Modelling Project Complexity

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# Abstract

**Purpose –** The purpose of this paper is to enhance the understanding of what project complexity is, what drivers and factors that influence complexity, and how consequences for organizational performance can be assessed.

**Design/methodology/approach** – The research is explanatory and based on literature review, model development, interviews and case studies. The model is validated through a case study.

**Findings** – The findings is a model for identifying and analyzing complexity drivers and complexity factors. The model starts with generic complexity drivers such as ambiguity, uncertainty, unpredictability and pace. These drivers are in each project influenced by nature and by socio-political, economic and technological surroundings to result in complexity factors that are specific to the project analyzed. The model can be used to analyze project complexity and to define requirements for the organization of the project and guidelines for the execution.

**Research limitations** – The research is limited to large projects with a technical delivery of some kind of facilities.

**Practical implications** – The model can be used to assess the required capability of the organization for successful project execution.

**Originality/value** – The contribution of the research is a new model for understanding project complexity. The distinction between project complexity drivers and factors is essential as well as the taxonomy for the factors building on and adding to already published research.

**Keywords:** Project complexity, project management, organizational capability, organizational performance, modelling

**Paper type:** Research paper.

#  Introduction

The research community on project management has over the last decades had a strong focus on how to achieve success in the delivery of projects and how to obtain successful project management. As an outcome of these efforts an abundance of methods and tools are available for project management. A dominant source is The PMI Guide to the Body of Knowledge (PMI 2013) which defines a set of “good” practices for managing most of the projects most of the time. Experience shows that as long as certain preconditions for planning and handling uncertainties are met, these established project management methods may function well. But experience also demonstrates that these approaches are challenged as projects are becoming more complex and subject to higher levels of uncertainty. According to Brady and Davis, the inability to manage increasing project complexity is generally recognized as a main reason why many projects fail to meet their targets on time, cost or quality (Brady and Davis 2014). They further claim that dealing with complexity and uncertainty in an era of rapid change and unpredictability requires a different approach than traditional project management can offer.

Brady and Davis’ reasoning is in line with Maylor et al. (2008) who criticize the dominant paradigm within project management for lack of contingency and for giving too little consideration to the management context, and in particular to the complexity of the project and the management task (Cicmil et al. 2009). Much of the literature within the field is said to be highly prescriptive and to ignore the project context. They further argue that many projects should be considered as complex adaptive systems. Such complex systems are characterized by path dependencies and are highly sensitive to initial conditions. One can therefore not assume regularity, separability of elements and clear cause-and-effect relationships. According to Shenhar (2001) the literature and existing bodies of knowledge can be characterized as dominated by ”a Tayloristic one-best-way approach” , which is said to be inconsistent with the contextual diversity that managers have to deal with.

Following the arguments of these and other authors two questions stand out as central. The first is how project complexity can be characterized, or even measured, in a systematic way. The second is how to match the capability of the project organization to the complexity of the actual projects.

To answer these questions, there is a need for a model that covers both characterization of the complexity and the performance of the project organization. The literature describes many approaches to modelling project complexity. However, they do not adequately cover organizational performance. This paper presents a model capable of handling both, and it demonstrates its applicability through a case study.

Focus in this paper is thus project complexity as experienced from the project management organization, with special emphasis on organizational complexity.

# Literature review

There is a vast literature on complexity. In this paper we will give an overview of central contributions on project complexity. The ambition is not to discuss complexity or complexity theory in more general terms.

Many authors have studied projects, defined taxonomies, and developed methods and tools to model and analyze project complexity. A common viewpoint in most contributions is that complexity is not a direct function of size, and that a complex project is something more than simply a big project (Williams, 1999). Apart from this there seems, however, to be no agreed upon understanding of what project complexity really is.

One of the first to conceptualize project complexity is Baccarini (1996), who distinguished between two main components of complexity: organizational and technological. He reviewed these two components from two perspectives: differentiation and interdependencies. For organizational complexity, differentiation and interdependencies stem from the number of organizational units, the relations between these and the type of tasks they handle. For technological complexity, differentiation is a function of number and diversity of inputs/outputs, actions/tasks to be produced and the number of specialties involved. The interdependencies have to do with activities within a network and between tasks, teams, technologies, or inputs.

Another early contribution comes from Williams (1999, 2002). He combined Baccarini’s two components into *structural complexity* and adds *uncertainty* as a second main component. Based on Turner and Cochrane’s (1993) goals and methods matrix, he then subdivided uncertainty into uncertainty in goals (ends) and uncertainty in methods (means). Figure 1 summarizes Williams’ taxonomy (1999).



*Figure 1: Taxonomy of project complexity (Williams 1999).*

Shenhar (2001, p 398-99) suggested a framework of four levels of uncertainty and three levels of complexity. His four levels of technological uncertainty are based on the degree of new versus mature technology involved: *Low-tech* – involving implementation of familiar technologies, *Medium-tech* – resting primarily on existing technologies but also with a limited amount of new technologies, *High-tech* – which constitute the first use of new, but existing technologies, and *Super High-tech* – which require the development of new technologies. His three levels of complexity are: *Assembly project* – defined as the collection of components and modules into a single unit, *System project* – which consists of many subsystems and is capable of performing a wide range of functions, and *Array project* (or Program) – described as a diverse collection of systems that function together to achieve a certain purpose.

Jaafari (2003) studied project management with a focus on complexity and change. Depending on the levels of these two factors he defined four types of project management models: (1) Ad-hoc model, (2) Bureaucratic model, (3) Normative model, and (4) Creative-reflective model. He argued that the fourth model, which relies on the principles of self-organization and the insight and competence of the players in the project value chain, is most suited for projects conceived and delivered within a complex society.

Hass (2009, p. 42) discussed complexity models and defined complexity as *“characteristics that make a project unpredictable and dynamic”*. Whitty and Maylor (2009, p. 305) characterized a complex system as “*a system formed out of many components whose behavior is emergent*”. Snowden defined complexity in relation to systems (Cognitive Edge Network, 2013): “*A complex system is a system composed of interconnected parts that as a whole exhibit one or more properties (behavior among the possible properties) not obvious from the properties of the individual parts.*” These definitions add an important qualification, namely that a system exhibits properties that are not evident from the properties of the single parts. This also allows us to distinguish between a complicated system and a complex system. An aircraft is a complicated system as it consists of thousands of parts. However these parts are all known, precisely defined and capable of being catalogued, as are all of the relationships between the parts. A human system, however, is complex as components and their interactions are changing and can never be quite pinned down (Snowden, 2002).

The system view of project complexity that Snowden and Boone (2007) and Hass (2009) took, is also supported by Brady and Davies (2014), who made a distinction between structural and dynamic complexity, where structural complexity has to do with the arrangement of components and subsystems into an overall systems architecture. This architecture comprises *the system produced*, *the producing system*, and *the wider system*. The system produced is the delivery of the project. The producing system contains a technological (the process of producing) and an organizational part (the project organization), whereas the wider system includes the owners and the users of the produced system. The dynamic complexity of a project is a function of changing relationships between system components and between the project and its environment and has to do with unpredictable situations and emergent events that occur over time. Brady and Davies also pointed to the fact that the two complexity dimensions may occur independently. A project can have a high degree of structural complexity with a low level of dynamic complexity.

Bosch-Rekveldt et al. (2011) commented on Shenhar’s classification and pointed to the fact that complexity in reality is treated as a «black box», because what factors that cause complexity is not further detailed. Even if Shenhar’s and other contributions demonstrate the importance of complexity, they therefore argue for the need of a more detailed and applicable framework for characterizing complexity in large engineering projects, which can be used to adapt the front-end development phase of engineering projects to the particular complexity. After going through a large number of scientific contributions, they identified a total of 40 elements contributing to project complexity, among them also a number of “softer aspects”. These elements were then sorted into three main categories; technical, organizational and environmental – named the TOE-framework. After supplementing the literature study with a few case studies, they found that these categories each contained a number of subcategories: *Technical subcategories*; goals, scope, tasks, experience and risk, *Organizational subcategories*; size, resources, project team, trust and risk, and *Environmental subcategories*; stakeholders, location, market conditions and risk. They further state that assessing a project’s complexity is a subjective phenomenon, in which previous experiences play an important role.

Lessard et al. (2013) build on the TOE framework and other published works and launched a concept which they called the *House of Project Complexity.* Basic in their reasoning is a conceptual distinction between project features that are inherent to project opportunities – *inherent features* and those features that are dependent on the selected project concept, governance structure and execution process – *architectural features*. A further contribution is a separation of the inherent features into a technical and an institutional domain. The technical domain is again split into factors having to do with *location* (e.g. geography, geology and climate) and *elements* (e.g. number, interdependencies and diversity). The institutional features have to do with the project’s social and political environments and are split into the main categories *framework* and *interests*. *Emergent features* then arise from the interaction of inherent and architectural features as the project is developed and managed over time. The term emergent here refers to system theory and can be understood as the unpredictable consequences resulting from interaction between different parts of the system. The house of project complexity is depicted with three levels, where the roof represents the emergent properties that may affect project outcomes. The ground floor of the house contains the fundamental technical and institutional features of the project, whereas architecture is the mediating layer between the features and the emergent properties.

Geraldi (2008) introduced a “thermometer of complexity” suggesting a method for assessing the perception of complexity in projects based on the concept of “*Pattern of Complexity”.* This Pattern of Complexity is the minimum manageable context of complexities within a project. Actions to reduce or deal with complexity should take into account both the singular characteristics of complexity, as well as its pattern. Three main sources of complexity are connected with faith, fact and interdependence. *Complexity of faith* refers to complexity arising from the creation of something unique or working with new problems and as such also with high uncertainty. Keywords are immaturity and dynamics. *Complexity of fact*, on the other hand, has to do with large amounts of interdependent information, and where decisions may be made without full overview or understanding. Characteristics are high number and interdependencies. Problems associated with interfaces between systems or locations of complexity are termed *complexity of interaction*, and take into account characteristics such as neutrality, ambiguity and multicultural aspects. All three complexities have both a technological and a commercial dimension. A similar line of thinking is presented by Girmscheid and Brockmann (2008). They have studied large-scale engineering projects and define the overall complexity as consisting of task complexity, social complexity, and cultural complexity. In a later paper, Giraldi et al. (2011) have done an extensive literature survey on complexity, where the aim is to integrate the findings and frameworks of complexity of projects into an overall umbrella typology. They claim that the work that has been done in this field so far can be synthesized into an overarching schema in five complexity dimensions: structural, uncertainty, dynamics, pace and socio-political. *Structural* complexity is the most mentioned type in the literature, focusing primarily on three attributes: size, variety and interdependence. *Uncertainty* relates to current and future state of elements, and also how they interact. *Dynamics* refers to changes in projects, such as changes in specifications or goals. Changes may also occur between participants in the project as well as in the relation with stakeholders. *Pace* is described as an important type of complexity, having to do with speed, urgency and criticality of time. The last of the main complexity dimensions has to do with *socio-political* factors such as stakeholder involvement, conflicting interests, alignment of opinions and transparency or hidden agendas. This factor also includes personal matters, such as having to deal with difficult personalities. These five dimensions present individuals and organizations with choices about how to respond in terms of business case, development, strategic choice, process choice, managerial capacity and managerial competencies.

The Treasury Board of Canada Secretariat (2013) has published a comprehensive method for assessing project complexity. The assessment is based on scoring on a number of questions and aggregating the scores to an overall complexity score. The questions are divided into seven sections or categories:

* Project Characteristics (18 questions)
* Strategic Management Risks (6 questions)
* Procurement Risks (9 questions)
* Human Resource Risks (5 questions)
* Business Risks (5 questions)
* Project Management Integration Risks (6 questions)
* Project Requirements Risks (15 questions)

Also Hass (2009) has developed a model for assessing project complexity based on eight dimensions: cost/duration, team composition and performance, urgency/flexibility, problem/solution clarity, requirements volatility, political sensitivity, level of organizational/commercial change, and risk external constraints and dependencies. She identifies six different sources of project complexity: details, ambiguity, uncertainty, unpredictability, dynamics, and social structure.

Managing complexity is related to the competence and capability of the project organization. The Global Alliance for Project Performance Standards (2007) has developed a framework for performance based competency which addresses two levels of project manager: junior project manager (Global 1) and senior project manager (Global 2) that are differentiated by the complexity of the project. The framework consists of three elements: (1) performance-based competency standards for the role of project manager, (2) a detailed approach to differentiating the two roles or levels based upon project management complexity, and (3) supporting material to aid in the application of the standards.

Crawford (2005) has developed an integrated model for identifying competence components. She distinguishes performance-based components (demonstrable performance) from attribute based components (knowledge, skills, core personality characteristics).

Azim et al. (2010) discussed soft skill in complex projects. They underline the importance of managing people in complex projects due to people being one of the more volatile and important contributors to project complexity. They also point to the fact that complexity is very much influenced by a practitioner’s experience, as well as the project context. This supports the authors’ view that the project complexity is a function of project characteristics and the organization managing it.

The literature survey shows that there is a varied view on what project complexity is and how it can be assessed. From the early work of Baccarini (1996) considering only technological and organizational complexity, other authors have contributed to the understanding of project complexity by taking uncertainty, external factors and different kinds of ”soft” aspects into account.

A preliminary conclusion from the literature review is that project complexity is a function of the characteristics that make a project unpredictable and dynamic (Hass 2009). It can further be concluded that project complexity is a multifaceted phenomenon composed of many and different components: technological, organizational and environmental, which again can be characterized and subdivided in different ways. If project complexity is considered as a sum variable, it is found that this can range from very low to very high, with corresponding demands on project management. Relative project complexity can thus be defined as a characteristic of the project combined with the capabilities of the project organization. The main challenge for project management will then be to match the capability of the project organization to the overall project complexity. This conclusion supports van der Hoorn’s and Whitty’s (2016, pp 970) thinking that “*a project is an experience that arises when there is a lack of inherent capability to undertake the activity*”.

# Research METHODOLOGY AND approach

Our research objectives are to:

1. Develop a comprehensive analytical model for evaluating project complexity
2. Validate the applicability of the model using data from a megaproject on the Norwegian Continental Shelf
3. Discuss the usefulness of the model for assessing the organizational capabilities needed to manage a certain level of project complexity

That the model is analytical means that it contains a breakdown of components.

The research approach contained three steps: (1) a review of relevant project complexity literature, (2) a case study of a large project, based on qualitative interviews and available written documentation, and (3) development and testing of a model of project complexity, using data from the case study. An important part of the model is also to locate variables and attributes which can be used to assess the performance of a project organization. The Pentagon model (Schiefloe 2011) described in Chapter 4 is applied for this purpose.

From an epistemological viewpoint, the approach can be characterized as a kind of exploratory, grounded research, which means that the development of the model is based on the literature review and on the analysis of the data which were collected through the case study.

The data for the validation of the applicability of the model were collected from the development of a large subsea oil and gas development project in Norway. Background data and technical documentation on the field development were retrieved from a number of available written sources. Six participants who had been holding central positions in the preparation and organization of the project were interviewed at the company premises. Based on the written documents and the results from the first round of interviews an open ended interview guide was developed. Then ten key project managers were interviewed by use of video- or teleconferencing. Three researchers participated in each of the interviews, which were recorded for later analysis. The interviews were extensive, lasting from one to one and a half hour, and the researchers also took separate notes during the sessions.

The persons interviewed were selected based on advice from managers having a good overview of the project, and came from both the onshore and offshore part of the project organization. Most of them were still working in the company, whereas a few had retired or were now working elsewhere. Everybody who was approached, accepted to take part, but practical difficulties made it necessary to drop a couple of the interviews originally planned.

The information obtained from the interviews showed agreement on what main factors that had been important for the outcome of the project. There were, however, some differences between the pre-sanction and post-sanction phases of the project, as well as between the onshore and offshore parts, especially when it came to organizational arrangements and management styles.

# Modeling the project organization

The literature review has demonstrated that themes such as formal structure, leadership, culture, trust, interaction, communication, and other organizational dimensions are often identified as possible factors which are contributing to the level of project complexity. What is missing in most of the studies, however, is a systematic treatment of such factors by means of a comprehensive analytical model of the project organization – the producing system; how do the different factors influence complexity, and how are they related to each other?

In organizational theory there are several well-known analytical models, which have been developed for different purposes. Typically such models contain both formal (“hard”) and informal (“soft”) aspects, and are visualized as sets of concepts and the relationships between these. Some models deal only with internal dimensions, whereas others also refer to environmental factors. Well-known examples are Leavitt’s diamond (Leavitt 1965, Scott 1981), Weisbord’s Six-box model (Weisbord 1976), Nadler and Tushman’s Congruence model (Nadler and Tushman 1977), and Hatch’s “model for the concept of organization” (2006).

Burke (2011:191) said that there are five ways whereby an organizational model can be useful:

* An organizational model can help to categorize as a means of sorting bits and pieces of information into a manageable set of categories.
* An organizational model can help to enhance understanding, by locating challenges in one or several of the main categories of the model.
* An organizational model can help to interpret data about the organization.
* An organizational model can provide a common, shorthand language, which makes it easier to cooperate effectively, e.g. in a project management team.
* An organizational model can help to guide action for change.

An example of a model that to a large extent fulfills these requirements is the “systemic lessons learned knowledge (Syllk) model” (Duffield and Witty 2016, Duffield 2016). This model is based on Reason’s (1997) well-known “Swiss cheese model”, which illustrates how different kinds of barriers function to avoid accidents in complex organizations. The Syllk model replaces Reason’s defense barrier layers with the organizational elements of learning, culture, social attributes, technology, processes and technology, and illustrates how learning from past project experiences is dependent on both people-related and system-related factors (Duffield 2016, p. 272). Duffield and Witty argue that the Syllk model is relevant for analyzing how organizations manage projects, as well as to understand how they run day to day business activities (Duffield and Witty 2016, p. 429).

The Pentagon model (Schiefloe 2011) which will be applied in this paper, combines a holistic system perspective with a social constructivist theoretical approach, characterized by keywords such as interpretations, sense-making, and interests. The model is based on sociological perspectives, focusing on organizations as socio-cultural systems and as contexts for action. The general dependent variables in the model are capabilities and performance. In a project setting the relevant capabilities includes the organization’s ability to manage the project in such a way that it is meeting the defined goals, such as time, cost and quality. Five main dimensions are identified in the model (Figure 2):

* Structure (defined roles, responsibilities and authority in the formal organization, defined procedures, regulations, and working requirements).
* Technologies (different tools and infrastructures the members of the organization use or are dependent on to perform their activities).
* Culture (language/concepts, values, attitudes, norms, knowledge and established “ways of working”).
* Interaction (management, leadership, work processes and information flow connected to communication, cooperation, and coordination).
* Social relations and networks (the informal structure and the social capital of the organization, i.e. trust, friendship, access to knowledge and experiences, informal power, alliances, competition, and conflicts).



*Figure 2: The Pentagon Model.*

The relevance of the Pentagon model has been validated both through cases (Rolstadås et al. 2014a), as well as in a number of empirical studies in different organizations and organizational settings (Schiefloe and Vikland, 2009).

# Modeling the project context

Parallel to the need of an analytical model of the project organization, there is also a need for a way of modelling the project’s external context, especially for being able to address the influence of different kinds of stakeholders.

In current project management theory a distinction is often made between primary and secondary stakeholders (Rolstadås et al 2014b), where the dividing line is drawn between different ways to influence the project. Primary stakeholders are those that are involved in the activities in such a way that they can exert direct influence on decisions in the project. The primary stakeholders will in most cases include the project organization itself, the project owners, the main suppliers, the mother organization and central resource owners. In some cases it is also relevant to include certain regulating authorities. This can be called the project’s *primary environment*. The group of secondary stakeholders consists of actors or organizations that the project is more or less dependent upon for services, finance, permissions, cooperation or goodwill. Unions and customers can also be added to this layer of interests. Secondary stakeholders may sometimes have some kind of direct influence on the project, but in most cases the influence will be of an indirect character. These stakeholders constitute the project’s *secondary environment*. Many projects will also have to deal with different kinds of endogenous stakeholders, comprising the *tertiary environment.* In the tertiary environment one can find local interest groups, NGOs, media, competitors, criminal groups, and others. Whereas the actors in the primary and secondary environment are often known on beforehand, the tertiary environment may be more or less unknown, complex or incalculable.

All stakeholders, as well as the project itself, can also be subject to influences from forces in their overall *socio-political, economic and technological surroundings*. Examples of such forces may be political changes, trends in the economy, technological breakthroughs, cultural differences and changing public opinion. The model of the project’s context, with examples of different kinds of stakeholders, is illustrated in Figure 3.



*Figure 3: Overall project context.*

# 6. complexity factors and complexity Drivers

The literature review has demonstrated that there are a number of different variables that are influencing project complexity. One way of sorting this is to start by following Brady and Davies’ argument that projects should be considered as complex, adaptive systems, and their distinction between structural and dynamic complexity (Brady and Davies 2014).

Brady and Davies divide the structural complexity into three systems: the system produced, the producing system and the wider system. The system produced, or the project deliverables, may be characterized using Shenhar’s three levels of product complexity: assembly project, system project and array program (Shenhar 2001).

What Brady and Davies call the producing system may be stated as consisting of the people engaged in the project and the technologies they use. The people engaged constitute the project organization and its primary environment, as illustrated in Figure 3. The organization and the primary environment may vary along different sets of variables, demonstrating lower or higher levels of formal and informal complexity and corresponding coordination challenges. The technologies in use may be classified according to the degree of maturity, which Shenhar (2001) says may range from low-tech to super high-tech. In a specific project the technological solution and the project organization define *the project design*, i.e. what to be produced, how it is produced and by whom.

The two factors of the producing system (project organization and production technology) influence the project complexity in different ways. The gap between the capability of the project organization and the required competence to manage the project is an expression of the complexity of managing the project successfully. The larger the gap is the more complex will the project appear to the organization. This also illustrates that project complexity is a relative term; a simple project may appear quite complex to an unexperienced organization. The complexity imposed by the production technology is dependent on the degree of novelty in the processes applied and how well the technology matches the requirements from the product (system produced).

Brady and Davies restrict the term wider system to those that will be using the output of the project. The authors’ view is that this is too limited, because there are also other stakeholders and external forces that may have interest in or have the possibility to influence both project deliverables, project organization and production processes. It may therefore be better to use the term *project context*, also taking into account stakeholders and other interested parties which may influence the activities, but that are not taking directly part in the project as suppliers, owners or users. In Figure 3, these are depicted as the project’s secondary and tertiary environments. In addition, come possible influences from the wider socio-political, economic and technological surroundings. Whereas actors in the primary, secondary and tertiary environments may to a greater or lesser degree be controlled or handled by project owners and project management, impacts from the outer surroundings will usually be beyond what can be influenced.

The overall structural complexity may be understood as a product of the components involved, the nature of these components, and the relationships and interdependencies between them. These structural elements can be characterized as as *complexity factors*.

Typical for many projects are that there are many unknown and varying factors that may impact the different components and their internal relationships and as such create disturbances and uncertainties. Hass (2009:48) said that project complexity is depending on dimensions such as urgency, clarity, political sensitivity, risk, external constraints, and levels of organizational and commercial change. Several authors use the term emergent dimensions. The author’s view is that the different kinds of unknown and emergent features are some kind of temporal forces, which may be characterized as *complexity drivers*. Such drivers may have their origin inside the project organization itself, or somewhere in its environment. Based on the literature review the following complexity drivers stand out as the most significant (Geraldi et al. 2011; Hass 2009):

* Ambiguity
* Uncertainty
* Unpredictability
* Pace

Complexity drivers are creating (driving) complexity in project execution and the technical design of the project result through complexity factors. As the complexity drivers tend to be generic, complexity factors are specific to the actual project. Understanding what complexity factors a project is exposed to, can aid the design of the project and subsequently allow management of project complexity during project execution.

Figure 4 shows the project complexity model. It illustrates the chain from *complexity drivers* through *complexity factors* to *project execution* and the final *project result* (product). In addition, it shows the sources influencing complexity drivers. The drivers are imposed on the project (and thus contributing to project complexity) by nature or by stakeholders (surroundings, see Figure 3). Together they define the complexity factors for the actual project. The complexity in the project context, the producing system (the project design), and the system produced influence the project execution and in turn defines the actual project result.

For stakeholders it can be distinguished between exogenous and endogenous sources. The endogenous stakeholders are depicted within the primary environment in Figure 3, whereas the exogenous stakeholders are found in the secondary and tertiary environments. Stakeholders also represent a significant source of uncertainty that again may lead to complexity in project execution and may strongly influence the performance of the organization.

Nature represents non-controllable factors such as weather conditions, climate change, landslides, rock properties, accidents etc. Although they cannot be controlled, some of them may be predicted with a certain probability based on experience and historical data. Nature represents a significant source of uncertainty in any project.



*Figure 4: Project complexity model.*

# CASE

In order to validate the project complexity model, a case is used.

The selected case is an oil and gas project in Norway comprising subsea wells with a multiphase pipeline to onshore process facilities. The field is situated more than 100 kilometers off the coast and at water depths at approximately 1100 meters. The project was geologically and technologically demanding. The field is located in a slide area, and the routing of the pipe to the onshore plant goes through a geologically complex area. The uneven seabed constituted a major technological challenge, as did low temperatures, strong currents, waves, and wind.

The field was discovered in 1997, and basic concepts for the development were decided in 2002. Onshore construction work started in 2004, followed by subsea pipe laying and installation of production templates. The onshore plant consists of well stream processing facilities, installations for gas export compression, as well as condensate offloading to tankers. The daily production capacity is 70 MSm3 and up to 50 000 BPD of condensate. The processed gas is exported to the UK through a 1200 km pipeline. The project also included this pipeline as well as the UK reception terminal. The total workforce numbered more than 9500 people coming from 54 different countries, working 12 hour shifts in two–week schedules. The project was successfully completed on time and within budget and the facilities started operation in 2007. The total cost was approximately 10 billion USD.

Due to the size and complexity, the project execution was organized as three separate sub-projects:

1. The pre-project where concepts were developed and a project organization and governance structure were established
2. The offshore project consisting of subsea installations, with templates, manifolds, and pipelines.
3. The onshore project consisting of gas processing facilities and transport.

# Validation

This case is now used to validate the complexity factor model defined in Figure 4. The various complexity factors are analyzed based on data from written sources and in-depth interviews. A summary of the analysis is shown in Figure 5, and explained in detail in the following.



*Figure 5: Application of model on case.*

## Surroundings and Nature

One of the initial challenges for the project was to decide the location of the onshore facilities. This decision was made relatively early in the process during the concept selection and therefore did not interfere with the later detailed planning and execution. With the location issue solved, the plan for development and operation was approved by central authorities, and the further development was executed in a political stable environment with predictable frame conditions.

The economic surroundings were also good with a robust financial climate. There were dedicated customers for the takeoff of the gas, and there was a rich market for the oil to be produced. The project was executed during a period of low inflation and excellent market access. The exception was the market for labor. As there were other large projects going on in the same geographic region, there was a shortage of locally available skilled labor for construction work in the onshore project.

Nature was a major complexity driver, because the field is located in a slide area, where a gigantic submarine slide occurred 8000 years ago. Extensive work was therefore necessary to evaluate present geological stability conditions, as the area has been experiencing repeated sliding for more than a million years. The performed risk analysis however concluded that it was safe to develop the field and place the four large templates on the seabed. Another complexity driver was connected to the construction and laying of the pipeline. The routing of the pipe to the onshore plant had to pass through a geologically complex area with an irregular and uneven seabed. Innovative pipeline engineering and installation were necessary to be able to transport the gas from 1000 meters depth, climbing steep hills, pass through rugged terrains and snaking the way through narrow subsea valleys. Successful completion of the project therefore required significant technological development involving considerable risk.

## Project Context

### Primary Environment

The project’s primary environment was made up of three important categories of actors; the owners of the production license, the main suppliers and the project operator’s mother organization.

*Owners.* Oil and gas fields on the Norwegian shelf are organized as licenses with several owners. In this case six different oil companies took part, with owner shares ranging from 7 to 36 %. The Norwegian company which discovered the field was pointed out by the authorities as responsible for the project. A top priority for the project management in the initial planning phase was to establish good relations to the other owner companies and to agree on the overall governance structure. In order to establish a foundation of openness, involvement, and trust between partner representatives, formal meetings were supplemented with informal arrangements, e.g., common dinner in the evening before a meeting.

All main issues were discussed early, and agreement was obtained before the final plan for field development was submitted to the authorities. Of specific importance was the development of a governance structure. The main parts of this were: (1) agreement on the kind of issues that should be decided upon, (2) how and when to make these decisions, (3) a “decision support package”, defining standards for documentation and decision criteria, and (4) procedures for managing changes during the execution phase. The combined effect of the governance structure, good relations and trust between the partner representatives contributed to continuous support from the partners during the execution phase.

*Suppliers*. Procurement teams worked with prequalification of potential suppliers, detailing bid packages and following up until contracts were signed. In this preparatory phase the supplier market was extensively surveyed, both regarding competence and capacity. Personal knowledge and experience from other projects were important in this work. The supplier market for important parts of the project was limited, with few possible contractors. For one of the main contracts there were only two possible suppliers worldwide. Much effort was put in in order to stimulate real competition in these situations.

Efforts were made to find an optimal balance between package size and content and the number of contracts. In order to obtain manageable interface complexity, contract packages were merged when suitable. The contracts had clear specifications, so that they could be followed up closely during execution. A common viewpoint among the participants is that the contract strategy has been of major importance for the success of the project. The participants also underscored the importance of good and trustful relations with the suppliers. Contributing to this was a conscious strategy to integrate the competence of the suppliers and contractors in the project teams, thereby lowering possible barriers between “us” and “them”.

*Mother Organization.* For the operator, who was known for a track record of good performance in managing complex projects, this was a prestigious activity. It therefore had full support and attention from the top management. The size and the technical complexity also made joining the project teams attractive for their most experienced and best people. The managers in charge of the organization build-up were therefore able to select participants on the basis of their known competence. Former relations and personal networks were actively used in the selection of participants, and as stated by one of the project managers: “We were allowed to pick the people we wanted from the top shelf”.

### Secondary Environment

Whereas national and regional political interests were both active and influential in the decision process concerning choice of concept and landing site during the pre-project, relations to the local community were the most important during the execution phase. For the local stakeholders, the project had an “open door” policy. The project management’s strategy for obtaining local support and assistance had openness as its guiding star. The clearly expressed aim was to obtain support and assistance, and to avoid local protests. The ambition was to create the necessary levels of trust by “including the project into the community”. This was obtained through frequent meetings with local authorities, as well as open information meetings for the neighboring inhabitants. One important reason for holding such meetings was to prepare the local community for the influx of thousands of workers from different countries.

### Tertiary Environment

The tertiary level of stakeholders was handled in such a way that it did not add to the complexity of the project. Early information to and communication with the supplier industry was given high priority, and seminars with possible bidders were arranged both in Norway and in the UK. Tender lists for most contracts were made public, making it possible for potential sub-contractors to express their interest. The top management of the operator company had good relations with the central authorities and the project had overall political support. National media were also satisfied with the open information attitude and played an important role in information dissemination.

## Technological Aspects - System Produced and Production Technology

The technological aspects comprise the system produced and the production technology of the producing system. As explained, both these factors can be characterized using Shenhar’s (2001) framework. The system produced falls into the category “array project” since the project is a collection of components and modules, consisting of subsea production templates, pipeline from the field to the landing site, onshore processing facilities, and pipeline across the Norwegian sea to consumers in the UK.

Although such large oil and gas projects to a large extent builds on proven technology, the size of the project and challenges imposed by nature made it a very complex project. Illustrating is that this was the first large offshore field development without platforms at such water depths. Never before had a pipeline of this size been installed at such depths and in so demanding underwater terrain. The fact that the pipeline had to go through a slide area added significantly to the complexity as there was limited previous experience to take advantage of. The installation work therefore challenged existing experiences in pipe-laying, where seabed preparation work to ensure a smooth and stable foundation was especially complicated and demanding. One of the central project managers expressed it like this: “Through the implementation of new technology and design codes, as well as development of new engineering practices, the pipeline design was elevated to a new level”. In this setting the required production technology should be classified as “high-tech” on Shenhar’s (2001) scale for technological uncertainty.

## Project Organization

There were two main challenges for the project organization, both of a general character. The first was to make sure that the organization had the capabilities necessary to handle the challenges posed by the external complexity drivers, the project context, the system to be produced and the production technologies. A prerequisite for any advanced project organization is to recruit a highly qualified staff. In this casecompetence in the project organizations was obtained by careful selection of participants, based on former knowledge, both inside the operating company and among the involved consultants. As the project at the time was considered both challenging and prestigious, recruiting “the best people” was relatively easy. Former relations and personal networks were actively used in the search for personnel; consequently, many of those who became involved knew each other from before. An important contribution to the overall success of the project, especially in the planning phase, but also during execution, was that all participants had a deep, common understanding of the whole project and how the different activities contributed to the final result.

The second main challenge was to build up, develop and manage the project organization itself, both regarding formal (“hard”) and informal (“soft”) qualities. The project organization will be analyzed using the Pentagon model described in Chapter 4 (Figure 2).

*Structure dimension*. The formal project organization was developed with a strong emphasis on clear roles and responsibilities, where different sub-projects were given a high degree of delegation and autonomy. In the pre-project phase the organization was gradually built up, continuously assessing the needs for competence and capacity. Important was also to obtain alignment with the following execution phase. This transition from planning to execution involved two sets of decisions. The first was to build up sufficient capacity in the pre-sanction phase to match the upcoming size and complexity in the execution phase. The second was to assure a certain degree of continuity, whereby key personnel held on to relevant positions into execution. The operating company had a strong focus on project governance as it had a well-established practice and documentation on how to manage large and complex projects. The alignment of governance, which had been successfully obtained between the partner owner organizations, could also be found inside the project organization, and between the project and its external suppliers. Separate multi-disciplinary procurement teams were established for each of the main contracts, working on prequalification of potential suppliers, detailing bid packages, and following up until contracts were finally signed. One company representative was assigned responsibilities for each contract, acting as the single point of contact with the main project, and all contracts and other important documents were continuously updated. This kind of delegation of responsibilities was also in accordance with established practice in the company.

*Technologies dimension.* The operator had access to well-proven project management tools suitable for large and complex projects, which were described in the project handbook. Important elements in the technical-administrative systems were schedule- and cost-control.In order to follow up on this, an extensive system for risk management was established, supported by a database containing information and descriptions identifying potential risks. An interaction matrix was also designed, illustrating how different contracts were inter-related. This matrix enabled improved on-site logistics and reduced potential negative interferences between different activities.Co-location of the main project teams, both within the planning and execution phases, contributed to good communication and team development, made it easy to share information, and also made it possible to combine delegation of tasks and responsibilities with the overall coordination of activities.

*Culture dimension.* Existing relations and established ways of working laid the foundation for developing a project culture characterized by openness, yet leaving room for discussion and generation of new ideas. Working on this large and important project contributed to a “winning team spirit”, where a common ambition was to control quality, cost and progress. This was enabled through a combined effect of careful selection of team-members, experiences and informal standards in accordance with company traditions, and deliberate management efforts in developing well-functioning teams.

The operator had a reputation of good performance in project planning and execution. One aspect of this was that there was widespread agreement within the company as to how development projects should be organized and managed. The general acceptance of this “way of working” made it relatively easy to establish a common conceptual and theoretical platform.

*Interaction dimension.* A mechanism for obtaining good coordination was to hold regular meetings, both within the management group and within each of the sub-projects. The project director’s ambitions were to include all relevant parties in the management team, and to create a climate for open discussion and for bringing up and commenting on possible problems and challenges.

The overall ambition was to have open decision processes where everybody was encouraged to express personal opinions and come up with new ideas. An important element was focused discussions addressing the coordination challenges connected to the interdependencies and interfaces between the different actors and activities. Open discussions and training sessions contributed to this. However, once decisions had been made, loyalty was expected.

The project director reported that his ambition was to have a hands-on contact with all main participants and sub-projects, and that he obtained this by practicing “management-by-walking-around”. His general management strategy can be characterized as following a “90/10-principle”. An important tool was the continuous updating of the top-ten list of risks for each of the main projects, which was continually reviewed in regular meetings. Project managers also checked in with contractors during examination meetings, focusing on potential risks and an early warning strategy, all through the execution phase. The rationale of the 90/10 principle is that if 90 % of the challenges and problems are dealt with locally, the project management can concentrate on the remaining 10 % that need closer attention.

Management styles were different in the planning and execution phases, and also between the onshore and offshore projects. Both the pre-project and the offshore project managers had a coaching (yet demanding) style and put much effort into team building. In contrast, the onshore project manager used a more hierarchical style, however combining openness and determination. Following the arguments of Rolstadås et al (2014a: 655), these different management styles can be characterized respectively as adaptive and prescriptive.

*Social relations and networks dimension.* Many project participants knew each other from earlier projects, and many had well-established relations with suppliers and external consultants. Several of the project leaders also invested time and energy in team-building and trust-building activities, and new colleagues were included in the project community through these activities. The overall impression is that positive personal relations and a high level of trust came to be one of the main characteristics of the project. This resulted in effective and un-bureaucratic internal communication and coordination with a high level of internal trust.

The pentagon analysis is summarized in figure 6.



*Figure 6: Application of the Pentagon model to evaluate the project organization.*

# Conclusion

In this paper, the authors have addressed what influences project complexity and its consequences for the execution of the project. The literature on project complexity has been reviewed, and a model developed for identifying and analyzing complexity drivers and complexity factors. The model starts with generic complexity drivers such as ambiguity, uncertainty, unpredictability and pace. These drivers are in each project influenced by nature and by socio-political, economic and technological surroundings to result in complexity factors that are specific to the project analyzed.

The complexity factors fall into three categories: the project context, the producing system, and the system produced. The project context is analyzed by studying the stakeholders involved. The authors have developed a stakeholder diagram (Figure 3) facilitating this. It distinguishes between three stakeholder environments (primary, secondary, and tertiary). The producing system includes the project organization and the production technology. The performance of the project organization has been analyzed with the help of the Pentagon model (Schiefloe 2011). The production technology and the system produced have been characterized using Shenhar’s (2001) framework.

The model can be used to analyze the complexity of a project. This is illustrated with a case from a successfully completed project.

The success of the case project stems from its pre-project management handling of project context and the associated complexities so that the uncertainties remaining to be dealt with in the execution phase were reduced to a minimum. The main concept was well defined, natural challenges were known, central and local political stakeholders were satisfied and the main stakeholders in the primary environment were aligned. As this was resolved in the pre-project, both the onshore and offshore execution projects could concentrate their efforts on dealing with technological challenges and coordination.

In the case it can be clearly seen how leadership and organization strategies vary over time, with the pre-project clearly operating as a flexible and innovative team, dealing with concept development, political processes and stakeholder management. In the execution phase, one can observe clear differences between the two main parts of the organization. The onshore project was operated more as a traditional construction project, whereas the offshore activities were run in a more adaptive and flexible way. These different leadership strategies were mostly due to the nature of internal complexity, but may in some ways also have been influenced by different leadership personalities. The correspondence between leadership style and approach was not, however, coincidental. The two managers of the onshore and offshore projects were appointed because they had different leadership styles and had different personalities. The success of the project seems to a large extent to be due to the different kinds of organizational and management strategies that were chosen for these three main parts of the project.

In conclusion, the project’s success appears to stem from:

* The pre-project and overall project management’s ability to set up and handle the project context for the execution projects, including contract strategy and governance structure.
* The project management’s ability to adapt leadership and organizational development to the actual internal and external complexity in the pre-project and execution phases.
* Continuity and alignment within the organization with regard to strategies and standards for project development, organizational culture, common knowledge base, and personal networks and knowledge.
* The conscious and controlled development of the project organizations, taking care of all the five dimensions in the Pentagon model.

The complexity model presented in this paper is capable of characterizing project complexity in an organizational context. The context is defined through a stakeholder model viewed from a socio-political, economic, and technological perspective. The model can be applied to assess and define capability requirements of the project organization by analyzing each of the components of the model (drivers, surroundings and complexity factors).

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