst others that complexity in IS development projects has a multidimensional nature; hence supporting the idea of developing a broad framework to grasp project complexity.

2.1.3. Softer aspects and environment

Whereas the authors mentioned above focused on “structural complexity” and “uncertainty”, also softer aspects and influences from the environment are assumed to influence project complexity (de Bruijn et al., 1996; Geraldi and Adlbrecht, 2007; Jaafari, 2003). Geraldi further developed the Williams concept earlier described and distinguished the complexity of fact and the complexity of faith (Geraldi and Adlbrecht, 2007) as well as the complexity of interaction. The complexity of interaction, taking place at the interfaces between people and organizations, includes aspects like politics, ambiguity and empathy (Geraldi, 2009), which are considered as the softer aspects that contribute to the overall project complexity.

Explicit attention for softer aspects was also found in work of de Bruijn et al. (1996). They assumed that project complexity would break down into technical, social and organizational complexities. Here technical complexity was assumed to be related to amongst others technological uncertainty, dynamics and the uniqueness of the project. Organizational complexity was assumed to be related to amongst others the organization structure, the project team, and the actors involved, and social complexity referred to (again) actors involved, their interests and the risks and consequences of the project in relation to its environment. Also other studies indicated the environment as an important contributor to project complexity (Jaafari, 2003; Mason, 2007; Xia and Lee, 2005).

2.1.4. Risk

As shown above, project complexity is often considered as being caused by uncertainties. Perminova introduced a new perspective on uncertainties in projects and how to manage uncertainties in projects (Perminova et al., 2008). She explained the link between uncertainties and risk management. Whereas traditional risk management scholars assume risk as uncertainty, Permoniva rather understands risk as one of the implications of uncertainty. She defined uncertainty as “a context for risks as events having a negative impact on the project’s outcomes, or opportunities as events that have beneficial impact on project performance (p. 76)”. Risk as an important contributor to project complexity (Turner and Cochrane, 1993; Williams, 2002), seems more focused on the first part of Perminova’s uncertainty definition. Risk management in this sense is seen as the core of modern project management and considered

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essential to successfully manage projects (Hillson and Simon, 2007). With increasingly complex projects, risk management becomes more important and risk management should be done throughout the whole life cycle of a project (Jaafari, 2001). Complexity modelling as an aid for project and risk management is discussed by Vidal and Marle (2008), who consider complexity as a source of risks, either directly or indirectly induced by the complexity in the project. However, we argue that the number of risks and/or their probability and impact can also be assumed to contribute to project complexity. For example, in a project with a high number of risks, more dynamics and more interactions might be expected, contributing to project complexity. Carefully identifying the project risks should not be considered as a goal as such, but as a means to manage the project and its uncertainties.

2.2. Gathering elements from literature

Several literature sources, including the ones mentioned in Section 2.1, were used to identify the elements that contribute to project complexity from a literature perspective. Literature databases were first searched for relevant articles with the keyword ‘project complexity’ (date of appearance was 1996 or later). Those articles were studied including the referenced articles. The process was stopped once no new relevant referenced articles were found. Elements contributing to project complexity were listed and compared to identify the key elements. In total 40 elements contributing to project complexity resulted from the literature search (see Table 1). The selected articles in Table 1 cover the most relevant literature about project complexity, in view of the authors of this paper.

Table 1
Elements contributing to project complexity from literature sources (40 elements in total).

Elements from literature	Authors	Elements defined, alphabetically ordered
Degree of definition of goal, scope	Geraldi and Adlbrecht (2007); Crawford (2005); Vidal and Marle (2008)	Clarity of goals
Company internal politics (ambiguity, hidden information)	Geraldi and Adlbrecht (2007)	Company internal support
Variety of project management methods and tools applied	Vidal and Marle (2008)	Compatibility of project management methods and tools
Form of contract	Müller and Turner (2007); Geraldi and Adlbrecht (2007)	Contract types
Partner’s transparency, empathy (the personal and intangible matter that improves cooperation)	Geraldi and Adlbrecht (2007)	Cooperation JV partner
Interrelatedness/interdependence of elements	Geraldi and Adlbrecht (2007) Williams (1999); Vidal and Marle, (2008)	Dependencies between tasks
Dependency on other departments, companies	Geraldi and Adlbrecht (2007); Williams (1999)	Dependencies on other stakeholders
Commercial newness of the project (new partners, team, processes, etc.)	Geraldi and Adlbrecht (2007)	Experience with parties involved
Knowledge (i.e. education and/or training)	Baccarini (1996)	Experience with technology
Multi-objectives, with conflicting goals	Williams (1999); Baccarini (1996); Thompson (1967); Vidal and Marle (2008); Geraldi and Adlbrecht (2007)	Goal alignment
Impact of a change in one production process on other production processes	Tatikonda and Rosenthal (2000); Vidal and Marle (2008)	Interrelations between technical processes
Competition	Vidal and Marle (2008)	Level of competition
Technological newness of the project	Geraldi and Adlbrecht (2007); Tatikonda (1999); Shenhar and Dvir (2004); Dewar and Hage (1978); Vidal and Marle (2008)	Newness of technology (world-wide)
Number of different disciplines	Geraldi and Adlbrecht (2007); Baccarini (1996); Williams (1999); Vidal and Marle (2008)	Number of different disciplines
Number of different languages	Geraldi and Adlbrecht (2007)	Number of different languages
Number of different cultures	Geraldi and Adlbrecht (2007); Vidal and Marle (2008)	Number of different nationalities
Number of different norms and standards	Geraldi and Adlbrecht (2007); Vidal and Marle (2008)	Number of different norms and standards
Variety of financial resources	Vidal and Marle (2008)	Number of financial resources
Variety of goals	Geraldi and Adlbrecht (2007)	Number of goals
Differentiation by territory	Müller and Turner (2007); Miller (1973); Hall (1979); Vidal and Marle (2008)	Number of locations
Number of partners, contractors, suppliers	Geraldi and Adlbrecht (2007); Baccarini (1996), Williams (1999); Ashby (1957); Vidal and Marle (2008)	Number of stakeholders
Number of activities	Vidal and Marle (2008)	Number of tasks
Differentiation by time (i.e. involved at different times during a project)	Baccarini 1996; Dewar and Hage (1978)	Overlapping office hours
Influence of politics	Geraldi and Adlbrecht (2007)	Political influence
Scheduling	Thomas and Mengel (2008)	Project drive
Project duration	Xia and Lee (2005); Vidal and Marle (2008)	Project duration
Configuration of macro-organization (local stakeholders)	Geraldi and Adlbrecht (2007)	Required local content
Skills	Thomas and Mengel (2008); Baccarini (1996); Vidal and Marle (2008)	Resource and skills availability
Risk management	Williams (2002)	Risk management

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Table 1 (*continued*)

Elements from literature	Authors	Elements defined, alphabetically ordered
Number of deliverables, largeness of scope (number of components etc.), number of decisions to be made, quantity of information to analyze	Vidal and Marle (2008); Geraldi and Adlbrecht (2007)	Scope largeness
Size of the project (in budget)	Geraldi and Adlbrecht (2007); Müller and Turner (2007); Thomas and Mengel 2008; Williams (2002); Weaver (1948); Vidal and Marle (2008)	Size in capital expenditure
Size of the project (in number of people)	Geraldi and Adlbrecht (2007); Müller and Turner (2007); Thomas and Mengel (2008); Williams (2002), Weaver (1948); Vidal and Marle (2008)	Size in engineering hours
Number of project members	Xia and Lee (2005), Williams (1999); Vidal and Marle (2008)	Size of project team
Frequency and impact of changes in macro-organization (suppliers, contract, raw material pricing, exchange rates)	Geraldi and Adlbrecht (2007)	Stability project environment
Client transparency, empathy (the personal and intangible matter that improves cooperation)	Geraldi and Adlbrecht (2007)	Trust in contractor
Team transparency, empathy (the personal and intangible matter that improves cooperation)	Geraldi and Adlbrecht (2007); Vidal and Marle (2008)	Trust in project team
Frequency and impact of changes in technological aspects (quality, velocity etc.), dynamism (i.e. changing information, specifications, change order, etc.)	Geraldi and Adlbrecht (2007)	Uncertainties in scope
Degree of definition of methods	Geraldi and Adlbrecht (2007); Crawford (2005); Vidal and Marle (2008)	Uncertainty in methods
Variety of perspectives	Geraldi and Adlbrecht (2007); Vidal and Marle (2008)	Variety of stakeholders' perspectives
Variety of tasks	Williams (1999)	Variety of tasks

Some elements, although found in literature, were not included in this final literature table.

In case of coverage in another element, the original elements were not included (like *uncertainty in goals and methods* (Williams, 1999), covered in "unclarity of goals" and "uncertainty in methods" respectively, or *the degree of interdependence between and among the product and the process* (Tatikonda and Rosenthal, 2000), covered in "dependencies between tasks" and "interrelations between technical processes").

In case the elements were too generic, such as *uncertainty* (Williams, 1999) or *dependencies with the environment* (Vidal and Marle, 2008), the elements were not explicitly added to the final list but implicitly they are covered.

Elements focusing on how to manage project complexity instead of contributing to project complexity, like *project manager leadership style* (Müller and Turner, 2007) or *responsibilities of partners* (Geraldi and Adlbrecht, 2007), were not included in the final list.

The elements were further developed, refined and defined (right column in Table 1, ordered alphabetically), in order to enable a comparison with the elements found in the case studies (Section 3).

2.3. Proposed structure for the framework

Looking at the literature review as well as the elements gathered from the literature (see Table 1), it was concluded that not only the technical or technological aspects in a project determine the project's complexity. As shown above, also organizational and environmental aspects play an important role. De Bruijn et al. (1996) already distinguished three dimensions of complexity: technical complexity, social complexity and organizational complexity. Further developing their work, a framework consisting of technical, organizational and environmental elements contributing to project complexity is proposed to cover the different aspects of project complexity in large engineering projects. The traditional technical view is mainly focused on the content of the project (T), the organizational view (O) includes the softer aspects and the environmental view (E) includes the influence from environment. Hence, in developing a framework to grasp project complexity, all elements will be assigned to either the technical, organizational or environmental category (see Table 4).

3. Project complexity elements from case studies

Subsequently, case studies were performed to identify aspects in the projects that had contributed to the project complexity from the perspective of project management practice. Because of the exploratory character of this study, the interviewees involved in this part of the research, were not aware of the results of the literature survey, see also Section 3.2.

3.1. Case study setup

The chosen unit of analysis was a completed project in the process engineering industry, where 'project' was taken in a wide definition, e.g. covering all activities from initiation to close-out (project proposal/initiation, project design/development, project execution/implementation and project commissioning/close-out, excluding operation and maintenance). A multiple-case approach was followed (Yin, 2002) in which 6 recently completed projects (>2002) within one company in the process engineering industry were studied in depth. Per project, three different persons were interviewed using a semi-structured interview approach, resulting in eighteen interviews in total.

Based on Yin (2002) a replication logic was used for case selection. This information oriented strategy was chosen in order to “maximize the utility of information from small samples and single cases” (Flyvbjerg, 2006, p.230). The cases together, as summarized in Fig. 1, covered both successful *and* less successful projects in terms of meeting budget and schedule estimates and delivering according to technical specifications (*project performance*). A range of project types in existing or new markets was included, such as innovative projects, construction of facilities and new businesses (*market/business*). Technology involved in the projects ranged from old/proven technology to new/unproven technology (*technology*). The capital expenditure (*Capex*) of these projects ranged between US$ 20 and 600 million. Different geographical areas were covered (Europe, Asia and Middle-America) and the project location varied between industrialised and remote areas (*location*). The projects differed in project ownership; e.g. from 100% owned to JV partnerships with partial ownership. Fig. 1 shows the broad variety in project characteristics for the projects included in the case studies.

3.2. Results

Following a protocol, in total 18 semi-structured interviews were held with the project manager, a team member and an owner representative of the six projects. All interviews were taped and from every interview, a transcript was created by the interviewer. The transcripts from the interviews were approved by the interviewee before starting further analysis. In the interviews, the candidates were asked by means of open questions what elements had contributed to the project complexity of the particular project, from their point of view. To start the interview and help the further analysis, their interpretation or definition of project complexity was asked for. The interviewees were not aware of the results of the literature study. All transcripts were studied to identify the elements contributing to project complexity. A matrix was created with the elements contributing to project complexity in rows and the 18 interviews in columns. The results of the interviews were added ‘blindly’ e.g. when filling the current interview results, the columns with the other interview results were made hidden. The number of ‘new’ elements, raised by the interviewees, reduced considerably after the first 6 interviews (which covered the 6 different projects) and no new elements were raised after the 14th interview; which indicates data saturation, see Fig. 2. Note that 5 of the 6 first interviews were with the project managers of the projects under investigation and the number of elements contributing to project complexity they were raising seems higher than the other interviewees did. This might be related to their specific role in the project: the project manager can be expected to have the widest view on elements contributing to project complexity. Next to the interviews, project documentation (already studied prior to the interviews) was used to verify and complement the interview results.

Based on these case results, the elements contributing to project complexity from a perspective of practice were gathered confirming or complementing the literature elements. Table 2 shows the 49 elements contributing to project complexity based on the case study results, ordered in number of occurrences from the interviews (maximum number is 18) and cases (maximum number is 6). Almost all elements found in the literature survey were independently confirmed by the interviewees, without explicitly asking for it.

Several aspects contributing to project complexity were brought forward in all six cases, showing wide support for particularly these aspects. In an attempt to summarize these aspects; they were clustered in terms of the “what”, the “who” and the “how” of the project which are as follows:

“what” of the project in terms of content (interrelations between technical processes, newness of technology, experience with technology),

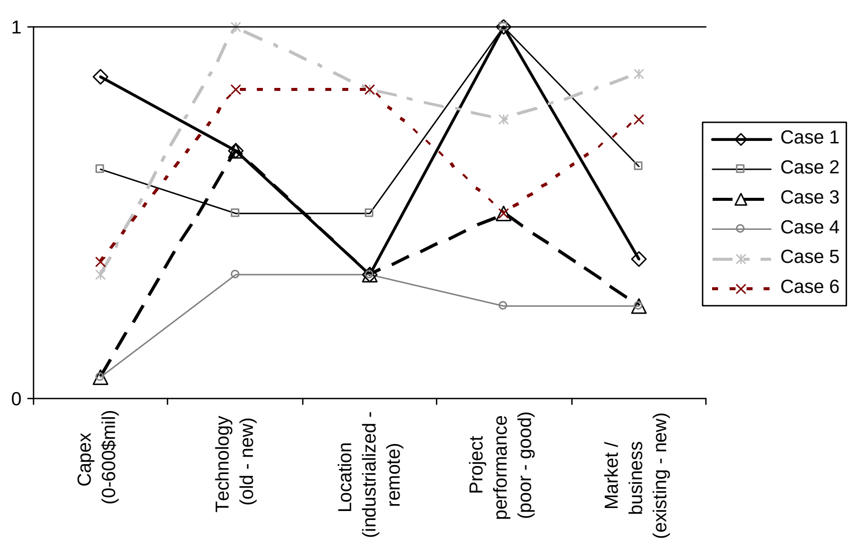

Fig. 1. Summary of selected cases, cases 1 to 6.

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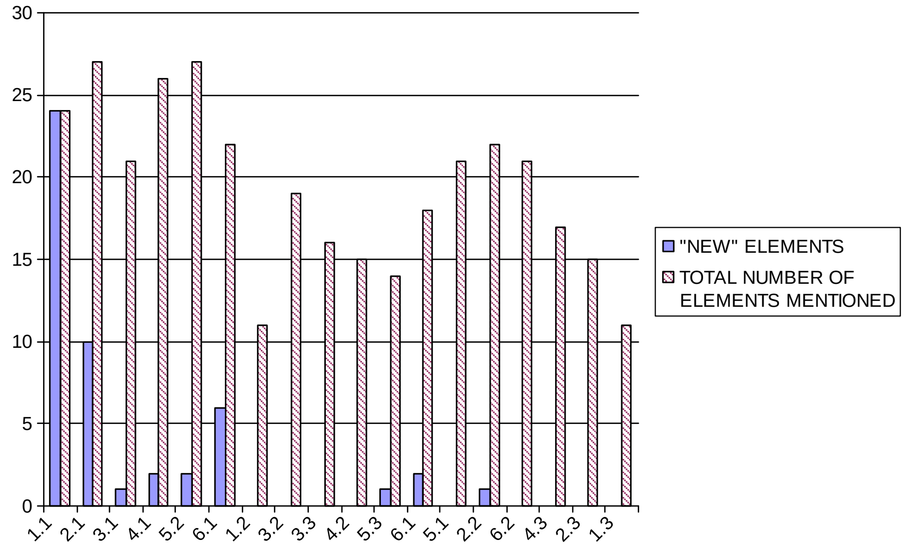

Fig. 2. "New" elements and total number of elements mentioned by the interviewees. Interviews are ordered according to interview date. #.1: interview with project manager. #.2: interview with team member. #.3: interview with owner representative. Note that case 6 involved 2 project managers and no owner representative.

"who" of the project in terms of parties involved and perspectives (number of stakeholders and variety of stakeholder's perspectives),

"how" of the project in terms of staffing and organizing the project (number of different project management methods and tools, resource and skills availability, trust in contractor, and contract type).

In translating these "what", "who" and "how" aspects to the complexity framework, the "what"-elements logically were assigned to the technical dimension of project complexity. The "who"-elements (both related to the stakeholders involved) were assigned to the environmental dimension of project complexity. The "how"-elements were assigned to the organizational dimension of project complexity. The elements describing the "what", the "who" and the "how" of a project, could be seen as the key elements determining the project's complexity. Note that risk was mentioned as contributing to complexity in different contexts and hence appears three times in Table 2.

Next to the elements listed in Table 2, the practitioners mentioned some elements that do not contribute to project complexity as such but rather make it more difficult to manage the project, e.g. factors like poor communication, poor motivation of the project team, poor relationship management and unclear distribution of responsibilities. These aspects are considered project management flaws that do not contribute to intrinsic complexity of the project since they are manageable; hence these are not included.

4. The TOE framework for project complexity in large engineering projects

To develop the framework for project complexity in large engineering projects, the elements list from literature and the elements list from the cases were combined and reordered. To obtain richness in the framework but to avoid adding "arbitrary" elements, the following criteria were defined to include an element in the framework:

Evidence both from literature and practice, in total at least three sources, or,

Evidence from at least two independent literature sources, or,

Evidence from at least three interviews, covering at least two cases.

Following the literature review conclusion (Section 2.3), the elements were clustered into a framework of technical complexity, organizational complexity and environmental complexity, called the TOE framework. On a lower level, the elements were further grouped into subcategories, see Table 3. Most of the subcategories consist of various elements related to the subcategory, together providing a broader view on that aspect of project complexity.

The resulting TOE framework is presented in Table 4 and consists of 15 T-elements, 21 O-elements and 14 E-elements. The table includes the origin of the elements; either from literature, from the cases or from both (indicated with L, E or B respectively). The majority of the elements in the T-, O- and E-categories have literature as well as empirical evidence (13 of 15, 18 of 21, 9 of 14 for the T-, O- and E-categories respectively), indicating support for these elements from both theoretical and practical perspectives. In the E-category, there are 5 elements with empirical evidence only, four of which are related to the location of the project and the fifth which is related to strategic pressure around the project. The apparent absence of these aspects in literature might be explained by the specific industry under consideration and/or the deliberate choice to approach this study from a project management perspective. This explanation might also yield for the elements with sole empirical evidence in the O-category, e.g. 'size of site area' and 'HSSE awareness', with the latter being very much related to

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Table 2
Elements contributing to project complexity based on 6 cases, 18 interviews (49 elements in total).

Elements defined	Mentioned in how many interviews?	Mentioned in how many cases?
Experience with technology	17	6
Variety of stakeholders' perspectives	16	6
Number of different project management methods and tools	15	6
Resource and skills availability	15	6
Number of stakeholders	14	6
Contract types	13	6
Uncertainties in scope	13	5
Experience with parties involved	13	5
Interrelations between technical processes	12	6
Newness of technology (world-wide)	12	6
Trust in contractor	11	6
HSSE issues	11	5
Cooperation JV partner	11	5
Trust in project team	10	5
Political influence	10	5
Company internal support	9	4
Number of different norms and standards	8	5
Number of different nationalities	8	5
Dependencies on other stakeholders	8	5
Level of competition	6	5
Environmental risks	6	4
Technical risks	6	4
Variety of tasks	6	4
Uncertainty in technical methods	6	3
Number of different languages	6	3
Interference with existing site	6	3
Number of tasks	6	3
Goal alignment	5	4
Number of locations	5	4
Scope largeness	5	3
Size of site area	5	3
Internal strategic pressure	5	3
Dependencies between tasks	4	4
Size of project team	4	4
Quality requirements	4	3
Number of financial resources	4	3
Project drive	4	2
Weather conditions	3	3
Remoteness of location	3	3
Organizational risks	3	2
Size in CAPEX	3	2
Number of different disciplines	3	2
Overlapping office hours	3	2
Experience in the country	3	2
Size in engineering hours	2	2
Union power	2	2
Required local content	2	1
Clarity of goals	1	1
Stability project environment	1	1

the process industry. The element 'quality requirements' (in the T-category) might not be found in literature because of the very limited attention for managing quality in the project management literature (Turner, 2010). Two elements have literature

Table 3
Subcategories of TOE.

Technical	Organizational	Environment
Goals	Size	Stakeholders
Scope	Resources	Location
Tasks	Project team	Market conditions
Experience	Trust	Risk
Risk	Risk	

evidence only ("number of goals" and "project duration"). Despite their assumed applicability to the sector, these elements were not mentioned by the interviewees; they might work on single goal projects and see "project duration" as a boundary condition rather than a factor contributing to project complexity.

In developing the TOE framework, it was decided to maintain the richness of elements contributing to project complexity as found in literature and practice and not to reduce to a 2×2 matrix, as suggested amongst others in a recent research of Whitty and Maylor (2009) on the Structural Dynamic Interaction matrix. The broad TOE framework with its three levels (categories, subcategories and elements) offers the opportunity to discuss on various levels of aggregation with the different parties and stakeholders involved in a project which aspects make the specific project complex, in their individual views. The current setup also allows extension of the framework for use in different industries.

The framework thus developed can be used to assess the complexity of an engineering project. Assessing a project's complexity is a subjective process by nature, in which perceived complexity based on previous experiences plays an important role. Because of the differences in skills and experiences, people using the framework and assessing a certain project or phase thereof may come to different conclusions regarding its complexity. The objective of the framework at this stage, however, is primarily to achieve a better understanding of project complexity and get a footprint of the project's complexity. Regardless of absolute scores for the different elements, this framework enables identification of the complexity areas in a specific project. Knowing these complexity areas, attention could be paid to the management of these. And, as stated by Geraldi (2009, p.665): the "assessment of complexity itself is a tool to enable such active management".

5. Discussion

Traditionally, size is seen as the dominant (but criticized!) measure of project complexity (Williams, 2002). In our study, few interviewees mentioned the traditional size (in terms of engineering hours or capital expenditure) as contributing to project complexity, despite the fact that four of the projects under investigation had a capital expenditure over US$ 200 million. Much more often, size *related* aspects like "number of different project management methods and tools" and "number of stakeholders" were mentioned, hence suggesting the need for refinement of the general aspect 'size' as contributing to project complexity. This supports the overall

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Table 4
TOE framework (50 elements in total).

TOE	Sub-ordering	ID	Source L/E/B[1]	Elements defined	Explanation
T	Goals	TG1	L	Number of goals	What is the number of strategic project goals?
T	Goals	TG2	B	Goal alignment	Are the project goals aligned?
T	Goals	TG3	B	Clarity of goals	Are the project goals clear amongst the project team?
T	Scope	TS1	B	Scope largeness	What is the largeness of the scope, e.g. the number of official deliverables involved in the project?
T	Scope	TS2	B	Uncertainties in scope	Are there uncertainties in the scope?
T	Scope	TS3	E	Quality requirements	Are there strict quality requirements regarding the project deliverables?
T	Tasks	TT1	B	Number of tasks	What is the number of tasks involved?
T	Tasks	TT2	B	Variety of tasks	Does the project have a variety of tasks (e.g. different types of tasks)?
T	Tasks	TT3	B	Dependencies between tasks	What is the number and nature of dependencies between the tasks?
T	Tasks	TT4	B	Uncertainty in methods	Are there uncertainties in the technical methods to be applied?
T	Tasks	TT5	B	Interrelations between technical Processes	To what extent do technical processes in this project have interrelations with existing processes?
T	Tasks	TT6	B	Conflicting norms and standards	Are there conflicting design standards and country specific norms involved in the project?
T	Experience	TE1	B	Newness of technology (world-wide)	Did the project make use of new technology, e.g. non-proven technology (technology which is new in the world, not only new to the company!)?
T	Experience	TE2	B	Experience with technology	Do the involved parties have experience with the technology involved?
T	Risk	TR1	B	Technical risks	Do you consider the project being high risk (number, probability and/or impact of) in terms of technical risks?
O	Size	OS1	L	Project duration	What is the planned duration of the project?
O	Size	OS2	B	Compatibility of different project management methods and tools	Do you expect compatibility issues regarding project management methodology or project management tools?
O	Size	OS3	B	Size in CAPEX	What is the estimated CAPEX of the project?
O	Size	OS4	B	Size in Engineering hours	What is the (expected) amount of engineering hours in the project?
O	Size	OS5	B	Size of project team	How many persons are within the project team?
O	Size	OS6	E	Size of site area	What is the size of the site area in square meters?
O	Size	OS7	B	Number of locations	How many site locations are involved in the project, including contractor sites?
O	Resources	ORE1		B	Project drive Is there strong project drive (cost, quality, schedule)?
O	Resources	ORE2	B	Resource and skills availability	Are the resources (materials, personnel) and skills required in the project, available?
O	Resources	ORE3	B	Experience with parties involved	Do you have experience with the parties involved in the project (JV partner, contractor, supplier, etc.)?
O	Resources	ORE4	E	HSSE awareness	Are involved parties aware of health, safety, security and environment (HSSE) importance?
O	Resources	ORE5	B	Interfaces between different disciplines	Are there interfaces between different disciplines involved in the project (mechanical, electrical, chemical, civil, finance, legal, communication, accounting, etc.) that could lead to interface problems?
O	Resources	ORE6	B	Number of financial resources	How many financial resources does the project have (e.g. own investment, bank investment, JV-parties, subsidies, etc.)?
O	Resources	ORE7	B	Contract types	Are there different main contract types involved?
O	Project team	OP1	B	Number of different nationalities	What is the number of different nationalities involved in the project team?
O	Project team	OP2	B	Number of different languages	How many different languages were used in the project for work or work related communication?
O	Project team	OP3	B	Cooperation JV partner	Do you cooperate with a JV partner in the project?
O	Project team	OP4	B	Overlapping office hours	How many overlapping office hours does the project have because of different time zones involved?
O	Trust	OT1	B	Trust in project team	Do you trust the project team members (incl JV partner if applicable)
O	Trust	OT2	B	Trust in contractor	Do you trust the contractor(s)?
O	Risk	OR1	B	Organizational risks	Do you consider the project being high risk (number, probability a nd/or impact of) in terms of organizational risks?
E	Stakeholders	ES1	B	Number of stakeholders	What is the number of stakeholders (all parties (internal and external) around the table, pm = 1, project team = 1, NGOs, suppliers, contractors, governments)?
E	Stakeholders	ES2	B	Variety of stakeholders' perspectives	Do different stakeholders have different perspectives?
E	Stakeholders	ES3	B	Dependencies on other stakeholders	What is the number and nature of dependencies on other stakeholders?
E	Stakeholders	ES4	B	Political influence	Does the political situation influence the project?
E	Stakeholders	ES5	B	Company internal support	Is there internal support (management support) for the project?
E	Stakeholders	ES6	B	Required local content	What is the required local content?
E	Location	EL1	E	Interference with existing site	Do you expect interference with the current site or the current use of the (foreseen) project location?
E	Location	EL2	E	Weather conditions	Do you expect unstable and/or extreme weather conditions; could they potentially influence the project progress?
E	Location	EL3	E	Remoteness of location	How remote is the location?

(continued on next page)

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Table 4 (*continued*)

TOE	Sub-ordering	ID	Source L/E/B[1]	Elements defined	Explanation
E	Location	EL4	E	Experience in the country	Do the involved parties have experience in that country?
E	Market conditions	EM1	E	Internal strategic pressure	Is there internal strategic pressure from the business?
E	Market conditions	EM2	B	Stability project environment	Is the project environment stable (e.g. exchange rates, raw material pricing)?
E	Market conditions	EM3	B	Level of competition	What is the level of competition (e.g. related to market conditions)?
E	Risk	ER1	B	Risks from environment	Do you consider the project being high risk (number, probability and/or impact of) in terms of risk from the environment?

[1]L = based on literature data, E = based on empirical data, B = based on both literature and empirical data.

idea of this paper that is to develop a detailed framework to grasp project complexity in large engineering projects.

The TOE framework contains many elements related to structural complexity and uncertainty (Section 2.1.2). Both technical complexity and organizational complexity are explicitly included as main categories of project complexity. The majority of the elements in the technical category of the framework have a structural character, like the number of goals, largeness of scope, number of tasks, dependencies between tasks, etc. Also uncertainties in goals and methods are covered in the elements from the technical category. Some structural elements are recognised in the organizational category such as the number of project management methods and tools, the number of different disciplines. Further, the stakeholders' multiplicity and multi-objectivity are covered in elements like goal alignment (technical category), the number of stakeholders and the variety of stakeholders' perspectives (environmental category).

In the TOE framework, softer aspects and environment (Section 2.1.3) are explicitly included. Softer aspects can be recognised in both the organizational category and the environmental category in the elements of the TOE framework such as trust, availability of resources and skills, experience with parties involved, interfaces between disciplines involved, etc. The environmental category further covers elements such as political influence, level of competition, strategic pressure, required local content, interference with existing site, weather conditions, etc.

In the TOE framework, risk (Section 2.1.4) is considered as a contributor to project complexity. To address the importance of risk as contributor to project complexity, the TOE framework includes a separate risk element in all three categories being high risk in either technical, organizational and/or environmental view. Also aspects of risk are covered in other various elements of all three categories, especially topics concerning uncertainty and also others like weather conditions, political influence, etc.

Overall, it is concluded that the presented TOE framework fits the current important literature concepts as described in Section 2.1. Moreover, the framework presents an "integrative" list of elements that contribute to project complexity in large engineering projects. It integrates the different theoretical concepts as well as the perspectives from practice.

Recently, Maylor et al. (2008) published the MODeST dimensions of perceived managerial complexity. Their extensive framework provides a 'grounded structural model of managerial complexity' based on a multistage empirical study in the telecommunications sector, the defence sector and a regional transport infrastructure provider. They distinguish the dimensions of "Mission", "Organization", "Delivery", "Stakeholders" and "Team" under which several concepts per dimension are defined, in total resulting in more than 100 underlying concepts. Although the levels of detail between the TOE framework (50 elements) and the MODeST model (>100 concepts) differ, the elements or concepts partly overlap. The developments of the TOE framework and the "MODeST model" were done independently from each other in about the same time frame but in different industry sectors and following a different approach. Compared to the grounded MODEeST model, the advantage of the TOE framework is its dual base: both literature and new empirical work form the foundation of the TOE framework.

6. Use and development of the TOE framework

The TOE framework can be used as a basis to assess the complexity of an engineering project. Applying the TOE framework for a project gives a footprint of that project in terms of where the complexity is expected in the project. Application of the TOE framework could for example support the risk assessment in early project phases. Since project complexity changes during the project life cycle, the use of the framework in various stages of the project should be considered in order to also grasp the dynamics of project complexity. Careful selection of the persons involved in the complexity assessment is needed because of the inherent subjective nature of the assessment. The use of complexity assessment might "uncover significant challenges of the project" (Geraldi, 2009, p. 665). The TOE framework could support such a complexity assessment.

The ultimate goal of the use of the framework is to better adapt the front–end development steps of projects to the specific complexities using the complexity footprint. A project in its early stage could be assessed on its expected complexity and specific actions could be taken. For example, a project in which predominantly technical complexities are expected might require a different project manager than a project in which

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predominantly environmental complexities are expected. Knowing, understanding and characterising these complexities by applying the TOE framework early in the project and in subsequent project phases are assumed to improve the project management.

Based on the footprint, it might be decided to put extra or less effort in process management, stakeholder management, risk management, etc., following the approaches as suggested for example by Jaafari (2001) on risk management or Aaltonen et al. (2008) on stakeholder management. In line with current literature ideas, the project manager could be selected and/or further developed based on the competences required to manage the particular complexity (Bosch-Rekveldt et al., 2009; Remington and Pollack, 2007; Thomas and Mengel, 2008).

Further developments of the TOE framework are foreseen to overcome current research limitations. The first limitation is the qualitative character of the presented study. In developing the TOE framework, our empirical results suggested data saturation for the studied cases. To strengthen current results, an industry wide survey study is performed with a more quantitative character. Another limitation is the specific focus of the current study on engineering projects in the process industry. More research is needed to investigate the applicability of the TOE framework (if at all) in different industries and on less technical projects. To enable application in different industries, additional elements can be added to the TOE framework. This can not only be seen as strength of the current framework, but also brings another research limitation. We can and will not claim completeness of the TOE framework.

7. Conclusion and recommendations

To help manage project complexity, this paper presented a framework for characterising project complexity in large engineering projects. The TOE framework is based on both literature and empirical data. Applying the framework for a specific project results in a footprint of its complexity, providing potential handles to better manage the project. The framework is intended to be used for assessment of complexity of projects in the process engineering industry. Because of the dynamics of project complexity, repeated use in different project phases is foreseen.

Using an inductive approach by combining literature insights strengthened with the elements resulting from the eighteen interviews about the six cases, the TOE framework enables a broad view on project complexity. In total 50 elements contributing to project complexity were identified in the following three areas: technical complexity, organizational complexity and environmental complexity. Deliberately, the number of elements in the framework was not reduced to be able to describe the richness of project complexity. To facilitate its use, three levels were defined within the TOE framework; three categories (TOE), fourteen subcategories (T: goals, scope, tasks, experience, and risk; O: size, resources, project team, trust, and risk; E: stakeholders, location, market conditions and risk) and fifty elements. This offers the opportunity to discuss on various levels with the different parties and stakeholders involved in a project which aspects make the specific project complex. The current setup is flexible and allows extension of the framework, for example if necessary for use in a different industry.

The resulting TOE framework was reflected against current literature concepts and was shown to integrate the current dominant concepts. Moreover, the concepts were developed into clear elements in the TOE framework bringing together theoretical perspectives and perspectives from practice. To overcome current research limitations, completeness of the framework and repeatability and reproducibility of using the framework will be investigated by means of a quantitative approach. For this, an internet survey is performed to investigate project complexity in a country specific, industry wide, competence network, including owner as well as contractor perspectives. Once the complexity of a project is better understood, it will be investigated as how to better fit the front–end phase of projects to the particular types of project complexity in order to improve the project performance. Part of this fitting could be mapping the project manager's competences to the particular project complexity using the TOE framework.

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Playing with Complexity

MANAGEMENT AND ORGANISATION OF LARGE INFRASTRUCTURE PROJECTS

Marcel Hertogh Eddy Westerveld

5.7 MANAGEMENT APPROACHES

Given the needs for management strategies are now clearer, the next question we address is: 'How can managers responsible for the implementation of LIPs manage the complexity inherent in these projects?' In our answer on this question, we introduce a framework of management approaches that can be used to deal with complexity. This framework, based on the need for both control and interaction, distinguishes 4 types of management approaches in LIPs (with reference to the chapter where the strategies are detailed):

1	Internal & Content focused approach (Chapter 6)	
2	Systems management (Chapter 7)	strategies focussing on control
3	Interactive management (Chapter 8)	strategies focussing on interaction
4	Dynamic management (Chapter 9,10)	balancing control and interaction

These four approaches are described in detail from both a theoretical and empirical viewpoint in chapters 6 to 10. In each of these chapters we describe the strategies used and their effectiveness – we also provide conclusions on the application of these strategies in practice. In this section we introduce a general framework and demonstrate how the four approaches are linked to detail and dynamic complexity.

Based on the distinction of systems management and interactive management we now have the building blocks to fit management strategies to detail and dynamic complexity. The four approaches are graphically presented in figure 5.9.

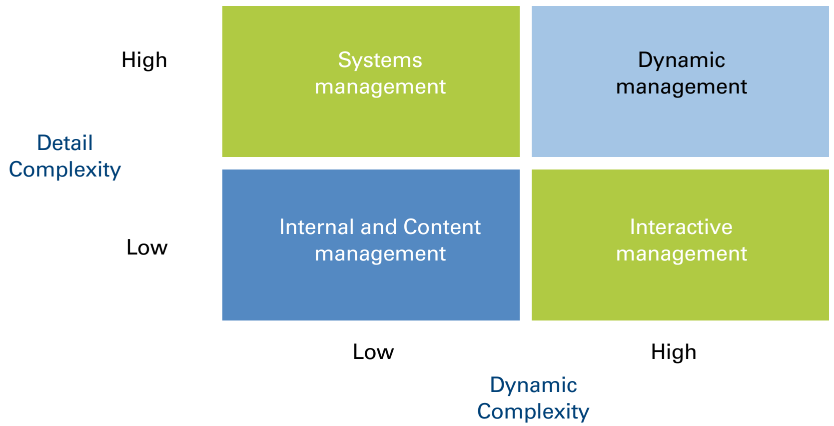


Figure 5.9: Four approaches on the management of complexity

The distinction into four separate management approaches results from a merger between theory and practice, based on our case findings.

1 Internal and content focused approach

In our case analysis it quickly became clear that there was a frequently used approach which was not a part of our theoretical framework. We labelled this 'the internal and content focused approach' because it involves a lack of clear management strategies but relies on a pure focus in finding a technical solution to a perceived problem without paying too much attention to strategies of control and interaction. The approach is highly internal: the satisfaction of involved stakeholders is not regarded a major concern. Our findings on the internal and content focused approach are described in chapter 6.

As we saw, the Betuweroute in the first years of the 1990s was 'a showcase' of this internal and content focused approach. In The Netherlands in the mid 1990's projects, especially the Betuweroute, but also in its slipstream some others, stimulated a conviction that a new approach was needed that would pay more attention to the needs of local inhabitants, (local) governments, private companies and interest groups (NGO's). This led to the development of the theory of 'interactive management'.

2 Systems management

The second approach observed, is that of systems management. Here strategies are focused on control. In many of our observed cases strategies of break down and control were successfully used. These strategies were found especially successful in the management of detail complexity: many components with a high degree of interrelatedness. Strategies of control originate from the field of systems management – which in turn can be linked to the field of organisational design – and are outlined in chapter 7.

Systems management can be classified as an approach based on a 'deterministic' perspective as described earlier in this chapter. Project control is basically tight monitoring and steering of costs, time and scope. This is intended to make sure the project will be delivered according to the set specifications and within the set boundaries of costs and time. Tools and techniques have been developed to structure the collection of information to as to minimise the chances of unpleasant surprises.

These control strategies have proved to be less suitable in dealing with dynamic complexity, especially of dynamic development of the stakeholder system in LIPs, but this is where our third approach, 'interactive management' comes into play.

3 Interactive management

Interactive management as an approach, was originally developed as an alternative or supplement to systems management. Traditional systems management strategies turned out to be insufficient to deal with the dynamics of (mainly local) stakeholders, often found in LIPs. Interactive management in essence focuses on interests of all stakeholders so as to improve their support of the project. But interactive management goes further than creating support for a decision that already has been made: it also covers joint initiative, co-production and co-financing.

The strategies of interactive management have an external focus – looking at stakeholder satisfaction – and also focus on the flexibility required to deal with the many changes within LIPs. This makes these strategies better able to deal with dynamic complexity. Interactive management addresses the social complexity which characterises the stakeholder network and the dynamic development of stakeholder preferences over time. The theory of interactive management which we used originates from the scientific fields of 'proces management' in The Netherlands and complexity management.

Based on the analysis of the available Dutch theory of 'proces management', two interesting strategies are available to help managers deal with complexity in LIPs: redefinition of the problem and the alignment of relevant players. The shared interpretation of information by stakeholders is important. Complexity management looks at how to deal with existing complexity in an effective manner. Literature on complexity is theoretical and recent, however interesting strategies which can be used in practice include: using short term predictability and applying variation. The strategies and findings of interactive management are described in chapter 8.

4 Dynamic management

Our fourth and final approach is called 'dynamic management'. This approach is based on a synthesis of our findings in the successful management of complexity. It is our answer to the question: 'How to manage complexity in LIPs'.

Dynamic management is based on:

1 Balancing control and interaction
2 Doing the extraordinary

1 Balancing control and interaction

Balancing means that there needs to be a fit between the strategies and structure of the project delivery organisation and the context of the project. This involves deploying an effective combination of strategies of control and interaction. Sometime more routine structures have a better chance of success and in other situations an organisation with a greater degree of freedom is more suitable. LIPs show both the characteristics of high detail and high dynamic complexity. This means that strategies of control and interaction need to be balanced in order to be successful (figure 5.10).

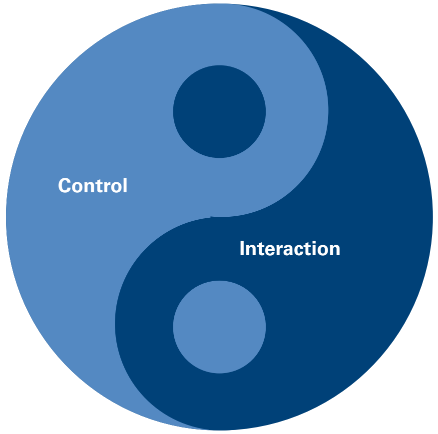


Figure 5.10: Balancing control and interaction

The strategies of control and interaction do not always mix well. Building in a new round of interaction might cause serious conflict with your project's time schedule. Based on the strategies derived from systems management and from interactive management we have developed an overview of dynamic management strategies which originate from control and interaction. This overview contains both the strategies from systems management and from interactive management (table 5.8).

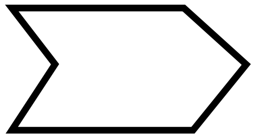
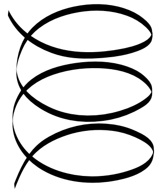
Strategy	Control	Interaction
Illustration		
		
Basis		
Fit for	Detail complexity	Dynamic complexity
Problems are	Unambiguous, fixed and independent of stakeholders	Ambiguous, changing, determined by stakeholders
Problem solving	Linear	Iterative
Theoretical basis	Organisational design Systems management	Interactive management Complexity management
Management strategies		
	1 Break down in terms of • in time • in end product • organisation	1 Alignment 2 Redefinition of the problem and change of scope
	2 Management processes • schedule • costs • quality • risks	3 Using short term predictability • systematic evaluation • selection of successful strategies
		4 Variation • in strategies • scenario building & pattern analysis

Table 5.8: Strategies of control and interaction

De Bruijn et. al. concluded in 2004 that control and interaction are complementary (De Bruijn, Hertogh, Kastelein, 2005). Both are needed. The challenge is to balance both approaches: when do you use elements of the one and when of the other? How do you switch? See text box 5.7.

Case Hilversum: From control towards interaction

In the medium-sized city of Hilversum, The Netherlands, the traffic situation was a big problem. In 2005, the project organisation of the city developed a solution for these problems and started 'consultation evenings' with stakeholders to promote their developed solution. During these evenings interaction took place between members of the project organisation and inhabitants of the city. Through the discussions that took place, the members of the project organisation got a better grip on the problem and moreover the inhabitants gave suggestions to improve the solution. What started with a promotion of the plans of the city, resulted in an improved plan with more support from inhabitants than the original solution, because of the use of 'local intelligence'.

Text box 5.7: Case Hilversum

2 Doing the extraordinary

So one key to the successful management in LIPs is clearly the effective combination of the strategies of control and of interaction. But is that all there is? When looking at our case material we found that the answer to this question is clearly in the negative. In order to be truly successful in the management of complexity we need, what we refer to as, 'extraordinary efforts'. This is the second element of our dynamic management approach which we present in chapter 10.

These extraordinary efforts can be at the following levels:

a Stakeholders system – achieving a higher degree of co-operation
b Level of the 'actor' or 'player' – going the extra mile, the project delivery organisation working as project champion
c Personal level – competent people making a difference

Apart from working at these levels we also need:

d extraordinary new management solutions
e participants in LIPs to recognise and use momentum in projects. They need to use the apparent windows of opportunity that occur within the lifespan of LIPs. Many times events perceived as threats may lead to 'golden opportunities'.

But now we turn to the management of complexity in our studied cases. What lessons and recommendations can be formulated? This is addressed in the next chapters in which we describe our four management strategies into more detail.

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Does lean & agile project management help coping with project complexity?

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Abstract

Still, projects in the construction sector are delivered with time delays and cost overruns. One of the reasons for poor performance was assigned to project complexity. A combination of lean construction and agile project management are hypothesized as a possible solution to cope with project complexity. In this paper we aim to understand if the implicit usage of lean and agile help coping with complexity. The research was done by means of correlation analysis on data gathered from a structured questionnaire (67 responses).In total, 51 significant correlations among 255 possible relations were found. To reduce the number of variables, factor analysis was performed. Correlation analysis on the defined factors showed 8 significant correlations among 25 relations. Several lean and agile elements were shown to significantly correlate to either reducing complexity or managing complexity. It was therefore concluded that these are promising to cope with complexity and improve project performance, which is to be confirmed in subsequent research.

Keywords: project complexity; lean construction; agile project management

1. Introduction

Poor performance, such as time delays and cost overruns, are not uncommon in construction projects and the reasons behind these problems have attracted the attention of construction practitioners and researchers (Mansfield,

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Ugwu, & Doran, 1994; Meng, 2012). Project complexity is claimed as one of the causes of cost overruns leading to poor performance and consequently project failure (Kaming, Olomolaiye, Holt, & Harris, 1997). Studies show that causes of poor performance can be divided into external causes and internal causes (Meng, 2012). External causes, which are usually beyond the control of project teams, may include adverse weather conditions, unforeseen site conditions, market fluctuation, and regularly changes while internal causes of poor performance may be generated by the client, the designer, the contractor, the consultant and various suppliers who provide labour, materials and equipment (Assaf & Al-Hejji, 2006). Hertogh and Westerveld also stress the influence of different interests of stakeholders and the way stakeholders interact (Hertogh & Westerveld, 2010). It can be argued that both external and internal causes happen because of project dynamics. Among all these efforts to find the reasons of poor performance, some scholars shed light on "the way that projects are being managed" as an important fact which could affect project performance and the successful delivery of the project (Gil & Tether, 2011; Olsson, 2006). Hertogh and Westerveld stated that the performance of megaprojects is influenced by their management (Hertogh & Westerveld, 2010). In a very recent study in 2014, Davis claims that based on the literature, project management is immature as a research field although project management processes must be in place for a project to be successful (Davis, 2014).

Apart from the importance of project management in general, differentiation in size, uniqueness and complexity of projects put emphasis on the necessity of tailored management methods. Increasingly it is argued that nowadays a pure project management approach (the traditional project management approach) is no longer effective (Hertogh & Westerveld, 2010; Priemus & van Wee, 2013). Nevertheless, most of the current project management methodologies still seem to underestimate the influence of the dynamic environment (ibid).

Based on above mentioned findings, the hypothesis of this research is that new management methodologies, Lean management and & Agile project management, can help coping with complexity. This paper explores the implicit usage of these methodologies and its influence on project complexity based on a literature review and a survey.

2. Literature review

This section provides the theoretical framework. First complex systems and project complexity are discussed, followed by the needs for improvements in project management and lean and agile project management.

2.1. Complex systems and project complexity

Projects over time have become more complex (Baccarini, 1996; Harvett, 2013; Hillson & Simon, 2007; Philbin, 2008; Williams, 1999). Van Marrewijk et al. (2008) state that large infrastructure projects are characterized as uncertain, complex, politically-sensitive and known for the involvement of large number of stakeholders (van Marrewijk, Clegg, Pitsis, & Veenswijk, 2008).

There are much efforts into defining complex systems and project complexity. Aritua et al. (2009) believe the studies on complexity is not necessarily a new challenge, but an old challenge that is being increasingly recognized in order to improving performance and understanding of management. An early definition of project complexity in construction industry was provided by Baccarini (1996). Also Hertogh and Westerveld (2010) recognize these dynamic effects. They proposed different management styles, dependent on the specific complexity in a project. Regarding complexity, Bosch-Rekveldt (2011) developed the TOE (Technical, Organizational, and External) framework to assess the complexity of engineering projects using 47 elements (Bosch-Rekveldt, 2011). This framework was used as the base for complexity assessment in this research.

2.2. Needs for improvements in project management

Project management as we know it today, or conventional project management, emerged in the 1950s in the defense and aerospace sectors. These sectors in this timeframe can be characterized as little flexible and complex (Morris, 1997). Starting in the 1990s and still growing is the awareness of the changing and dynamic project environment (Bosch-Rekveldt, 2011). It is recognized that the complex and changing context of a project makes it impossible to make reliable predictions, and instead of predicting and correspondingly avoiding changes, changes need to be incorporated in the project (Priemus, Bosch-Rekveldt & Giezen, 2013). This asks for a broader approach, which Koppenjan et al. (2011) named the '*prepare and commit*' approach. This approach recognizes that scope changes are inevitable, due to the many unknowns and the client's learning curve, and thus acknowledges the uncertainty and complexity of many infrastructure projects (Koppenjan, Veeneman, van der Voort, ten Heuvelhof, & Leijten, 2011). Several researchers (Atkinson, Crawford, & Ward, 2006; Joana G. Geraldi, 2008; Joana G Geraldi et al., 2008; Koppenjan, et al., 2011; Perminova, Gustafsson, & Wikström, 2008) argue that project management should evolve or mature in this direction, and thus conventional project management should be combined with the '*prepare and commit*' approach. Geraldi (2008) states: '*projects demand both mechanic and organic paradigms, both order and chaos*'. With order being reflected by conventional project management and chaos by the awareness of complexity and uncertainty. Combining both approaches means that a certain degree of flexibility is needed in order to cope with complexity and uncertainty (Joana G. Geraldi, 2008; Koppenjan, et al., 2011).

2.3. Lean management and agile project management

Since the 1950s, lean production have evolved and were successfully implemented (Aziz & Hafez, 2013). Several years later Womack and Jones studied this system and started calling the philosophy behind the system: Lean thinking (Womack & Jones, 2010). Lean thinking is a method to achieve more with less. Studies into the applicability of Lean Thinking to the construction sector resulted in the formation of Lean Construction. Marhani et al. (2013) believe lean construction is excellent in managing the construction process and achieving the project's goal by eliminating waste (Marhani, Jaapar, Bari, & Zawawi, 2013). Eric Gabrial (1997) believes the lean approach to project management has worked very successfully in potentially difficult and complex areas (Gabrial, 1997).

Another development in project management was the introduction of Agile project management. The Agile approach was developed in the software industry but many other industries, including the construction industry, have also adapted the agile approach. Agile aims to increase the relevance, quality, flexibility, and business value of software solutions. This approach is specifically intended to address the problem that have historically plagued software development and service delivery activities in the IT industry- including budget overruns, missed deadlines, low-quality outputs, and dissatisfied users (Cooke, 2012). Although there is a broad range of agile methodologies, all agile methodologies share the same basic objectives including: replacing upfront planning with incremental planning that adopts to the most current information available, building in quality upfront, addressing technical risks as early in the process as possible, to minimize the impact of changing requirements, delivering frequent and continuous business value to the organization, entrust and empower staff, encouraging ongoing communication between the business areas and project team members, and increase in the client's involvement (Cooke, 2012; Johansson, 2012).

Since Agile is an umbrella name, in itself, cannot be seen as a tool. In order to describe the more practical application of the Agile idea it was chosen to focus on one of the most applied and most popular Agile methods: Scrum (Agile-Methodology, 2014). For this research it was chosen to follow the guideline for Scrum as set up by Jeff Sutherland and Ken Schwaber (2013).

3. Research design

Quantitative data was required to investigate the relation between the implicit usage of lean and agile elements to cope with project complexity. Several complex projects are used as cases. From these complex projects, team members are asked to fill out a questionnaire. In this questionnaire the participants are asked to assess the complexity of the project they are currently working on and to assess the implicit usage of Lean and Agile elements.

The data gathering is done by means of conducting a digital questionnaire. The software program SurveyMonkey was used as format for the questionnaire. SPSS was chosen for analyzing the data.

For assessing the respondents' perceived project complexity, a framework based on the earlier mentioned TOE framework was used (Blom et al., 2014). The elements were translated into seventeen statements for which the respondents were asked to assess them on a five-point Likert scale ranging from totally disagree to totally agree.

For assessing the implicit usage of Lean and Agile the distinguishing elements of Lean and Agile from literature, section 2 of this paper, were used as a basis. Selection of these elements was based on finding a proper answer to complexity criteria extracted from literature. For these statements again a five point Likert scale ranging from totally disagree to totally agree is used. This decision was made in order to keep the survey simple and quick to fill out.

3.1. Respondents

The respondents are selected based on whether they are working on a complex project. Eventually the survey was sent to 120 possible respondents. There were 82 persons who filled out the questionnaire, yet only 67 actually completed the entire questionnaire. Therefore in the total amount of respondents is 67, resulting in a good response rate of 56%. The questionnaire was conducted in Dutch, because all possible respondents are Dutch we expected that the response would be higher and more accurate with a Dutch questionnaire.

3.2. Analysis set-up

Performing a correlation analysis for ratio variables is mostly done by means of Pearson's correlation. For this correlation a two-sided approach was adopted because regardless of the direction we looked for the relation itself not the direction of influence. The conceptual model (Figure 1) was used as starting point for this correlation analysis. The null hypothesis for this research implies there is no correlation, dependency or relation, between the complexity on the one hand and implicit usage of lean and agile on the other hand. The hypothesis to be researched implies there is a correlation, dependency or relation between the two.

Fig 1: Conceptual model

By means of a Pearson's correlation matrix all seventeen complexity statements and fifteen Lean and Agile elements were analyzed, leading to 15 x 17 matrix. Thus 255 correlations were calculated. In total 51 significant correlations were found. For this analysis a correlation is assessed as significant when $\rho \leq 0.05$.

Subsequently, factor analyses are performed in order to identify underlying variables that explain the pattern of correlations within the observed variables. Factor analysis is often used in data reduction to identify a small number of factors that explain most of the variance observed in a much larger number of manifest variables.

3.3. Results

After running the correlation analysis, in order to group the sets of variables, factor analysis was done once for complexity elements and separately for lean & agile elements. Setting the extraction value on eigenvalue and NOT on the fixed factors, and using Varimax rotation ended up to 5 distinguished factors of complexity elements and 5 distinguished factors of lean & agile elements. These factors are extracted based on the percentage of variances. In the next step the correlation analysis was done among the factors. There were 8 significant correlations among the 25 relations. Table 1 presents the results. Grey shaded boxes are those that have significant correlation.

Table 1: Correlation matrix between complexity and lean & agile factors

	Complexity 1 (technical complexity)	Complexity 2 (uncertainty)	Complexity 3 (organizational complexity)	Complexity 4 (stakeholder)	Complexity 5 (external complexity)
Lean & Agile 1 (structure & integration)	0.443**	0.205	0.594**	0.175	0.521**
Lean & Agile 2 (coordination)	0.079	0.092	0.173	0.157	0.261*
Lean & Agile 3 (planning)	0.249*	0.278*	0.325**	-0.093	0.112
Lean & Agile 4 (resource allocation)	0.147	0.195	0.196	-0.080	0.180
Lean & Agile 5 (communication)	0.226	0.120	0.431**	-0.173	0.198

**. Correlation is significant at the 0.01 level
*. Correlation is significant at the 0.05 level

4. Analysis

The first significant correlation is between technical complexity and structure & integration elements of lean and agile. Based on this significant correlation we made a number of assumptions. First, working together as one team, instead of dividing the project in several parts and merging them at the end leads to a better understanding of the overall goals of the project. Second, a more experienced project manager will advocate a project in which all team members work together. It is not assumed that the experience of the project manager will increase when all team members work together. Third, keeping the constructability of the project in mind makes that the project goals become clearer. This because in almost all cases the constructability of the project in fact makes up a big part of the goals of the project. Thus when the constructability is kept in mind, also a big part of the goals are kept in mind, and are thus clearer. Fourth, a more experienced project management is also better in taking the constructability into consideration. Fifth, using more standardization in a project could lead to an increased level of experience of the project management. Since using more standardization means that the project becomes more similar to other (previously performed) projects and which thus also means that the project management most likely already has some experience with a somewhat similar project. Sixth, cutting the project into smaller batches, or mini projects, with intermediate deliveries will lead to a better understanding of the goals of the project. For a mini project there are less goals, which can be made more clear compared to a large project where the vague overall goal mostly consists of many smaller goals. Finally, an increased level of smaller batches leads to an increased level of the project management's experience. This is meaningful because only several project managers have much experience with large projects, yet many have experience with smaller projects. Therefore cutting a large project into several mini projects with intermediate delivery will increase the level of experience of the project management.

The second significant correlation is between organizational complexity and structure & integration elements of lean and agile. This group of complexity elements consist of number of resources, contracts and communication links among them which can directly influence the technicality elements in management aspect because the work is being done by people and contractors and the communication among them influence the efficiency of the work. Based on this relation we again made a number of assumptions. First, in case all team members work together the availability of the resources increases. This because all team members also have and/or are specific resources. In case all team members work together each other’s resources are better available to them compared to in case all team members work on individual projects. Second, in case all team members of the project work together as one team, the communication level will increase. Team members will communicate more easily with other team members when they truly work together, instead of them all working on their own individual projects. Third, in case the standardization usage increases the amount of readily available resources also increases. This because using more standardization also means that more standard resources are used. Since the availability of standard resources is higher compared to the availability of uncommon resources it seems plausible that using standardization increases the amount and level of readily available resources. Finally, in case the project is divided into smaller batches, with intermediate delivery and thus also a feedback moment, the amount and level of communication in the project will increase.

The structure & integration elements of lean and agile have significant correlation with external complexity which includes the environmental aspects and availability of information in proper time. The structure of the project or constructability of it has an influence on environment and vice versa. The availability of information can affect the procedure of the project especially the pace. The wrong information or vague one can cause rework or failure. Based on this relation we made a number of assumptions. First, working together as one team will increase the amount of information available. Second, in case the availability of information increases the level of taking the constructability into consideration increases.

The coordination elements of lean and agile consist of daily meetings, information circulation, tracking of performance, and monthly/weekly detail planning. This group has significant correlation with external complexity elements. Based on this relation it is assumed that visualizing information and making this information insightful at any given moment inherently leads to the fact that information is available to all team members on any given moment of the day.

Planning elements of lean and agile have significant correlation with three groups of complexity elements named technical complexity, uncertainty, and organizational complexity. By this correlation it can be concluded that proper planning can reduce uncertainty and also technical and organizational complexity can mitigate. In this relation we made the following three assumptions. First, the more experience the project management has, the more they will involve the team members in the planning process. Second, priority in tasks in planning influences the duration of the project. Looking at the significance of this correlation this does not seem very unlikely. Third, involving team members in the planning process leads to an increased level of communication. This is because involving team members in the planning process in fact is an extra and high level communication moment.

And lastly there is significant correlation between communication elements of lean and agile and organizational complexity elements. Since organizational complexity is representative of number of people, contractors, and communication links, the relation between them and communication elements in management is meaningful. It is concluded that when the number of people or contractors is increased then much efficient communication is needed to tackle complexity. In this relation we made two assumptions. First an increased level of awareness amongst the team member of who is doing what will lead to an increase in the availability of the resources. This because all team members also have and/or are specific resources. In case each team members is perfectly aware of what the other team members are doing, he is thus also aware of who entails which resources. This awareness positively influences the availability of the resources. Second, in case the awareness of who is doing what increases, the level and amount of communication also increases. This correlation in fact is inherent, the awareness of who is doing what is caused by aligning this frequently. Aligning frequently increases the amount of communication.

Based on the above mentioned assumptions and found significant correlations it is assumed that some of the lean and agile elements work in a way of reducing complexity while some others are managing the complexity (see Table 2). There are a few lean and agile elements that did not show significant correlations with complexity.

Table 2: Summary of correlation matrix

element	Statement	reduces complexity	manages complexity	unsure
Lean 1	all specialists work together in the project, instead of the project being divided into parts and merging all the parts at the end of the process	X	X	
Lean 2	all relevant alternatives are considered and worked out		X	
	the decision making process related to the alternatives is delayed as much as possible		X	
Lean 3	the constructability of the project is taken into consideration	X	X	
Lean 4	much information, like problems and corresponding action plan and the project's performance, is visualised and insightful to me at any given moment	X		
Lean 5	standardization is used in this project	X		
Agile 6	I have selected the tasks I am performing myself		X	
Agile 7	performance is tracked on a daily basis			X
Agile 8	the team or sub-team meets on a daily basis			X
	amongst the team everyone is aware of who is doing what, since we often align this	X	X	
Agile 9	the work is divided in smaller batches, which after completion are delivered to the customer so he/she can provide feedback	X		
Merged 10	I was involved in the planning process	X	X	
Merged 11	a detailed planning was not made at the beginning of the process, but a one week/month planning is made on a weekly/monthly basis		X	
	in the planning only tasks with high priority (according to the customer) and for which all prerequisites are met are included			X
Merged 12	Problems, even the smaller ones, are reported when they occur and made insightful to all team members			X

Also there are some other relations that were anticipated to be significant, but there was no significant correlation among them based on the data gathered from questionnaires. First, it was anticipated that coordination elements of lean and agile (daily basis meetings and tracking, visualized information, and decision making at the last responsible moment) has correlation with uncertainty elements of complexity. Second, it was anticipated that communication elements of lean and agile (awareness of team members of what is happening in project, and problem reporting and solving) has significant correlation with external elements of complexity (availability of information, and impact on environment). Third, diversity of stakeholders, their expectations and goals influence the project complexity. This element of complexity can be managed by well-communication strategy which means it was anticipated that communication elements of lean and agile has significant correlation with the named element of complexity.

5. Discussion

Based on literal evidences, project management needs to evolve in some features that can fit into nowadays complex projects. Baccarini (1996) believes the construction industry has displayed great difficulty in coping with the increasing complexity of major construction projects (Baccarini, 1996). He states that certain project characteristics provide a basis for determining the appropriate managerial actions required to complete a project successfully and complexity is one such critical project dimensions (Baccarini, 1996). Cooke-Davies et al. (2008) argue that a paradigm shift is needed from the traditional project management concepts in order to deal with future project management challenges and requirements of modern practice (Cooke-Davies, Cicmil, Crawford, & Richardson, 2008). In this way, we decided to explore the usage of new-born project management methods (Lean management & Agile project management) in construction projects as a possible response to this gap.

Why a combination of lean and agile? Beside all positive aspects of lean discussed in section 2, Lean Construction has its limitations when looking at the changing and dynamic project environment. This is not only stipulated by Bertelsen (2002), but also Ward (1994) already concluded that Lean Construction does not provide a method to cope with a changing project environment (Bertelsen, 2002; Ward, 1994). This is why recent research is done into how a project could cope with this type of complexity. Agile has been put forward to fill this gap (Demir, Bryde, Fearon, & Ochieng, 2012). Even though Agile methods are currently merely applied in the construction industry, it does not mean that Agile methods are not applicable or successful in the construction sector (Owen, Koskela, Henrich, & Codinhoto, 2006). Since Agile is merely applied to construction projects, little is known about it. Yet, the interest of the construction industry on the subject is rising (Owen, et al., 2006). Since Lean Construction has its limitations related to the project environment, the construction sector is looking for (complementary) methods that do provide tools to handle this kind of complexity. But why are they searching in the direction of Agile methods? One of the main characteristics of complex systems is that they are capable of self-organisation (Bertelsen & Koskela, 2004). They do not need a detailed plan, but attention should be paid to creating a clear objective and the improvement of the reliability (ibid). This fits well with the Agile concept. Owen, Koskela, Henrich, & Codinhoto (2006) elaborately discussed the applicability of Agile Project Management to the construction sector in their paper: is Agile Project Management applicable to construction?. Agile Project Management is based on the idea that change can be transformed into added value for the costumer. The scope of the project, and a corresponding planning, are only defined as far as value for the costumer at that moment is known and can be specified. This makes it possible to deliver value on the short-term. By receiving early and recurrent feedback, continuous learning will be achieved. This will lead to a continuous evolving of the value for the costumer. This results in an end-value which satisfies the costumer's requirements at the end of the process, instead of an end-value which meets the value as defined at the beginning of the process. To see change as something positive, as an opportunity to improve customer value, a more proactive organization is required compared to Lean organizations (Owen, Koskela, Henrich, & Codinhoto, 2006).

6. Conclusion

Increasing complexity of projects needs a tailored project management methodology in order to deliver complex projects successfully. In this paper we looked at the combination of lean and agile project management as a potential answer to this problem. The lean approach has limitations in construction projects, as discussed before, but the combination of lean and agile was assumed to be a solution. Currently, agile project management is rarely used in construction projects and the aim of this research was to explore if lean and agile methodologies could be used in this type of projects to influence the performance in a positive way by coping with complexity. Based on the results of correlation analysis it was concluded that the implicit usage of lean and agile elements can help coping with project complexity. Hence the conceptual model of the research (figure 1) is confirmed, regardless of the direction of the arrows. Finding out the direction could be a topic for subsequent research.

By proving the existence of this relation, further research on how lean and agile elements can be implemented in construction projects could be a way forward to improve project performance.

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White paper

How to make smaller projects more successful: a fit-for-purpose approach

by

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Abstract
A lot of focus in present day project management literature is on large and mega projects. Since these projects become bigger and bigger the complexity is quite often seen as the main reason for not delivering the project within the budget and schedule as approved at the moment of the investment decision. But not only large projects run into difficulties, also small projects quite often do not live up to their promises. Small projects too become even more complex nowadays, but a more important issue could be that the project management approach as developed for large projects might not be fitting these small projects. Applying all the steps and procedures required for a large project on a small project might be overzealous and overburden the budget and the capacity of the project team. One size does not fit all projects. The main objective of this study is to investigate what a fit-for-purpose approach for the management of small projects might look like. In this study it is shown that the approach is not contingent with complexity but it is made plausible that a scaled project management approach is the most suitable way forward rather than reducing the management efforts by skipping important steps.

1. Introduction

Project management, as we know it today, only exists for about 60 years. Mankind has been constructing impressive structures and artefacts already for centuries before the launch of project management as a profession. But over the last sixty years the profession has been maturing by learning from completed projects and handing over best practices from project to project, from master to apprentice and from industry to industry. Quite often the foundation on which these best practices have been based has not always been as sound as it could have been, but it definitely has been a way to improve the management of projects. However, after sixty years the overall performance of our projects and thus our project management are not as good as might be expected. Going through recent literature it becomes clear that especially the performance of the megaprojects (Merrow, 2011) but also the large projects within the oil and gas industry (Ernst and Young, 2014) are failing by spectacular numbers. This is not a recent trend. Already in 1987 Morris and Hough (Morris and Hough, 1987) published an overview of roughly 3500 projects completed in the period from 1959 to 1984, showing comparable and sobering results.

Most of the project management processes that have been developed over the years have been focussing on large engineering projects. Over the last decade these projects have become even bigger, which means that a 10 % cost overrun on such a project will result in enormous losses for the contractor or the owner, depending on the type of contract. Not many contractors can afford these types of losses and recently the contractors in the Dutch infrastructure industry have sounded the alarm bell in this respect (NRC, June 2015). Talking to the project managers of these mega projects their solution seems to be to try to reduce the complexity of these mega undertakings by cutting them up in smaller packages and managing them as a collection of smaller projects. In that way the subprojects become more affordable for the contractors but this will introduce an additional challenge of managing an increased number of interfaces and integrating the various subprojects into the final product or result.

Large multinational companies in the oil and gas industry have over the years developed their own project management processes and procedures. Quite often this comes together with a formal education (combined with on the job learning) of future project managers and the accreditation of the project management system as well as the certification of the individual project managers. Over the years we have seen that these companies have been able to improve their project management performance at a sizeable cost and time expense. By doing that they have been able to reach the top 20 % of the annual benchmarking results as reported during the annual benchmarking conferences (IPA, 2015). Although not all the results are successful and surely not every company can afford such an approach, we have seen positive results of such a strict compliance approach. But even then, one size does not fit all. The methods that are applied on large projects might be beneficial for smaller projects, but one has to be careful that the project will not be overly expensive by introducing all these procedures and processes as they are applied on large projects.

Finally, project management receives much interest because projects are believed to be a key to the success of a company, enabling innovation and change. There are different bodies of knowledge that describe the project management practices and these practices assume scalability to any type of project. These bodies can be summarized as a general approach to solve a specific case, as every project has its own unique characteristics. However, a high failure rate of projects may raise questions on whether the current approach is still applicable and useful. It might be necessary to adapt the project management approach to the specific characteristics of a project in order to be successful.

The interests of the companies in the Dutch process industry competence network have triggered our study. This network consists of large and small engineering, consulting and construction companies and large and small owner companies in the food, pharmaceutical, manufacturing, energy and oil and gas industry. All these companies are to some extent struggling with the management of small projects. Although the losses are smaller in absolute terms compared to the large industrial projects, for these owners/contractors the losses can still be substantial. So all are interested in a fit for purpose management of in particular small projects. The main question coming out of this network is: how can we improve the performance of the management of projects and with that our overall project performance?

2. Literature review

2.1 Fit-for-purpose project management

The term fit-for-purpose project management is not a well-established term in project management literature, though captures perfectly the modern view on how to approach the management of projects: Where the classical view is seen as one size fits all, the modern view stresses to fit the management practices to the project's purpose. Another term, also referring to this modern view is the adaptive project management approach (Shenhar & Dvir, 2007). Though all the modern approaches have their differences, they all agree on the topic that a more flexible attitude must be adopted towards the management of projects. This originates from the conviction that just only a small portion of today's projects is well-addressed with the traditional approach and that the majority of today's projects have become too uncertain and complex for a straight forward project planning, due to increased dynamics of the environment, technology and markets (Shenhar & Dvir, 2007). Thus instead of approaching projects like they are all the same, the modern approaches consider projects to differ and argue to adapt the project management practices to each project's specific purpose. The development of these modern approaches for project management is currently a hot topic in project management literature (Turner et al., 2012). Hence, there is not yet consensus on the one best modern project management approach. By using the term fit-for-purpose project management, this research adopts the philosophy of the modern project management approaches, but not the connotations in terms of solutions that belong to either the adaptive, agile or lean project management approach.

2.2 Small projects

Small projects are addressed since it is assumed that small projects, relative to large projects, benefit more from a fit-for-purpose project management approach. This assumption is based on the consideration that a regular project management approach and small project's purpose are often a misfit (Liang, Thomas, & Gibson, 2005). Large project management approaches are for example likely to smother small projects with obliged paperwork that in large projects have a clear purpose, but in small projects can be considered overabundant and just consume the already limited project resources. Therefore, especially at small projects, it becomes apparent that projects are performed ineffective and inefficient, because project management methods lack the feature to be fitted to a project's purpose.

Thirteen papers originating from the PMI website have been analysed that provide information on the management of small projects. Most of these are based on the experience of a practitioner. Although the papers are by different authors, most of the methods, which are discussed in those papers, are already included in a publication by Campbell (1998). Campbell indicates that the smallest projects do not necessarily require the least management, as very small projects can still be very risky. Thus, the project management method should depend on the project risks. The three methods he suggests are:

1. "Just do it": bare bones, relying on documentation of purpose, scope, objectives, assumptions and risks (PSOAR) and getting agreement on this from the customer;
2. Typical Small Project methodology which follows a define, design and deliver life cycle;
3. Typical medium project methodology, which includes more substantial project initiation and post-implementation stages, as well as most of the steps recommended in the Guide to the PMBoK (PMI, 2008; Campbell, 1998).

The first method seems to be a two-step approach, whereby the lifecycle phases are joined together to form a Definition and Execution phase. In the second method the Concept and Feasibility phases seem to be combined in a Define phase. The third would be similar to following the lifecycle as given by Turner (1999).

Though, what is considered a small project is subject for debate. As a conservative estimate the Construction Industry Institute states that 40 to 50 percent of all construction industry capital budgets are now spent on smaller projects (CII, 2002). The industry however lacks a widely accepted consensus on what is considered a small project (Liang et al., 2005). In Table 1 an overview is given what project characteristics are used in literature to determine a small project.

		Parth, 1998	Turner, 1999	Payne & Turner, 1999	Dunston & Reed, 2000	Liang et al., 2005	CII, 2006	Hwang, Zao & Toh, 2014
1	**Project capital budget**		v		v	v	v	v
2	**Project budget as percentage of company turnover**	v		v				
3	**Project duration**					v	v	v
4	**Number of staff hours**					v	v	
5	**Full/part-time involvement PM & project team**	v				v	v	

Table 1: Discriminating elements between large and small projects

Here it is shown, that the intuitive 'project capital budget' is often used as an indicator for the size of a project in the selected papers. However, a project of 1 million Euro can be large for one organisation and small for another. To solve this issue the project capital budget as percentage of the organizations turnover has been suggested. Though, no specific percentage is stated as the cut-off for defining a 'small' project. Furthermore, for characteristics 3 and 4: 'the duration of a project' and 'how many man hours are put in a project', can be said the same as for the criteria 'project capital budget'. What is small for one company is large for another. Finally, the extent of the involvement of the project manager and project team is suggested: if a project has the full time attention of both a project manager and a project team, it is likely to be an important project for the organisation. In case of part time involvement, a lack of importance is assumed, making it a small project.

The variables that are mentioned the most are project capital budget, project duration and the full/part time involvement of the project manager and project team. But still the term 'small' is rather subjective. Therefore, in this research the decision has been taken to use the following criteria. A project is small as the budget is smaller than 1 million, the duration is shorter than 12 months, the project manager and project team are only part time involved and the number of staff hours is less than 20.000. When all these conditions are fulfilled the project is considered small in all other cases the projects is called larger.

2.3 Project performance

Project performance is one of the most discussed topics in project management literature (Crawford & Cooke-Davies, 2012) and there is no consensus concerning the criteria by which success is judged (Baccarini, 1999; Freeman & Beale, 1992; Pinto & Slevin, 1988; Shenhar, Levy, & Dvir, 1997). Traditionally it was defined by whether the project is delivered on time, within budget and with satisfactory quality. In literature these three indicators – time, cost and quality – are referred to as the iron triangle (Atkinson, 1999; Morris et al., 2011), the triple constraint (Conchúir, 2011; Meredith & Mantel, 2011) or the golden triangle (Westerveld, 2003), and are still used often to determine the success of a project. The triple constraint is however not the sole criteria of project success (de Wit, 1988). Project management success relates to the short-term success of the execution of the project. Here the triple constraint is often used, as this data is almost directly available at the handover of the project. Project success on the other hand, is related to the long-term success; 'did the project deliver what the investor aimed for?'

More detailed Shenhar et al. (Shenhar, Dvir, Levy, & Maltz, 2001) identified four dimensions by which the success of a project can be determined over time. The first dimension 'efficiency of a project' can be measured almost directly after the project management cycle ends and corresponds with project management success as mentioned by de Wit. Over time, the success of the other three dimensions can be determined and are related more to project success. Hence, different standing points (in time) influence the perceived success of a project.

In this study particular interest goes to project performance within the context of projects in the Dutch process industry. The perspective on project success from the project managers in the Dutch process industry has been studied recently (Bakker, Arkesteijn, Bosch-Rekveldt, & Mooi, 2010). The top 6 criteria from this study are safety, client satisfaction, budget, schedule, quality and start-up. These 6 criteria will be used to assess the project performance of the projects in the present survey. The criteria are combined into one variable. Each criterion is assessed on a scale from zero to one, which when summed up results in one variable, project performance ranging from 0 to 6. Subsequently two levels of project performance are defined: a project is considered to have a good project performance when scoring at least 5 out of 6 with the requirement that the project did not endure any lost time incidents. A project scoring 4.5 or lower is considered a project with a poor project performance. See Table 2 for the detailed scoring per criterion.

Criterion	Answer range	Value
Lost time incidents	0 Lost time incidents	1
	1 Lost time incidents	0
	2 Lost time incidents	0
	3 Lost time incidents	0
Client satisfaction	Very satisfied	1
	Satisfied	1
	Not completely satisfied	.5
	Absolutely not satisfied	0
Budget	Estimate exceeded with more than 20%	0
	Estimate exceeded with 11-20%	.5
	Estimate exceeded with 1-10%	1
	Similar to estimate	1
	Cost were 1-10% less than estimated	1
	Cost were -11-20% less than estimated	.5
	Cost were more than 20% less than estimated	0
Quality	All quality requirements were met	1
	Most of all requirements were met	1
	Half of the requirements were met	.5
	Failed most of all requirements	0
	Failed all requirements	0
Schedule	+20%	0
	+11-20%	.5
	+1-10%	1
	Similar to estimate	1
	-1-10%	1
	-11-20%	.5
	-20%	0
Start up production	> 80% of the planned production	1
	50 – 80% of the planned production	.5
	< 50% of the planned production	0

Table 2: Translation of the project outcomes into a single figure for project performance

2.4 Contingency theory in project management

Contingency theory finds its origin in organizations studies from the sixties and seventies (Burns, Stalker, & Woodward, 1961; Dessler, 1976; Galbraith, 1973; Lawrence & Lorsch, 1967) and became again popular in the late nineties and the beginning of this century after the work of Donaldson (Donaldson, 1996, 2001). Although originating from organization studies, when applied to project management, contingency theory can be viewed as the theoretical foundation of the fit-for-purpose project management approach: "Applying the contingency approach to project management would mean that project management should be made dependent on the contingency factors, with a fit or congruence between those factors leading to best project performance" (Bosch-Rekveldt, 2011). The contingency factor is thus the variable with which a project manager could determine a project's specific type. The applicability of the fit-for-purpose project management approach in practice is hereby heavily dependent on how well the contingency factor or set of factors fulfil their role as a categorisation system for projects (Maylor, 2010; Meredith & Mantel, 2011; Turner, 1999).

Three prominent studies into the application of contingency theory in project management (Bosch-Rekveldt, 2011; Howell, Windahl, & Seidel, 2010; Shenhar & Dvir, 2007) have been used to provide insight in the different suggested contingency factors. This resulted in the TOE framework for project complexity as derived by Bosch-Rekveldt. The TOE framework considers complexity as the sole contingency factor for determining which project management practices best fit the project's purpose. Further study in the form of interviews and a survey resulted in operationalisation of 47 complexity elements that all contribute to the project's complexity divided over three subcategories: technical complexity (T), organisational complexity (O) and external complexity (E). The TOE complexity framework does not directly result in advised project management approaches. Empirical research has shown some relations between complexity elements, project management practices and project performance, though is in need of further research before the conclusion can be drawn that the TOE framework can be used to apply contingency theory into project management practice.

In conclusion a project's complexity can be explained in multiple ways. The interpretation has been developed over the years and is still a hot topic for research today. In this research the project's complexity is considered as follows: the project's complexity consists out of an undefined number of elements which can all be considered to cause few or many difficulties during the project's execution. Some elements cause the structural complexity of a project and other the dynamic complexity of a project. All combined determines the project's complexity. Since Bosch-Rekveldt's model has been developed in the process industry, the TOE complexity framework is considered the best fit for this research. This research adopts the TOE complexity framework for providing a comprehensive set of elements, establishing a complexity footprint for the project as perceived by the project manager. This can function as starting point for discussions on the project's complexity.

3. Methodology

The objective of this study is to investigate whether the project management approach can be made contingent on the perceived complexity of the project under study. The idea behind this approach is that the project manager assesses the complexity of the project using the TOE framework and based on the outcome of this assessment the project management approach is selected. Or in other words, the necessary and sufficient elements, the front-end activities, of the project management approach are then selected based on the complexity and the size as derived in section 2.2. Via a survey the relation between the approach chosen and the final project performance is derived to draw a final conclusion on the fit-for-purpose project management approach. The only limitation to this approach is that the complexity is decided with hindsight since the project managers of completed projects have been surveyed who did not have access yet to the TOE framework at the launch of their project.

The data for studying the relations between project complexity, front-end activities (FEAs) and project performance is acquired via a survey that has been distributed amongst project managers in the NAP Network (Dutch process industry competence network) and by means of interviewing a number of project managers in a single organisation. In respective order the survey questions addressed general characteristics of the most recent finished small project, the project´s complexity, the performed front-end activities, project performance and personal background.

The project's complexity is questioned on the basis of the TOE complexity framework by (Bosch-Rekveldt, 2011). The TOE complexity framework consists out of three themes in project complexity: technical, organizational and external complexity, which respectively consists out 17, 17 and 13 elements of their own. Each element was questioned by asking the respondents to scale the perceived contribution of this element to the project's complexity on a four point Likert scale, ranging from very little to very much contribution to the project's complexity.

Which FEAs have been carried out in the respondents' projects is questioned by means of the activities listed in the publication of Oosterhuis et al (2008). This list contains 28 activities divided over three sub phases within the FED phase, which consist out of 9, 10 and 9 activities, respectively. Similar to the way complexity was surveyed, the respondents were asked to indicate to what extent each practice was carried out in the project on a four point Likert scale ranging from: to a very small extent, to a very large extent.

Phase 1: Appraise
1. (A) Translate business objectives into required project performance
2. (B) Preliminary cost and revenue assessment
3. (C) Prepare level 1 schedule
4. (D) Analyse safety issues
5. (E) Risk identification and management
6. (F) Determine contract strategy
7. (G) Feedback to and from stakeholders
8. (H) Plan the FED phases
9. (I) Set up the FED organization
Phase 2: Select
1. (J) Define the scope
2. (K) Select the site
3. (L) Select technology
4. (M) Define main equipment
5. (N) Identify critical unit operations
6. (O) Cost and revenue assessment
7. (P) Prepare level 2 schedule
8. (Q) Analyse safety issues
9. (R) Risk identification and management
10. (S) Compose the project team
Phase 3: Define
1. (T) Basic engineering
2. (U) Cost and revenue assessment
3. (V) Prepare level 3 schedule
4. (W) Analyse safety issues
5. (X) Risk identification and management
6. (Y) Define project funding strategy
7. (Z) Prepare the contracting plan
8. (AA) Define project strategic interfaces
9. (AB) Team building

Table 3: Front-end activities per phase (Oosterhuis, 2008)

The validity of the survey was ensured by the following measures:

- Before the online survey was published, the survey was tested by a number of experts to assure the validity of the survey. The experts consisted both of academics and practitioners. With the help of the feedback from these tests the questions were further sharpened.
- Second, to increase the data validity answers 'not applicable' and/or 'do not know' were included as option. Hereby it is prevented that respondents would have to answer questions that they are not able to answer, due for instance lack of knowledge. Subsequently, the cases with missing values were thus just excluded from the specific analyses, rather than removed from the dataset.

As a last step a separate group of project managers was interviewed, all employees of the same company with its own standardised project management process. This last group was introduced to rule out the different interpretation of some of the project management activities in various companies. At least this last group had all been using the same tools and procedures enabling the researcher to purely focus on the differences between the various projects.

4. Data analysis and discussion

The survey was targeted to project managers of small projects in the Dutch process industry. The survey was send to 511 email addresses. From this amount the large part, 463 emails were send to the members of the Dutch process industry competence network NAP, by the director of this network. In the mail, the receiving party was asked to fill out the online questionnaire and to send the invitation to fill out the questionnaire to other colleagues, if they would fit the target group of the survey. To keep track of how many times the invitation to fill out the online questionnaire was forwarded it was requested to copy the researcher while forwarding the e-mail. This way the number of sent invitations could be counted. In addition, to improve the number of responses one reminder was sent two weeks before the deadline and five professionals, who were involved in this research via an interest group from the NAP network, were asked to point their colleagues at this survey. From these 511 invitations we received 54 completed responses, resulting in a response rate of approximately 11%. This response rate is just a bit lower than the typical response rate for online surveys, which is around 15% (Porter & Whitcomb, 2007).

From the 54 respondents, 52 were male and 2 were female. The majority had a study background in engineering: 44 respondents. The others did predominantly have a background in business. Regarding the education level, from the 52 respondents 48 possessed a bachelor's degree or higher and 6 respondents indicated secondary vocational education as highest level of education. Furthermore, the group of respondents can be considered 'senior', since 48 out of the 54 respondents had at least 11 years of working experience and 50% worked even more than 21 years. Consequently their project management experience was also considerable: 30 respondents worked as a project manager for at least 11 years.

The projects for which the respondents filled out the survey are predominantly situated in the petrochemical sector: 27 out of the 54 projects. The other well-represented sector is the food & beverage sector: 11 projects and the remaining projects (16) were situated in the construction, energy, manufacturing, pharmaceutical and waste sectors. With respect to the location of the projects, 46 were performed in the Netherlands and the other 8 in Australia, Brunei, China, Germany, Greece, Qatar and Russia.

- The durations of these projects were very diverse. They range from shorter than three months to longer than 25 months. The majority of the cases have a duration between 3 to 12 months.
- In just 7 projects both the project manager and project team were full time involved. From the remaining projects 35 were performed without any full time involvement.
- The size in capital expenditure shows that the majority of the projects had a Capex of 2 million euro or less: 32 out of 54 projects. Of the remaining projects, 12 had a Capex between 2 and 20 million euro, 7 between 20 and 500 million euro and for 3 cases the capital budget was not shared.

Based on Table 2 the 54 projects were split into 23 successful projects and 31 unsuccessful projects. Thus 43% of the projects in the survey are labelled successful. This in itself is already a first message. The failure rate of small projects is on the basis of this sample certainly not less than the failure rate of large projects. Following the logic explained in Section 2.2, the total survey response consisted out of 22 small projects and 32 larger projects. Of these 9 small projects were successful (41%) and 14 larger projects (45%).

In Figure 1 the average score of the amount of front end activities executed is plotted for successful and unsuccessful projects. Only the activities K, L, M and N are supposedly more applied on unsuccessful projects then on successful projects. Of these only the difference in activity K, selecting the site, is significant. The main reason for this difference is most probably that only 6 out of the 54 projects were new developments. And out of these 6 only 2 were successful. All other were maintenance projects, expansion or restoration projects in which case site selection is clearly not an issue.

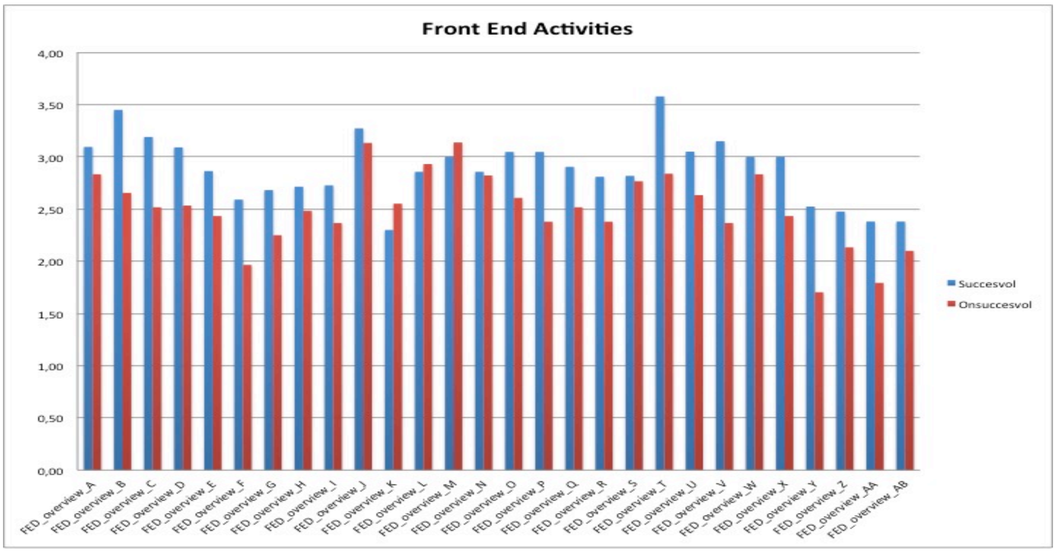

Figure 1: The average application of front-end activities for all projects

The next step is to look at the split between larger and smaller projects. Is there a difference in the amount of application and can the first indications of a fit-for-purpose approach maybe be discovered? To this end a similar overview to Figure 1 has been made but now to discriminate between larger and smaller projects.

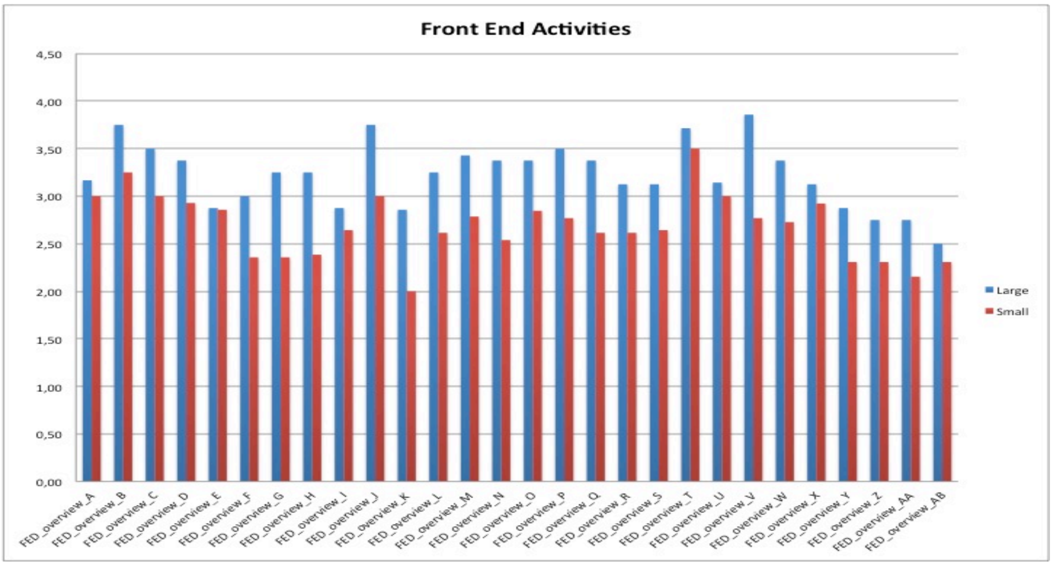

Figure 2: The difference of application of front-end activities between larger and smaller projects

It can clearly be seen from this figure that all activities are more often applied on larger projects than on smaller projects. The differences are significant for all activities but one. Activity E, risk identification and management, is equally applied on larger and smaller projects.

Now that is established what activities are applied the question is whether the perceived complexity of the project makes a difference in either the application of the activities or the resulting project performance. Unfortunately we were only able to establish the perceived complexity after completion of the project. The respondents were asked to complete the survey based on their most recent completed project. This to prevent that only responses from successful projects would be received, but the drawback is that the respondents were only asked to give a view on the complexity of the project after its completion.

The fact that complexity and certainly the TOE framework as used by the authors is subjective in its application is not a concern. Using the framework in the way it is meant it will be used to establish in an early stage - the assess or feasibility phase - what the complexity footprint of the opportunity is as perceived by the project manager. That will be the same person who ultimately decides which activities to apply or not to apply or to what extent. So in the end the complexity assessment and the selection of front end activities is made by the same person. What is an issue in this study is that we were not able to perform the complexity footprint up-front. So we cannot rule out that the final performance of the project influenced the perception of the complexity. As an example, arguments like it has taken too long and it costed too much so it must have been complex cannot be ruled out.
The way the TOE framework has been applied was as follows. The respondents were asked to assess all 47 elements of the TOE framework on a 4 point Likert scale and these scores were initially used to assess whether a project was predominantly technical complex, organisationally complex or externally complex. Since the Likert scales ranged from very little contribution (1), via little contribution (2), much contribution (3) tot very much contribution (4), a project is only called complex if either or all of the scores on T, O or E are 3 or above. In the latter case the project is called complex, in the other cases it is called technical, organisational or external complex, depending on the highest score.

In the whole of the survey there is only one project with an overall complexity score above 3. Unfortunately that project was considered unsuccessful based on the performance score. The first conclusion is that the small and larger projects that we surveyed are not considered (very) complex. Also because, as explained earlier, the majority of the projects are maintenance or revamp projects and even the 6 new developments all had a complexity score ranging from 1.6 to 2.4, so little complex on average. Even when the standards are lowered a bit, accepting a complexity score of 2.5 or larger as an indication for a complex project, only 6 projects make the mark: 2 successful projects, one larger and one small, and 4 unsuccessful projects, two larger and two small. So nicely distributed, but no discriminating power on the basis of these survey responses.

Looking at the relative individual scores for technical, organisational and external complexity it is remarkable to see that the majority of these projects (36) are considered more technical complex than organisational (11) or external (7). This is in contrast to earlier findings (Bosch-Rekveldt, 2011) where technical project managers were not concerned too much about the technical complexity because that is what most of them were trained for. They were more concerned about organisational and external complexity because these elements were slightly more out of their comfort zone. Here we see an opposite trend.

Despite this, an effort has been made to look for correlations between the perceived complexity and the amount of front-end activities applied on the project. To this end the average complexity scores have been plotted against the average score of front-end activities based on the Likert score results, where a score equal to 2 stands for marginal application and a score of 3 or higher for substantive application. The result of this plot is shown in Figure 3. The spread is rather wide but to guide the eye a linear regression has been performed for both the successful as well as the unsuccessful projects. Not too much should be read into this but it does show that the unsuccessful projects are considered to be slightly more complex according to their project managers, admittedly in hindsight. The successful projects on the other hand have a tendency of a slightly higher application of front-end activities. As mentioned before, not too much should be derived from these results. The main conclusion should be that for these type of projects, small or larger, complexity as used is not a discriminating factor.

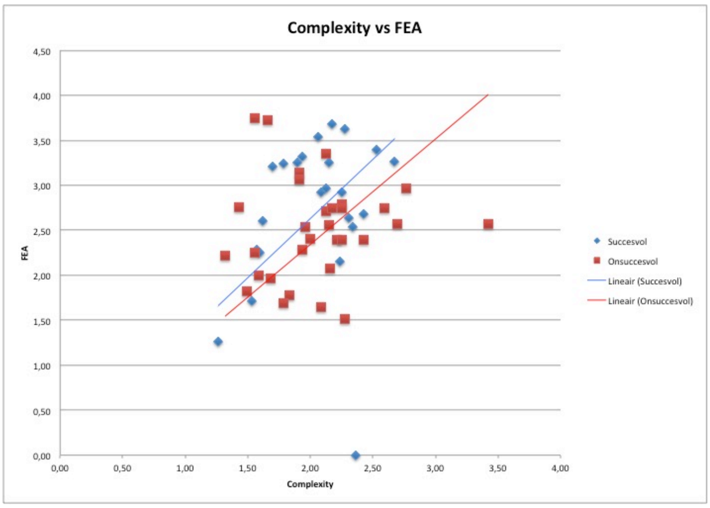

Figure 3: Complexity versus front-end activities for successful and unsuccessful projects

This study is originally initiated to improve the project management of small projects. When the focus is once more put on the smaller projects in Figure 3, an interesting result surfaced. In Figure 4 the attention is solely on the 9 successful small projects from the survey.

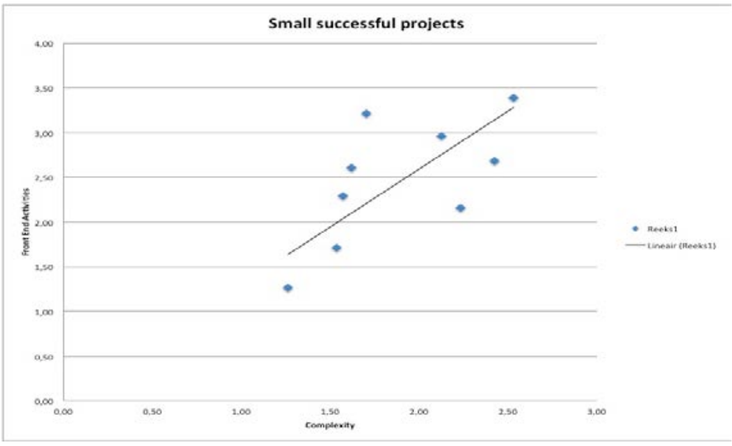

Figure 4: Complexity versus amount of front-end activities for small successful projects

Again not too much should be derived from this figure, but it at least suggests that the more complex the project is perceived by the project manager the more front-end activities are applied. When we look in a bit more detail it is interesting to see that 5 of the projects are considered to be mostly technical complex. The other four are evenly spread over organisational and external complexity. The front-end activities are almost evenly spread over the FED1 and FED2 phase, with only one project spending the majority of front-end activities in FED3. There is no correlation between the detailed complexity (T, O or E) and the various front-end activity phases (FED1, FED2 or FED3).

Looking at the whole of the survey it is remarkable to see that almost twice as many times most effort is spend on the FED2 phase (in 27 of the projects the red bars peak above the others). Most effort is spend on the FED1 phase in 14 projects (blue bars) and in 11 projects most effort is spend on the FED3 phase (green bars). A graphical representation of these differences is given in Figure 5.

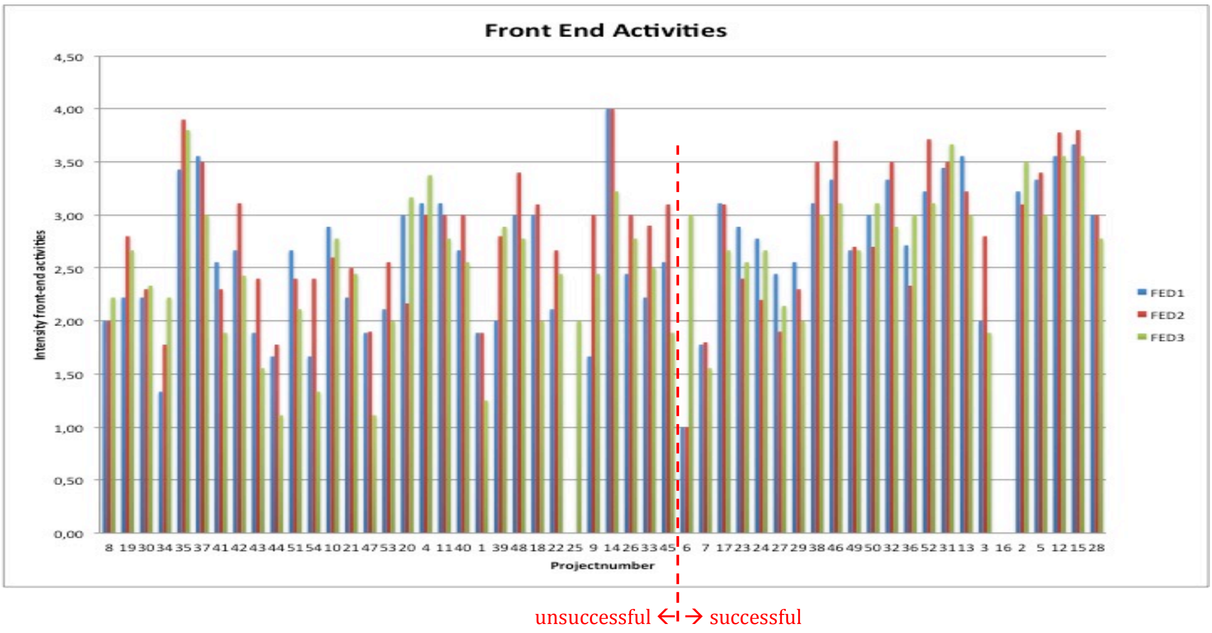

Figure 5: The intensity of front-end activities in each of the phases FED1/2/3 per project. The first 31 projects are unsuccessful, the last 23 the successful projects

In summary all the front-end activities as listed by Oosterhuis (2008) are more or less applied on all 54 projects, successful or unsuccessful. There is no clear activity that is either applied more often or not at all on either small or larger projects. Furthermore, there is no clear correlation between the perceived complexity, the amount of activities applied and the performance of the projects. That means that with the results from this survey we cannot get very much further in discovering what the best fit-for-purpose approach would be to manage small projects. At this moment in time the fit-for-purpose approach seems to gravitate towards scaling the efforts based on the type of project rather than skipping any of the activities.

5. Additional data gathering

Based on these results the authors decided to perform an additional investigation with the same purpose, but with slightly different boundary conditions. In order to minimise the differences of opinion and interpretation, it was decided to perform a number of additional interviews in a single operating company of a multinational company that manages its project portfolio by a single project management standard across the globe. In that case the risk of multiple interpretations of a similar activity was reduced to a minimum. In order to reduce personal bias and improve triangulation more staff from the project department was interviewed. In total 17 projects were considered and 34 staff were interviewed.

Of the 17 projects 12 qualified as small projects according to the criteria in Section 2.2. Of these 12 small projects the capital expenditure ranged from 160k Euro to 1000k Euro and 7 of them were considered successful. A slightly better success score, actually 58 %, is reached in this dataset compared to the first survey. In broad terms we are looking at a comparable dataset, but executed by a single project management approach.

The interviews provided the bulk of the data for this section. The questions used in the interviews were semi-structured and open-ended. The questions raised in the interviews are not based on any themes in order not to bias the respondents. The interviews consisted of the following questions:

1. What is your involvement in small projects?
2. What are your experiences (positive/negative) with small projects?

    - How do you experience cooperation between different stakeholders?
    - How do you experience the current structure applied to small projects?
    - What are advantages and disadvantages of the current process?
3. What would you like to see improved?

In order to determine the relevant issues it is important to find the common denominators in the answers that can be captured in one issue. The recorded data is summarized in a written format. These formats are subsequently used to transform opinions into issues. In order to transform an opinion into an issue, the first interview is selected and issues are identified. These issues were thereafter used in the analysis of the other interviews (not in executing the interview in order to prevent improper influencing of the interviewee) and any new issues were added. The list of issues was thus growing while all interviews were analysed. This resulted in a list of 61 issues after the analysis of 34 interviews. Critical analysis of this list (correcting for different descriptions of in essence the same opinion) resulted in a reduced list of 27 issues. After identification of the issues they were grouped in themes. Some issues fitted into two themes. The theme that is mentioned most is considered to be the main theme.
The data presented in the interviews were opinions and therefore biased. In order to select issues that are most likely to be valid or at least not based on a single opinion selection criteria were defined. An issue is considered to be relevant if it is meets the following selection criteria:

- The issue must have been indicated by at least three respondent groups because this shows the issue is concerning different stakeholders. One group can have a very strong opinion about a project, but if three groups mention the issue, it is more likely a real issue.
- The issue must have been mentioned by at least seven respondents. This number is found by dividing the total amount of opinions by the total amount of issues. 195 opinions were found and summarized in 27 issues, resulting in an average of 7.2. For this case all issues with an average higher than or equal to 7 is used. This criterion is used to select between 'single' opinions and 'shared' opinions.

For each criterion that is true the issue is flagged with a '1', otherwise '0'. Issues with a final score 2 or higher are considered supported (2) or likely valid (3). Based on this approach the following issues surfaced:

- Scope definition is not always clear and complete (3)
- Contracting engineer focuses on quality and not solely on the minimum engineering (3)
- Different stakeholders do not work well together (3)
- The quality of the basis of design is not sufficient (3)
- Opex or Capex is not a good way to discriminate projects (2)
- Projects are initiated too late (2)
- Project managers are changed out too often (2)
- Project management skills and behaviours are important (2)
- Costs are in general underestimated (2)

Following on from the listing of these issues, the three themes this operating company decided to focus on were then finally 1) more attention to front-end development, 2) a fit for purpose approach represented by scaling not skipping and 3) more attention to the formation of the project team. Furthermore, from the interviews it became clear that a fit-for-purpose execution of small projects should comprise minimally an opportunity framing step (Bakker and de Kleijn, 2014) attention to project team formation (many of the required skills came in too late), project assurance (independently checking that the required steps have actually been completed), stakeholder management, a detailed scope definition, proper scheduling, an executable contracting and procurement strategy and thorough risk management including frequently reviewing the risk register. This coincides to a great extent with the activities shown under FED1 in Table 3.

6. Conclusion

Via a somewhat unconventional approach the authors have come up with a solution to the question raised by the project managers in a special interest group (SIG) on project management as organised by the NAP

Network. The SIG was struggling with finding a better way of managing small engineering projects. The challenged posed on the researchers was to come up with a method to support the decision on how to manage a small project and thereby forecasting a better outcome or project result.

To this end the researchers tried to come up with a contingency approach based on the perceived complexity of the projects. Unfortunately this approach did not result in a tangible result. The main conclusion of the first part of the study has been that for the type of projects in this survey, small or larger, the complexity elements as used are not a discriminating factor. Nevertheless, what was found was that the more complex the project is perceived the more front-end activities are applied. Looking at the whole of the survey it is remarkable to see that almost twice as many times most effort is spend on the FED2 phase.

This is in sharp contrast to the outcome of the second stage of the research where a number of project managers were interviewed about their views on the management of small projects. From these interviews it became clear that a fit-for-purpose execution of small projects should comprise minimally an opportunity framing step (Bakker and de Kleijn, 2014), attention to project team formation (many of the required skills came in too late), project assurance (independently checking that the required steps have actually been completed), stakeholder management, a detailed scope definition, proper scheduling, an executable contracting and procurement strategy and thorough risk management including frequently reviewing the risk register. This coincides to a great extent with the activities shown under FED1 in Table 3. The reason for this difference is most probably that in the first part of the survey owners and contractors were mixed in the responses. Quite often the contractors only come on board in the project in FED2. When we are looking at project managers from a single owner company it becomes clear that the early stages of front-end development are crucial for future project success.

In summary, all the front-end activities as listed by Oosterhuis (2008) are more or less applied on all 88 projects, successful or unsuccessful. There is no clear activity that is either applied more often or not at all on either small or larger projects. Based on the results of this combined study the conclusion can be drawn that a fit-for-purpose approach for the management of small engineering projects seems to gravitate towards scaling of the efforts based on the type of project rather than skipping any of the activities. Finally, apart from a fit for purpose approach represented by scaling and not skipping, more attention should be paid in general to a thorough development of the front-end phases and the formation of the project team should be more carefully done in order to be successful in the management of the small projects.

Acknowledgement

We are grateful to all 88 respondents who participated in the survey or the interviews. Without their contribution this study would not have been possible. The authors would like to thank Sara Kraus MSc for performing the interviews at the refinery of the multinational oil company. We are also most grateful to the members of the Special Interest Group Project Management of the NAP Netwerk and then more specifically the Fit-for-purpose group for many valuable interactions and exchanges of experience and views. These have most definitely contributed to improving the outcome of this research. Finally, we are indebted to Ir. Jeroen Wagenaar for consistently fulfilling the role of the most demanding client, which has contributed to coming up with a result after all.

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3.5 WEST COAST MAINLINE

In this section we will describe the story of another large infrastructure project: the West Coast Mainline (WCML). This brings us also to a different institutional setting since the project is located in the United Kingdom. The information presented in this chapter is partly drawn from the interviews held and report written for the EU funded NETLIPSE project. The information and analysis was also used as a basic for chapter 4. 'Appearances and Sources of Process Dynamics; the Case of Infrastructure Development in the UK and The Netherlands' in the book Managing Complex Governance Systems (Teisman, 2009).

In the Dutch cases we have more or less centred on the elements of complexity. In the Swiss project we have added some first insights into the management of complexity as well. We will continue to do so in the case of the WCML where we will show how major changes in the institutional context along with major differences in management have lead to completely different results. But we will start of with presenting the facts and figures of this highly dynamic project.

3.5.1 Project Facts & Figures and stakeholder constellation

Project Purpose and Project Definition

This section represents the status of the project as at the start of 2007.

The West Coast Main Line (WCML) is Europe's busiest mixed-use railway (see figure 3.23). It links London with major urban areas in the northwest. More than 2,000 trains a day use the line, transporting both passengers and freight. The train services consist of long distance, regional and local (short distance) commuter trains, along with substantial freight traffic. The latter represents around 40% of the total rail freight traffic movements in the UK. The WCML relates to the 650 km main line between London Euston and Glasgow, which also serves the West Midlands (Birmingham), the North West (including Manchester & Liverpool) and North Wales (with connections to & from Ireland). Presently, there are some 22 million passenger-train km a year and 6 million freight-train km a year.

The objectives of the WCML project have shifted several times. The current objectives (2007) were formulated in the WCML Strategy report of June 2003:

1 The upgrade had not only to address the major backlog of maintenance and renewals on the route, but should also ensure value for money;
2 The upgrade should also establish sustainable and cost effective maintenance regimes;
3 The upgrade should provide additional capacity for anticipated growth in passenger and freight business over the next 20-30 years, with substantially faster and more competitive journey times between major cities served by the West Coast route;
4 The upgrade should also provide an improved level of performance, safety and reliability which will, in turn, help the railway regain lost market share and increase the role it can play in the national and regional economies;
5 Finally the upgrade should achieve above the objectives on a 'railway in use' allowing for the continuation of freight and passenger services during the rebuilding and enhancement work.

In meeting the above objectives, the project will deliver a modernised and sustainable West Coast railway. The success of the project will also depend on key outputs being achieved: for example, a 125 mile/h route between London and the West Midlands, Manchester, Liverpool, the North West, North Wales and Scotland, exploiting the capability of tilting trains to deliver much faster journey times. There will be capacity for 80% more long distance passenger trains than today and for up to 60-70% more freight paths than at present.

Fastest journey times to/ from London Euston:	Pre-Project	May 2006	Post-Project (Expected, Dec 2008)	Reduction in journey time (Pre-/ Post-Project)
Birmingham New St.	1h 39m	1h 21m	1h 18m	-21,2%
Manchester	n/a	2h 05m	1h 59m	-
Liverpool	n/a	2h 09m	2h 06m	-
Preston	2h 25m	2h 10m	2h 07m	-12,4%
Glasgow	5h 06m	4h 24m	4h 15m	-16,7%
Number of fast line train services to/from London per hour:				
Peak time	7	11	13	
Off peak	5	6,5	11	

Table 3.2: WCML Frequency

Figure 3.23: West Coast Mainline

Facts and Figures

Renewal elements:

- Track works: 780 miles of track (out of a total of 1,660)
- Bridges: 30 spans
- Number of stations: 20 intercity & 30 regional/ local

Finance

The first calculations of the costs of the upgrade made by Railtrack (RT) went no higher than £ 3 bn. More realistic estimations at the beginning of the 2000's indicated that a renewed and modernised line might well cost in the region of some £13 bn. plus. Government, as part of an agreement, approved the project budget based on the content of the June 2003 WCML Strategy report. The budget was set at £9,9 bn. (2002/03 price level). Cost control has been achieved and the project has been kept well within this limit. By joint assessment of cost reduction opportunities, value maximisation and scope control, the current baseline amounts to £8,3 bn. (2005/06 price level).

Although the UK rail industry has been privatised since 1994, it is still reliant on substantial public subsidy for both capital investment and ongoing revenue support.

The funding flows according to figure 3.24.

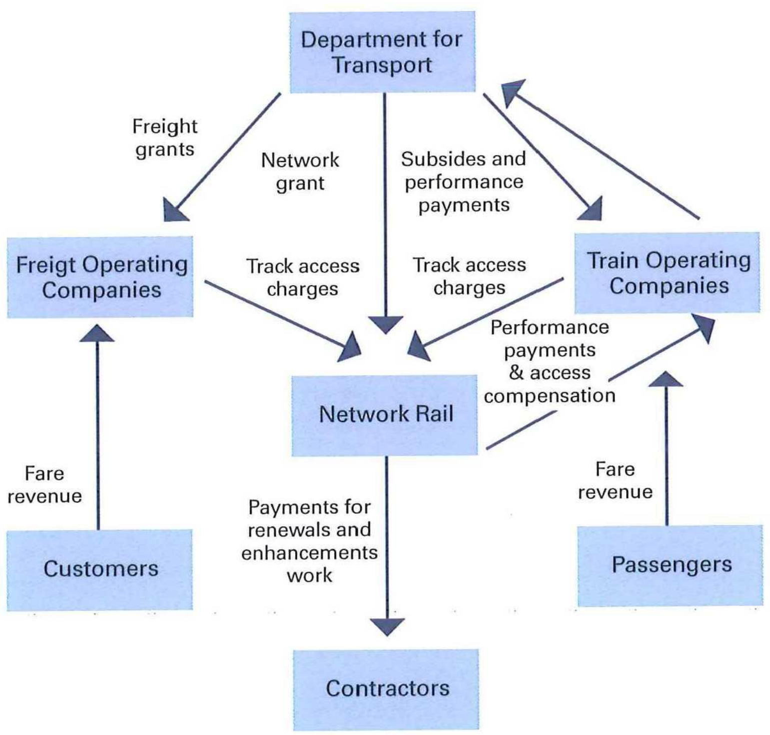


Figure 3.24: Funding flows for the West Coast Programme

Planning

Present stage of project (1 January 2007)	Approximately 2/3 completed (final 1/3 completed by the end of 2008)
Time of decision to build (go/no go decision)	Spring 2002 (present project)
Time of start of construction works	2002 (earlier work started in 1998)
Time of delivery	December 2008 (complete project)
Time of begin operations	Staged between 2004 – 2008: Sept 2004: London Euston – Crewe Dec 2005: London Euston – Glasgow Dec 2008: All

Contracting

Network Rail has a formal procurement and contracting strategy:

- EU and UK regulations are the basis.
- The preferred contracting option is to enter a series of contracts split by discipline with the contract deliverers, rather than to main contractors – who then sub contract the majority of work and in effect act as Construction Managers.
- The preferred forms of contract will be either fixed price, lump sum or 'bids of quality with re-measure'.
- Due to the nature and present time scales each contract will need to be reviewed independently to determine the form of contract.

Organisation

Given the high profile nature of the project, the importance of the route and the high level of expenditure, the government decided in October 2001 to take the strategic lead for the project through to completion, with Network Rail being responsible for the delivery of the infrastructural aspects.

The governance of the project is managed through a Project Board. See figure 3.25 for the project's governance arrangements in December 2002. This Board is made up of Network Rail, The Strategic Railway Authority (SRA), and Office of Rail Regulation (ORR) Board Members and Network Rail and SRA West Coast Directors, dealing with strategic decision-making. Reporting to this Board is a Project Development Group (Network Rail, SRA & ORR) dealing with detailed decision-making on delivery, costs, resources and operational issues and a WCML Joint Board (train and freight operators) considering operational performance and maintenance issues. Reporting to the Development Group are Network Rail's and SRA's West Coast Teams.

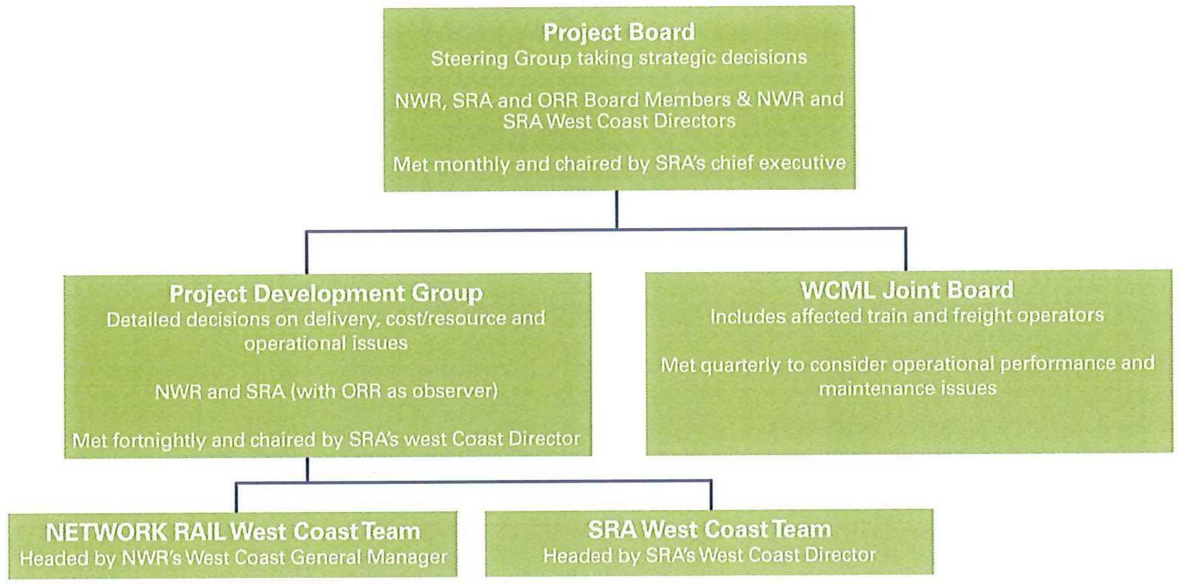


Figure 3.25: WCML project's governance arrangements (December 2002)

Stakeholders: internal and external

The first group of internal stakeholders are those parties within the rail industry, or those directly associated with it, that play a direct role in the delivery of the project and are directly affected by its outputs. These parties comprise the following, see next table.

Internal Stakeholder:	Responsibility:
• Government (represented by the SRA prior to Summer 2005, DfT after summer 2005)	Project strategy definition.
• Network Rail, a not-for-profit organisation	Infrastructure works delivery.
• Passenger & freight train operators	Train service delivery (timetables), revenue generation and customer service.
• Office of Rail Regulation (ORR) (prior to July 2004: Rail Regulator)	Protection of the interests of users and the promotion of competition, efficiency and economy in the provision of railway services.

Each of these parties has a major responsibility in the project. The project was presented as "Britain's railways working together".

External stakeholders are the bodies that are indirectly affected by the outputs of the project; that can influence funding or support for the project; and, in some cases, which have a statutory right to be consulted in the process of development of the

project. In total there are over 700 organisations identified and the Department for Transport and Rail (DfT) contacted each of them individually.

External stakeholders are separated into 2 groups: a group which the West Coast Team has to consult from a statutory standpoint, which like the Passenger Transport Authorities and Executives have responsibility for the delivery of regional transport services in the major provincial cities. The West Coast Team does not have to consult the second group from a statutory responsibility (none of the bodies in the second group has a 'veto' over the content or delivery of the work being undertaken, except in for few local planning issues). However, consultation of this group of stakeholders is highly desirable, because it is vital to ensure that their local knowledge is aligned with the overall direction of the project. Many of the bodies represent areas that would benefit by the improved services or would generate business to support the investment.

In order both to inform and to seek agreement to the strategy underpinning the revised project scope and outputs, a consultation document was published in October 2002. This was provided to all parties in both the first and second groups. Details of this activity and the results of the consultation exercise are contained in the final WCML Strategy report published in June 2003.

There continues to be an ongoing dialogue with external stakeholders, to keep them abreast of developments at the side of the WCML, but also to consult with them over the more detailed aspects of the project as they emerge, and to receive early indications about developments in the stakeholder context that could be useful or prejudicial to the process of upgrading. To facilitate the link with such bodies, a number are grouped together. An organisation entitled 'West Coast Rail 250' represents many of the local authorities along the line of route and also has a Parliamentary branch enabling a direct dialogue with Members of Parliament. DfT, along with Network Rail and the train operators, continues to meet this body on a regular (bi-monthly) basis.

3.5.2 Storyline West Coast Mainline

Built in stages over three decades from the 1830s. The description of the reconstruction of the line starts in 1984.

In the case of the West Coast Mainline there is a variety of crucial events. We can distinguish three institutional periods starting and ending with main events. In this section we summarise the key elements in which we illustrate the complexity and how it was managed.

Round 1 Locked in a non-innovative British Rail *1984 - 1990*

British Railways was created in 1948 out of ailing private regional rail companies which were bankrupt following the stresses of the Second World War, British Rail was for a long period the manager of the West Coast Mainline. Although the route was extensively renewed and upgraded as part of major electrification investment schemes, work carried out since has been limited. Although British Rail recognised that further renewal work was necessary and contemplated options during the 1980s, the route had not seen any significant renewal since its electrification in the 1960s and 1970s. This period can be described as 'the public monopoly period'. British Rail was in charge, had a lot of 'tacit' knowledge of what should be done with the West Coast Main Line, but did not have the ability to put this into action. The main objective seemed to be 'preventing the system from breaking down'. Money was put where the biggest impact on reducing failures with severe effects were expected. The route needed renewal in the 1990s because, with its infrastructure ageing, train service reliability was deteriorating, leading to a fall in demand. Plans for upgrading the line were made, but were never implemented.

This, combined with the overall global wave of privatising and market orientation, led to the erosion of support for the nationalised British Rail and stimulated people to look for other (and therefore private) approaches. In the mid 1990s the breakup and privatisation of British Rail was completed. This ended a period of stagnation and technical degradation on the WCML.

Round 2 Chaos in the private domain: The story of broken dreams *1990 - 2001*

The Railway Act 1993, introduced by John Major's Conservative government, started the privatisation of British Rail. British Rail was broken up into over 100 separate companies and sold off. By doing so the Railway Act 1993 created a complex structure for the rail industry.

Railtrack (RT) took over ownership for all track, signalling and stations and was hastily privatised in 1997. In 1996, the Passenger Upgrade 1 (PUG1) contract was agreed between Railtrack (RT) and the Office of Passenger Rail Franchising (OPRAF) to modernise the rail infrastructure with existing technologies. RT then owned and was responsible for operating, maintaining, renewing and developing the rail infrastructure. Virgin Rail Group (VRG) a joint-venture of the Virgin Group and the Stagecoach Group won the franchise to operate long-distance passenger trains on the WCML in 1997 until 2012.

However, Virgin Rail Group (VRG) wanted to go further than PUG1. It agreed with RT a renewal and upgrade programme known as Passenger Upgrade 2 (PUG2) that allowed higher speed trains with a higher frequency. VRG took the view that significant increases in capacity would be needed for its franchise. After being approved by OPRAF and the Rail Regulator, PUG 2 was signed in 1998.

RT and VRG were confronted with the worn-out line and started enthusiastically with plans for high quality upgrading. Their plan was reliant on new technology, such as moving block signalling to increase capacity and train speeds at low cost. The plan drawn up by Railtrack estimated that the upgrade would cost £ 2 bn. and would by ready by 2005 (in two phases: 2002 and 2005). The ambitions were high: the upgrade would cut journey times from London to Birmingham from 1hr 40 minutes to 1hr. This would be achieved through increasing the line speed to 225 km/h. VRG ordered a fleet of new tilting trains that would be capable of running at 140 mile/hr, with delivery planned for May 2002.

Both the private newcomers, Railtrack and Virgin, were anxious to show how an innovative, quick and smart private sector could deal with the neglected system. They focused mainly on financial return, delivered through innovation and market expansion. These objectives were at the core of the contracts between RT and Virgin to upgrade the line – the core purpose was to make money, rather than deliver transport improvements. The two private parties however seriously underestimated the restrictions that came with the existing (lack of) quality on the line.

The programme ran into difficulties. RT's estimates of the expected final cost increased rapidly and in December 1999 Railtrack decided not to use moving block signalling, as the technology was not sufficiently mature. Other factors, including West Coast contract liabilities, created a financial crisis for RT which resulted in October 2001 in the government putting RT into Railway Administration. In effect Railtrack was bankrupt. VRG's procurement of its new tilting trains rolling stock also fell behind schedule. With hindsight the plan was doomed from the beginning, since Railtrack had not assessed the technical viability of 'moving block signalling' prior to promising the speed increase to Virgin and the Government. Moving block signalling had never been implemented on such a complex line as WCML before. It soon became apparent to experts that the technology was not mature enough to be used on the line. The bankruptcy of RT in 2001 brought a reappraisal of the plans whilst the original costs of the upgrade continued to soar. The revised estimates indicated that the line upgrade would cost a total of £ 13 bn. and would be ready by 2008 with a maximum speed of 200 km/h for tilting trains. The ever-present 'phantom' of cost overrun and delay in infrastructure was beginning to re-emerge.

We have referred to the PUG2 contract. In interviews, we heard a firmly negative judgement about the contracting by Railtrack to Virgin in PUG2. Two quotes taken from the interviews:

> *"Railtrack was a bank, not a railway company."*
> *"Contractors had basically Railtrack's cheque book."*
> Manager West Coast Mainline, interview 2006.

Due to ignorance and lack of local knowledge of the rail system the two parties managed to make highly ambitious, but unrealistic (in retrospect) plans and contracts, hoping for the big money prize. In the process they created enormous cost overruns and delay, contributing significantly to the fall of RT and the need for a new project definition by public authorities. A further dramatic moment occurred with the railway accident at Hatfield in 2000, where the lack of competent asset management led to the derailment of an East Coast High Speed Train. In order to deal with the perceived risks, RT imposed over 1200 emergency speed restrictions on its network, creating enormous delays and severe losses for the service providers. This was a classic moment of crisis. The lack of asset knowledge in RT became fully apparent to the nation.

Secretary of State for Transport, John Prescott decided that SRA, a non-departmental public body responsible for providing strategic direction for the British rail industry would impose a solution for this crisis. This means that political intervention led to the return of Railtrack and its assets into the public sector, as hastily as it was previously handed over to the private sector.

Virgin renegotiated their contracts with the government from high risk, high return to low risk, low return.

Round 3 Reinventing public-private cooperation: A realistic approach 2001 - 2007

In Autumn 2001, Government took direct control of RT and its assets. As already noted, Secretary of State for Transport, John Prescott decided that Strategic Rail Authority SRA, should impose a solution. The renewed role for government did not lead to a return to the British Rail regime since many aspects of privatisation had proved to be successful. SRA concluded that abandoning the project was not viable. 80% of the works were needed to replace ageing infrastructure and cancelling works already contractually agreed would incur substantial financial penalties. The project could however be respecified with deliverable outputs and a clear positive business case. In 2004 the SRA in its turn was abolished. Its strategic tasks were transferred to the Department for Transport (DfT), as was the letting of contracts for passenger franchises. The operation of the infrastructure remained with Network Rail, the successor of Network Rail.

The WCML Strategy report, published in June 2003 addressed the need, not only to repair and renew the railway to ensure its continued operation, but also to provide the capacity and capability for high-speed long distance trains. Moreover, it allowed the continued provision of local and regional passenger services and the serving of the important freight market. It was decided that proven technology was to be used wherever possible: the project had a huge scale and could not continue to be burdened with the uncertainties in timescales and costs associated with the development of new technology. A business case was built, leading to clear insights about the revenues of upgrade activities and working as a communication instrument

with all parties involved. Finally the predictions of the cost of the project were brought back from £ 13 bn. to £ 9 bn., following further cost reductions the expected costs are less than £ 8 bn. (December 2006).

The West Coast strategy was built upon an extensive consultation with stakeholders, both within the railway industry and with other interested bodies, such as local authorities and user groups. Trust was built up and kept. Indeed, there has been overall consensus throughout over the specification and delivery of this stage of the West Coast Project. These close links have been maintained and have assisted the continued development of the route and its outputs.

The WCML Strategy report sets out three stages of project delivery. The first of these was introduced in September 2004, involving the upgrade of the line between London Euston and Crewe / Manchester. These also enabled accelerated improved services to be introduced on all key inter urban corridors, including increased frequencies and faster journey times. Trains were also permitted to operate at 125 mile/hr in tilt mode south of Crewe. The second stage was planned in 2005, when the line North of Crewe was upgraded to provide for 125 mile/hr in tilting mode. By April 2006, around three quarters of the physical work of the project was complete. Remaining key works include the enlargement of Milton Keynes and Rugby stations and the widening of the Trent Valley route (third stage).

The upgrading activities are performed mainly by Network Rail. They prepare schemes for upgrading parts of the line and announce when the line is to be closed for use. The line is out of use to a considerable extent, especially, at weekends.

Nevertheless it seems to be clear that the upgrading activities will be finished in 2008. The first Pendolino trains were operating on the WCML in 2004 and the amount of users is growing very strongly. The expectation is that, at constant price levels, revenue will triple between 2003/04 and 2012/13, from just over £ 300 mln. p.a. to £ 1 bn. p.a. and that freight traffic on the route will also grow strongly. Looking at these achievements one could say "all's well, that ends well", but there was some significant waste in the early, uncontrolled, days of the project, mostly borne by the loss in the share price of the private infrastructure controller, Railtrack.

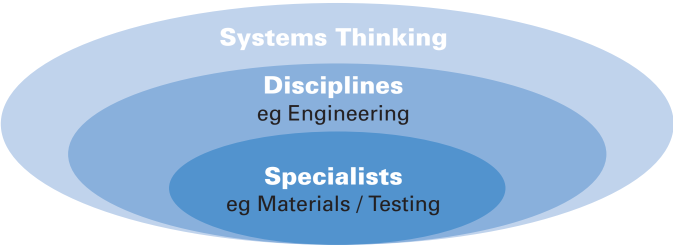
The approach in this third round of upgrading was different from the previous rounds. The strategy was build up in consultation with shareholders within the industry and with stakeholders such as local authorities and user groups. The passenger and freight operators, who had been excluded from contributing to the project, became heavily involved and provided the SRA with an immense amount of practical advice and guidance. This plan was not made in splendid isolation as was done before, but in interaction with the whole rail industry and important stakeholders. This led to an arrangement beyond the boundaries of the public and private domain that was based partly on control but for a large part on building and maintaining trust.

This led to a complex institutional arrangement once more. This time, however the managers in charge were able to deal with this complexity. They focused on desirable outcomes, managed support and dealt with the continuing institutional change, like the abolition of SRA and the division of its tasks between DfT, Network Rail and ORR.

This third period is still going on and has led to an intriguing combination of public guidance and private production. An effective network of parties has been built up capable of dealing with the network characteristics and interdependencies of the physical rail network and future delivery. On the one hand there were clear formal divisions in tasks and responsibilities, but on the other there were effective informal networks and methods of collaborative planning; building up sufficient knowledge and support.

How Systems Thinking contributes to Systems Engineering.

Systems Thinking is an essential skill for Systems Engineers which is shared with many disciplines and provides a key intellectual underpinning for Systems Engineering.



Benefits of Systems Thinking

Systems thinking provides a rigorous way of integrating: people, purpose, process and performance and

- relating systems to their environment.
- understanding complex problem situations
- maximising the outcomes achieved.
- avoiding or minimising the impact of unintended consequences.
- aligning teams, disciplines, specialisms and interest groups.
- managing uncertainty, risk and opportunity.

Background – Systems thinking:

- is complementary to other ways of thinking e.g. scientific reductionism which focuses on a component itself rather than its relationship with others.
- applies to any discipline or practice e.g.
  > *Social Science, Management, Engineering, Biology and Pure Science.*
- origins are distant > 2500yrs.
- recent cross disciplinary groupings include:
  > *Learning Systems, General Systems Theory, Cybernetics, System Dynamics, Soft Systems Methodology, Critical Systems Thinking, Complexity Theory and Systems Engineering.*

This leaflet is intended to provide an introduction to Systems Thinking and how it relates to Systems Engineering. It is grounded in a review of definitions from divers sources and related to engineering through the strong systems heritage at the University of Bristol and recently validated at INCOSE AA 09

Further information about Systems Thinking can be obtained from the following:

http://www.bristol.ac.uk/engineering/systemscentre

http://openlearn.open.ac.uk/mod/resource/view.php?id=183660

http://en.wikipedia.org/wiki/The_Fifth_Discipline

http://www.incoseonline.org.uk/Program_Files/Publications/Publication_Search.aspx?CatID=Publications

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For further information, advice and links to helpful websites go to: www.incoseonline.org.uk
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What is Systems Thinking?

How does it relate to Systems Engineering?

Systems Thinking is a way of thinking used to address complex and uncertain real world problems. It recognises that the world is a set of highly interconnected technical and social entities which are hierarchically organised producing emergent behaviour.

It is founded on three key ideas:

Layers

Loops

'New process*'

*See panel 4

Open University Definition

Systems thinking enables you to grasp and manage situations of complexity and uncertainty in which there are no simple answers. It's a way of learning your way to effective action by looking at connected wholes rather than separate parts. It is sometimes called practical holism.
Open University

Business Management Definition

Systems thinking is a framework for seeing interrelationships rather than things, for seeing patterns rather then static snapshots. It is a set of general principles spanning fields as diverse as physical and social sciences, engineering and management.
Peter Senge , The Fifth Discipline

A Framework for Systems Thinking

Integrating models	Context Belief systems Perceptions Viewpoints
Parts, wholes and layers **Connections and loops** **Processes** How change happens	Boundary (open or closed) Holon / Hierarchy Emergence Synergy Relationships Communications Feedback / Foresight Learning loops / Life cycles Purpose Requirements Progress / Evidence Opportunity and risk

Parts and Wholes in Layers

- A holon, is anything considered, at the same time to be both a part and a whole.
- Components are seen as being organised in hierarchies of Holons, which have emergent properties that derive from the co-operation of the parts. An example of a soft system is you. You are a part of: your family, your neighbourhood, your country etc and yet you are also a whole made up of parts or sub-systems i.e. skeleton, nervous system etc..
- Inside and outside are defined by boundaries.

Connections and loops

- The behaviour of a system cannot be determined by consideration of the parts in isolation
- The relationships between the holons and their ability to communicate determines the emergent behaviours and the possibility of unintended consequences.
- It is generally useful to think in terms of feedback and feed-forward loops to create learning and foresight and so to manage the processes involved.
- Systems Dynamics is one way of simulating processes.

Context

- The context for a system is its environment sometimes referred to as its meta-system or meta-holon.
- An open system is one which continually interacts with its environment, where as a closed systems is assumed to be self contained.

'New process'

The phrase *'new process'* is used to identify a holistic view of process, which describes natural, people and physical processes in a consistent way. This helps to integrate all types of system. It also helps to align stakeholders to purpose and reduce a substantial source of complexity.

Processes define 'How change happens'.
This definition includes naturally occurring change as well as man made.

Answers to the questions 'who', 'what', 'why', 'where', 'when' and 'how' enable us to describe a process in terms that are applicable to both people and physical processes. 'Why' identifies the **purpose** and hence drives the change in 'who', 'what', 'where' and 'when' through the transformations identified by 'how'.

The output of a process may be a product but that in itself has a **life cycle** and is also a process.

Integrating models

Systems thinkers use models to make sense of complex problems.

A Systems Thinker's Goal is to fulfil Purpose

- **Purpose** is the result, outcome or effect that is intended from the system. Purpose is the answer to the question: Why are we doing this process? It is the driver of intended change and defines unintended consequences.
- A **requirement** is an unambiguous statement of the capability that the system must deliver. A requirement is expressed in operational terms (what the system will do) rather than solutions (how the system will do it).
- **Effective requirements can only be produced once purpose is clear.**

Systems Thinkers recognise that -

People:

- through their perceptions, determine purpose, use process to deliver performance and use change in patterns to measure progress;
- understand the need to be good team players;
- are our customers, stakeholders, designers, developers and users;
- have varying levels of rationality, intentionality and even perversity;
- have **belief systems, perceptions and viewpoints** developed through culture, training and views of best practice within disciplines;
- are not separate from the problem, project or programme with which they are engaged. They are an integral part of System Thinking models.

Performance measurement:

- evidence should be used and suitably monitored to ensure that the purpose of the system is being fulfilled;
- will need to be a combination of quantitative and qualitative measures that communicate a historical and forward view of performance
- is often done inappropriately because people choose to measure what is easy to measure, rather than what needs to be measured to ensure that purpose is delivered.

Uncertainty:

- is an inevitable attribute of a complex system.
- is managed by first recognising what we do not know and expecting unintended consequences particularly when new systems are being introduced or systems are used in a different context.
- requires the inclusion of feedback and feed-forward learning loops in the process to minimise its impact.